german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

MEKONG RIVER COMMISSION FOR SUSTAINABLE DEVELOPMENT
MRC

Initial Project Concepts

A Network of Nature Based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan

MEKONG RIVER COMMISSION - JOINT PROJECT ON FLOOD AND DROUGHT MANAGEMENT

June 2023

This document was prepared by the Mekong River Commission (MRC) with support from Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) and ICEM – International Centre for Environmental Management, Consultants of Technology Co., Ltd. (COT) and Phnom Penh International Consultants Co., Ltd. (PPIC) for the project: *Mekong River Commission – Joint Project on Flood and Drought Management.*

Prepared by

MRCS-GIZ Joint Project team comprising Thim Ly, Chief River Basin Planner, MRCS; Nittana Southiseng, Deputy Project Director of GIZ; Yia Yang Technical Advisor, GIZ; Nike Hestermann, Development Advisor, GIZ, Richard Mueller, Development Advisor, GIZ; Sompong Boonprasert, Senior Advisor to TNMC; and Chantha Oeurng, Senior Advisor to CNMC.

Supported by the ICEM/COT/PPIC team comprising Jeremy Carew-Reid, Hubert Lohr, Nguyen Huy Trung, Khan Ra, Sanidda Tiewtoy, Toy Monireth, Wannee Lattitawanich, Kimhor Chitt, Leila Macadam, Nguyen Thi Phuong Thao and Harvey Rich.

Suggested citation

MRC. 2023. *A Network of Nature based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan. Initial Project Concepts.* Mekong River Commission - Joint Project on Flood and Drought Management. Vientiane, Lao PDR

More information

http://www.mrcmekong.org/
Unit 18, Ban Sithane Neua, Sikhottabong District, Vientiane 01000, Lao PDR
Ph: +856 21 263 263.

Front page photo

ICEM

ABBREVIATIONS

ADB	Asian Development Bank
asl	Above sea level
ATT	Ang Trapeang Thmor
BOD	Biochemical oxygen demand
CNMC	Cambodia National Mekong Commission
DEM	Digital Elevation Model
DNP	Department of National Park, Wildlife and Plant Conservation
GIS	Geographic Information Systems
Ha	Hectares
IBA	Important Bird and Biodiversity Area
ICF	International Crane Foundation
IWRM	Integrated Water Resources Management
MAFF	Ministry of Agriculture, Forestry and Fisheries (Cambodia)
MLUC	Ministry of Land Management, Urban Planning and Construction (Cambodia)
MOAC	Ministry of Agriculture and Cooperatives (Thailand)
MoE	Ministry of Environment (Cambodia)
MoNRE	Ministry of Natural Resources and Environment (Thailand)
MOWRAM	Ministry of Water Resources and Meteorology (Cambodia)
MRC	Mekong River Commission
MUA	Multiple Use Area
NbS	Nature-based solutions
NDWI	Normalized Difference Water Index
NTFP	Non-timber forest products
NWG	National Working Group
ONWR	Office of National Water Resources (Thailand)
PDOWRAM	Provincial Department of Water Resources and Meteorology (Cambodia)
UAV	Unmanned Aerial Vehicle
UN	United Nations
USACE	United States Army Corps of Engineers

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The report sets out concepts for nature-based solutions (NbS) to be demonstrated within a network of collaborative projects conducted by Cambodia and Thailand for strengthening urban and rural flood and drought resilience in the 9C-9T sub-basin. The 9C-9T is a shared river network flowing down to the Tonle Sap comprising the Cambodian area called the Mongkol Borey river basin and the Thai area named the Tonle Sap River basin. Both parts of the sub-basin, and hence the two countries, are bound together in their shared management challenges and solutions. Mitigating flood and drought is the overarching objective because of their far-reaching impacts on every aspect of life in the sub-basin, with the threat to become more severe as climate changes take hold.

Scope

This report covers three degraded landscapes in each country that are in urgent need of restoration. The network of NbS and hybrid projects for each landscape have been defined by the National Working Groups (NWG), established in each country and chaired by the Cambodian Ministry of Water Resources and Meteorology (MOWRAM) and the Thai Office of National Water Resources (ONWR).

The landscapes represent a diversity of ecosystems, infrastructure assets, and flood and drought challenges within Cambodia and Thailand. Some are transboundary in nature – and all aim to demonstrate restoration using NbS and hybrid measures across headwaters, rural landscapes, and peri-urban and urban areas. The network of demonstration measures in each landscape will contribute to reducing flood and drought risk and bring multiple benefits – strengthening hard infrastructure resilience and ecological integrity and connectivity, the management and improvement of water quality, the conservation of water resources, and the restoration of watersheds and degraded forests. The proposed measures are the focus of an economic cost benefit analysis so that governments have the needed information to justify ongoing national and local government budget commitments.

9C-9T Flood and Drought Master Plan alignment and use

The NbS project descriptions are at the conceptual stage for further development with lead implementing agencies during Master Plan implementation during 2023 onwards. The projects are a starting point leading to architectural landscape drawings and then detailed engineering design. This report is intended for use by agencies responsible for 9C-9T Master Plan Outcome 2 implementation.

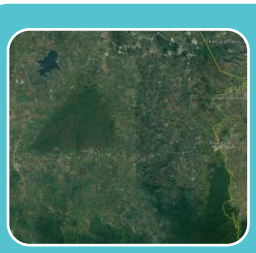
A network of nature-based solutions for six priority project concepts

NbS use a set of structural and non-structural interventions that protect, manage, restore, or create natural features. NbS measures should build on, restore and extend the fragments or corridors and networks of natural systems that remain in a landscape. Any NbS initiative must achieve win-win outcomes and adhere to several core principles.

Each project concept outlined below present a network of NbS interventions to build flood, drought and ecosystem resilience. These six landscapes provide for the demonstration of 15 specific nature based and hybrid solutions laid out in networks across connected forest, agricultural and urban landscapes. Proposed measures include rehabilitation of degraded upper catchments and drainage corridors; restoration and expansion of forest cover and wetlands; canal, river and reservoir rehabilitation including vegetated buffers, sediment trapping and bank stabilization; vegetated buffers on boundaries of agricultural fields and along roads; and a wide range of NbS in urban areas, including swales, rain gardens, constructed wetlands, expansion of green space and urban forest canopy cover.

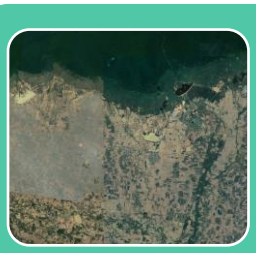
1. Samlaut Multiple Use Area (Battambang, Cambodia) & Khlong Kreua Wai Chaleum National Park (Chanthaburi, Thailand)

- ***Drivers, impacts and selection factors:*** Protected area encroachment, watershed and forest degradation with downstream impacts
- ***Proposed interventions:*** Watershed rehabilitation, protected area ecological restoration, protected area management (forest restoration, riparian buffers)



2. Khao Soi Dao Wildlife Sanctuary and Pong Nam Ron (Chanthaburi, Thailand)

- ***Drivers, impacts and selection factors:*** Forest fragmentation, protected area encroachment (agriculture and hunting), biodiversity loss
- ***Proposed interventions:*** Establishment of forest corridors in critical watersheds, protected area management (forest restoration, sustainable irrigation), Urban waste and stormwater management through nature-based measures (retention of runoff, river rehabilitation, urban greening)



3. Sompoi, Taduang and UN reservoirs (Sa Kaeo, Thailand)

- ***Drivers, impacts and selection factors:*** Low water availability, high drought frequency, soil erosion and sedimentation, protected area and buffer area encroachment
- ***Proposed interventions:*** Reservoir and watershed rehabilitation and management (riparian buffers, sediment traps, forest restoration, nature-based drainage, sustainable irrigation and agricultural buffers, catchment water management)

4. Poipet (Banteay Meanchey, Cambodia) & Aranyaprathet (Sa Kaeo, Thailand)

- ***Drivers, impacts and selection factors:*** Wastewater management issues, low water availability, moderate flood risk, high frequency of drought
- ***Proposed interventions:*** Cross-border waste and stormwater management through nature-based measures (urban greening, river rehabilitation, sediment traps, water retention, drainage improvements, nature-based retention, constructed wetland)

5. Kamping Puoy Reservoir (Battambang, Cambodia)

- ***Drivers, impacts and selection factors:*** High flood risk, forest to agriculture transitions, wetland encroachment, low water availability, soil erosion, sedimentation
- ***Proposed interventions:*** Reservoir, wetland and watershed rehabilitation and management (riparian buffers, sediment traps, forest restoration, reservoir/wetland zoning, catchment water management, sustainable irrigation)

6. Ang Trapeang Thmor Lake and Protected Forest (Banteay Meanchey, Cambodia)

- ***Drivers, impacts and selection factors:*** Protected area encroachment, biodiversity loss, forest to agriculture transitions, soil erosion and sedimentation, increasingly drought frequency
- ***Proposed interventions:*** Sediment management, watershed rehabilitation and protected area management (forest restoration, riparian buffers, water management, sustainable irrigation, agricultural buffer, sediment traps)

Implementation

Further development of the project concepts will be progressed as the 9C-9T Master Plan is implemented with national and international funding contributions. The project concepts will be included in international funding applications from 2023. Once national and international funding is secured, detailed designs for each project concept and their network of NbS will be developed, accompanied by comprehensive assessments, plans and stakeholder engagement, as outlined in the 9C-9T Master Plan. Cross-sectoral and multi-level cooperation nationally/bilaterally will be essential for successful implementation of NbS for flood and drought resilience.

1 INTRODUCTION

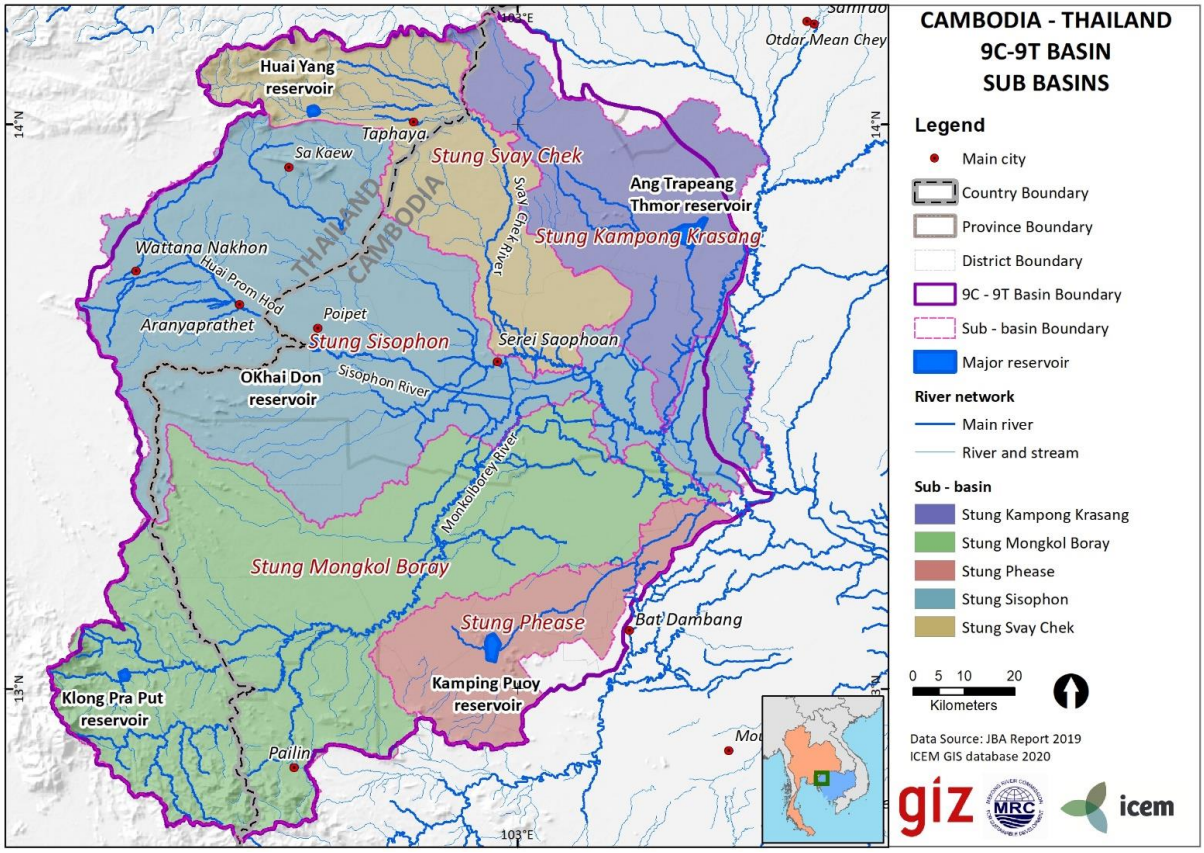
1.1 The 9C-9T river basin

In 2018, Cambodia and Thailand established a collaborative governance structure for management of the shared 9C-9T sub-basin under the auspices of the Mekong River Commission (MRC). The aim of this arrangement is to facilitate a joint planning and implementation process to restore the 9C-9T sub-basin as the foundation for flood and drought resilience.

This shared river network flows down to the Tonle Sap Lake and comprises the Cambodian area called the Mongkol Borey river basin and the Thai area named as the Tonle Sap River basin. Mitigating flood and drought is the overarching objective of the Joint Project because of their far-reaching impacts on all aspects of life in the 9C-9T sub-basin, with the threat increasing as climatic changes proliferate.

Key drivers of flood and drought have been identified as population growth and associated pressures such as deforestation, largely uncoordinated hard infrastructure development altering hydrological function, and climate change exacerbating watershed degradation. Both parts of the sub-basin, and hence the two countries, are bound together in these shared management challenges in an area that has degraded to such an extent that it is impeding economic development and social well-being.

Figure 1: 9C-9T boundary and sub-basin



1.2 The 9C-9T master plan

In response, in December 2021, the two governments endorsed the 9C-9T Flood and Drought Master Plan with a focus on basin-wide rehabilitation of the 9C-9T sub-basin to bring back ecological health through nature based and hybrid solutions that reinforce and leverage existing and planned investments in hard infrastructure. This Master Plan was prepared through this collaborative structure to reflect and integrate the work of the two countries to date, with a clear action plan for implementation starting from 2022. It provides the strategic framework to scale up investment for flood and drought resilience of the 9C-9T sub-basin in five strategic areas – river basin planning,

regional capacity building, strengthening of urban and rural flood and drought resilience, hydrometeorological and early warning and data sharing. The concepts presented in this report initiate definition of projects as specified in the 9C-9T Flood and Drought Master Plan and Action Plan, under Outcome 2.1, 2.2 and 2.3.[1]

1.3 The NbS project concepts

This report presents initial concepts for nature-based solutions (NbS) to be demonstrated within a network of collaborative projects conducted by Cambodia and Thailand for strengthening urban and rural flood and drought resilience in the 9C-9T sub-basin. These NbS project concepts have been developed through intensive Geographic Information Systems (GIS) analysis, field survey and consultation under the Joint Project on Flood and Drought Management for the 9C-9T sub-basin (Figure 1). They aim for rehabilitation of the 9C-9T sub-basin through nature based and hybrid solutions linked to existing hard infrastructure.

At this stage the focus is on initial conceptual design of NbS measures. Detailed engineering design will be developed at a later stage under the Master Plan implementation process.

Six projects located in degraded landscapes have been identified by the Cambodian and Thai National Working Groups (NWG). Some are transboundary in nature – and all aim to demonstrate a network of nature based and hybrid solutions across the sub-basin in headwaters, rural landscapes, and peri-urban and urban centres. The network of measures in each landscape will contribute to reducing flood and drought risk, to strengthen hard infrastructure resilience, ecological integrity and connectivity, the management and improvement of water quality, the conservation of water resources, and to the restoration of watersheds and degraded forests.

The overall goal is to demonstrate measures that can be replicated, upscaled and rolled out across the basin's agricultural, urban and headwaters landscapes as a connected network so that their cumulative impact will substantially reduce the risks of flood and drought. Two projects seek to rehabilitate reservoirs and their catchments, a further three are focused on protecting headwaters and protected area landscapes, while one other aims to safeguard investments in urban areas either side of the major Cambodia-Thailand border crossing from Poipet into Aranyaprathet by increasing water retention and infiltration to reduce flood and drought and to improve water quality.

1.4 Purpose, scope and application of the report

With the goal of rehabilitating the 9C-9T sub-basin in mind, this report identifies an initial set of NbS projects to reduce the risks of flood and drought in specific locations as the targets for priority investment under the 9C-9T Flood and Drought Master Plan.

This report outlines an NbS approach for flood and drought risk within target landscapes. It presents the mapping of thirteen priority landscapes identified as having high risk of flood and drought and suffering from serious ecosystem degradation, affecting existing infrastructure and community livelihoods. Those locations were reduced to six priority landscapes to be targeted for more detailed field-based investigation, to confirm and detail their suitability for NbS demonstrations by the Joint Project.

[1] Outcome 2.1: Strengthened urban flood and drought resilience through innovative climate-sensitive and ecosystem-based planning tools and adaptation interventions.
Outcome 2.2: Strengthened rural flood and drought resilience through ecosystem-based planning tools and adaptation interventions.
Outcome 2.3: Rehabilitated basin headwaters and wetlands, to improve water security and climate resilience through ecosystem-based adaptation interventions.

These six project concepts are presented in detail as individual chapters, each consisting of the following components:

1. A **project overview** and **objectives**,
2. An outline of the project **alignment to the 9C-9T Masterplan,**
3. The **implementing stakeholders**, including the **leading and supporting agencies** for the particular project location and **alignment with lead agency priorities;**
4. A **site description;**
5. An assessment of the **flood and drought drivers** and **impacts;**
6. The **nature based and hybrid solutions concepts** proposed, including **concept design**; and
7. An overview of **project benefits.**

The six project concepts – each with a network of multiple NbS – relate to transboundary landscapes crossing the international border between Cambodia and Thailand, and specific landscapes entirely within each country. The landscapes cover various major developments and infrastructure all depending on the restoration and maintenance of ecosystem services for their sustainability and productivity – i.e. urban areas (Aranyaprathet in Thailand and Poipet in Cambodia for example), industrial zones and transport corridors, large irrigation reservoirs and canal networks, and extensive areas of private agricultural development. The landscapes also bring in many forms of land tenure and management from protected areas in the headwaters, large scale commercial enterprises relating to plantations and industry, small scale private commercial allotments and government areas and infrastructure.

These NbS project descriptions in this report are at the conceptual stage for further development with lead implementing agencies during Master Plan implementation in 2023 onwards. The NbS river channel rehabilitation concept for the sister projects in Aranyaprathet and Poipet (Project 4) has been taken further in design based on hydrologic modelling to illustrate the benefits of NbS measures in reducing flood levels and management.

This report is intended for use and application by government agencies, river basin planners, provincial development authorities, city planners and private developers. It is an essential initial roadmap for implementation of Outcome 2 of the Master Plan.

2 THE IMPORTANCE OF A NATURE-BASED SOLUTIONS APPROACH FOR THE 9C-9T SUB-BASIN

2.1 Defining the nature-based solutions approach

NbS have not been systematically applied in Cambodia and Thailand. It is therefore important to define the NbS approach used in this report – and underlying the 9C-9T sub-basin Master Plan.

Nature-based solutions are "*actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits*".[2]

This report aligns with the IUCN Global Standard for Nature-based Solutions[3] and the principles outlined by the Nature-based Solutions Initiative[4][5]. NbS comprise the protection, restoration and/or sustainable management of natural and semi-natural ecosystems; in natural areas or working lands (cropland or forestry land); including the creation of new ecosystems in and around urban areas or across wider natural or agricultural landscapes[6].

NbS use a set of structural and non-structural interventions that protect, manage, restore, or create natural features. NbS measures should build on, restore and extend the fragments or corridors and networks of natural systems that remain in a landscape. If nature-based and hybrid solutions are present then further NbS interventions should reinforce and enhance them on the understanding that it is the cumulative impact of an expanding network of nature-based measures that counts. No single NbS initiative will achieve the wider outcomes needed in terms of protection of infrastructure and ecosystem services.

NbS innovation needs to follow a hierarchy approach as set out in Figure 2.

Figure 2: Hierarchy of approaches for NbS. Adapted from World Bank (2021)

[2] The formally agreed definition under the United Nations Environment Assembly (UNEA).

[3] IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN

[4] Nature-based Solutions Initiative (2021). Nature-based solutions to climate change: key messages for decision makers in 2021 and beyond. https://nbsguidelines.info/

[5] Supporting the goals of the UN Decade on Ecosystem Restoration, from 2021 through 2030

[6] NbS is an umbrella concept covering green, blue-green, bioengineering and natural infrastructure as sub-categories although the terms are often used interchangeably. For the purposes of this report, NbS will be the term used to bring in those other concepts. Hybrid measures combine NbS and elements of hard or grey infrastructure – they are the most common approach when combined with hard infrastructure or existing well-developed landscapes such as urban centres. Hybrid measures can include, for example, green roofs and walls, bioswales, rain gardens, water retention structures, sediment traps, canal or river vegetated buffers, permeable paving, urban tree canopies, urban parks and community green spaces.

Any NbS initiative must achieve win-win outcomes and adhere to several core principles. The 9C-9T Joint Project will promote the following principles and approach throughout the planning, identification and development of NbS in the sub-basin:

1. Prioritising the protection of existing natural systems and NbS; enhancement and restoration of degraded areas, and the creation of new NbS in networks across sites and landscape;
2. Building on existing natural landscapes and processes;
3. Strengthening natural processes using native species and assemblages seeking net gain in biodiversity; and
4. Involving the right stakeholders, which includes local communities and those that are most affected and key to NbS establishment and maintenance.

NbS need to be applied taking an ecosystem approach, with the aim of rehabilitating and conserving ecosystem structure and function, so that ecosystem services and biodiversity are enhanced.

2.2 Why take a nature-based solutions approach for the 9C-9T sub-basin?

2.2.1 The challenges

The 9C-9T basin is seriously degraded and needs to be rehabilitated. Integrated planning and transboundary impact assessment of development within the 9C-9T sub-basin is absent. Infrastructure, urban and agricultural expansion, and encroachment on headwaters has continued without concern for ecological sustainability and the maintenance of ecosystem services. Therefore, the benefits of healthy ecosystems for flood and drought resilience and security in water supply and quality are being lost in both countries upstream and downstream. There is little on the ground investment in restoration of watersheds within the 9C-9T sub-basin or neighbouring areas. Most investment goes to reservoirs, irrigation systems, dams and transport infrastructure, which suffer from increasing watershed erosion, sedimentation and flood damage.

The role and potential application for NbS are not well understood. Skills, policies, standards, and high-level commitment are required in both countries for systematic field implementation within the context of integrated river basin planning. A wide range of capacities are needed to fully integrate NbS and the requirements of ecosystem maintenance into investments and field practice on a cross sectoral basis.

2.2.2 The importance of a landscape scale approach

The introduction of NbS measures needs to go beyond site level, to take a landscape or watershed perspective so that upstream/downstream processes and influences are taken into account. Where the scale of the needed NbS innovations extends beyond jurisdictional boundaries, suitable mechanisms must be in place to enable joint decision-making by stakeholders.

Flood and drought drivers, impacts and interventions upstream have knock-on effects downstream. The effects of floods and drought are particularly severe in the downstream areas. Those conditions are exacerbated by forest loss and degrading land uses in upstream and head water areas. Their effective management has a critical role in moderating flood and drought extent and severity across the 9C-9T sub-basin.

2.2.3 A focus on demonstration

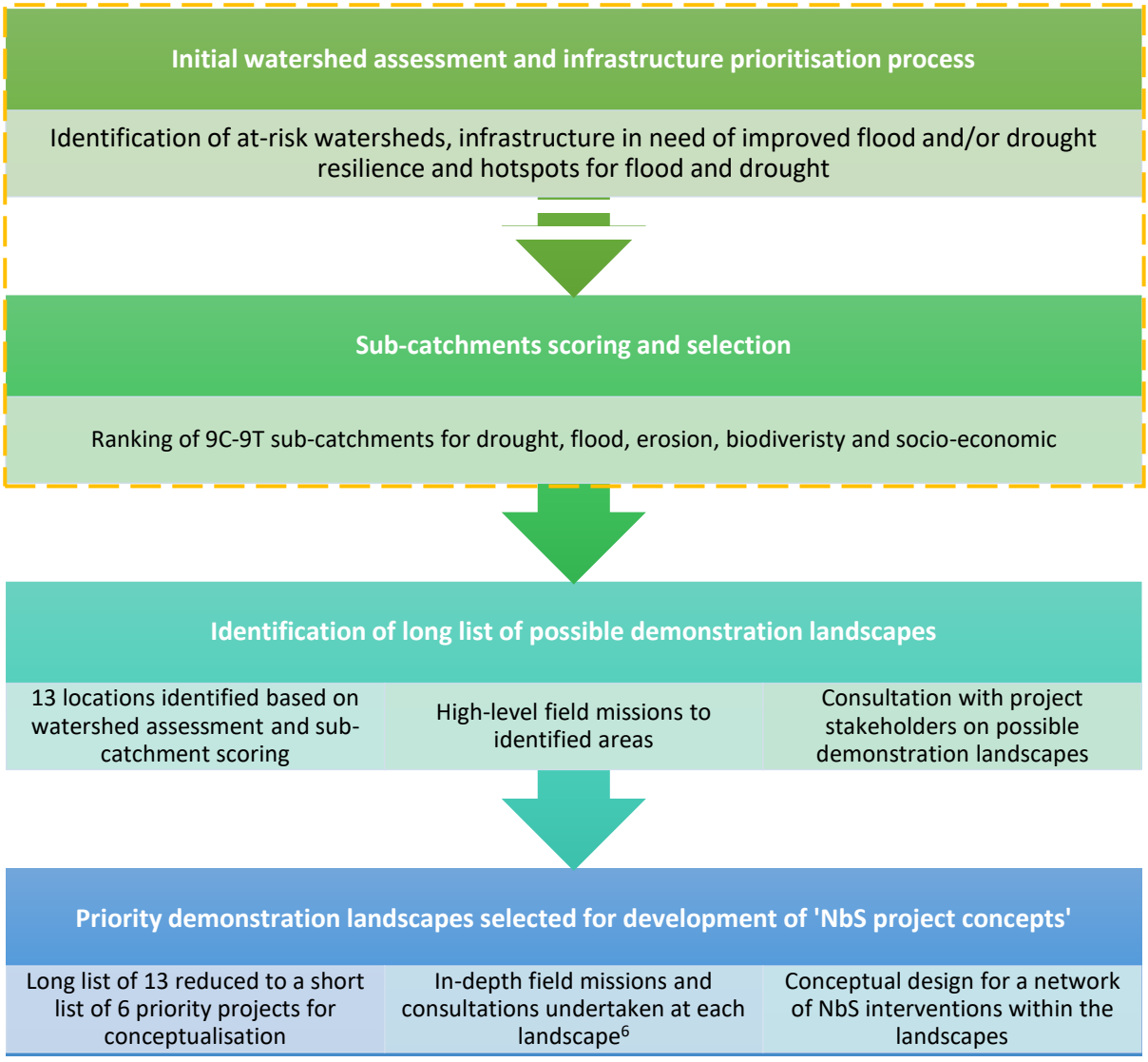
The 9C-9T NbS approach is to concentrate on piloting and testing a collection of small to medium scale NbS measures, rather than implementing large scale schemes. This will be achieved by identifying a network of NbS demonstration sites within each landscape.

Ultimately, the ambition is for such measures to be scaled up and replicated across priority landscapes and within the wider 9C-9T sub-basin, in line with the Flood and Drought Master Plan.

3 IDENTIFYING PRIORITY LANDSCAPES TO DEVELOP A NETWORK OF NBS DEMONSTRATION PROJECTS

The following section outlines the process for identifying priority demonstration landscape areas to implement a network of NbS interventions in the 9C-9T. The process is outlined in Figure 3.

Figure 3: Steps for identifying priority landscapes to develop a network of NbS interventions

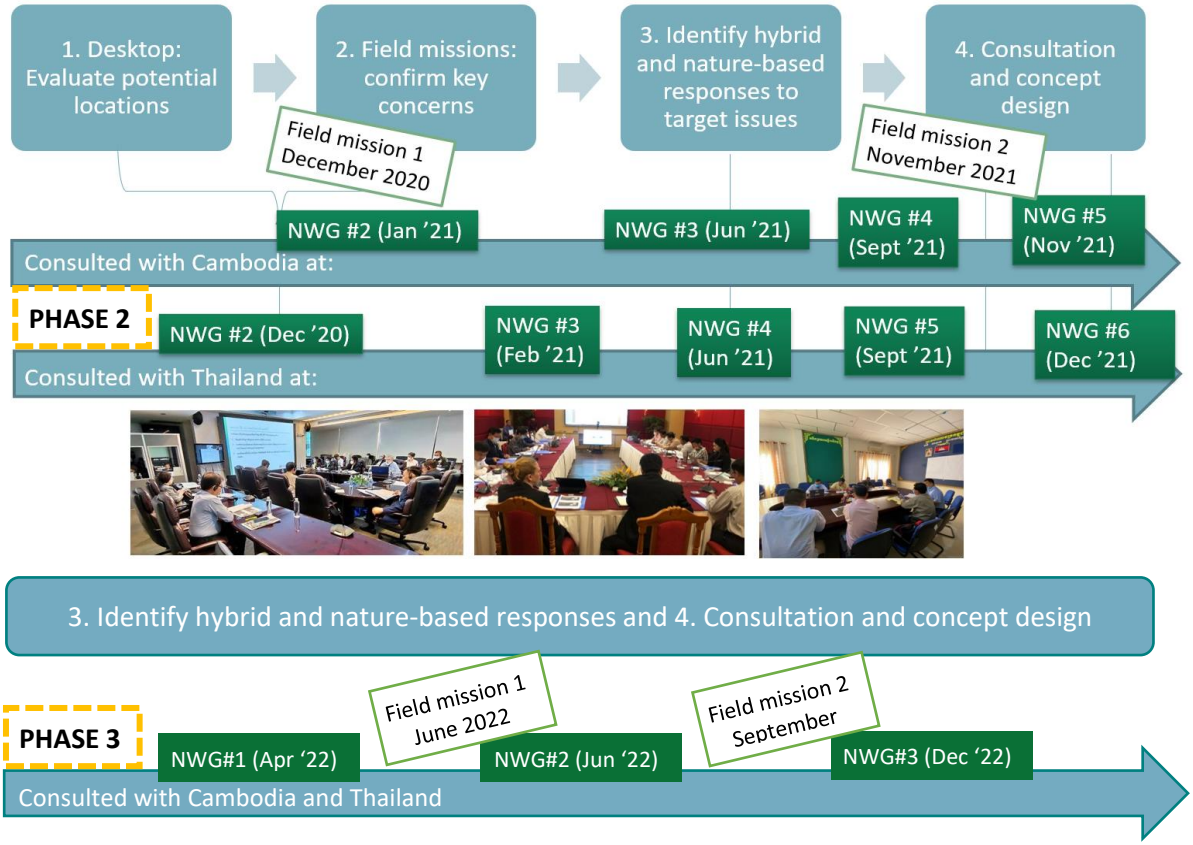


3.1 NbS concept preparation process

Preparation of the project concepts has been conducted with the cross sectoral NWGs established in both countries chaired by the Cambodian Ministry of Water Resources and Meteorology (MOWRAM) and the Thai Office of National Water Resources (ONWR). The process followed is shown in Figure 4, with the first step being a desktop assessment to evaluate potential landscapes according to restoration needs ranking followed by field missions to identify and document priority sites in consultation with local stakeholders.

[7] No site visit was conducted to the Samlaut Multiple Use Area (Cambodia) and Khlong Kreua Wai Chaleum National Park (Thailand) to support design. This was therefore achieved through secondary data and spatial analysis. Future field missions will allow for detailing of the NbS network in these critical biodiversity areas and headwaters.

Figure 4: Consultation and assessment process to inform NbS concepts



During 2021-22, four field missions in each country have been conducted to prepare the concepts. The mission objectives were to collect more detailed information from the local level, further specify potential sites for measures at each location, and check assumptions about conditions on the ground based on advice from local authorities and field inspection - with activities as follows:

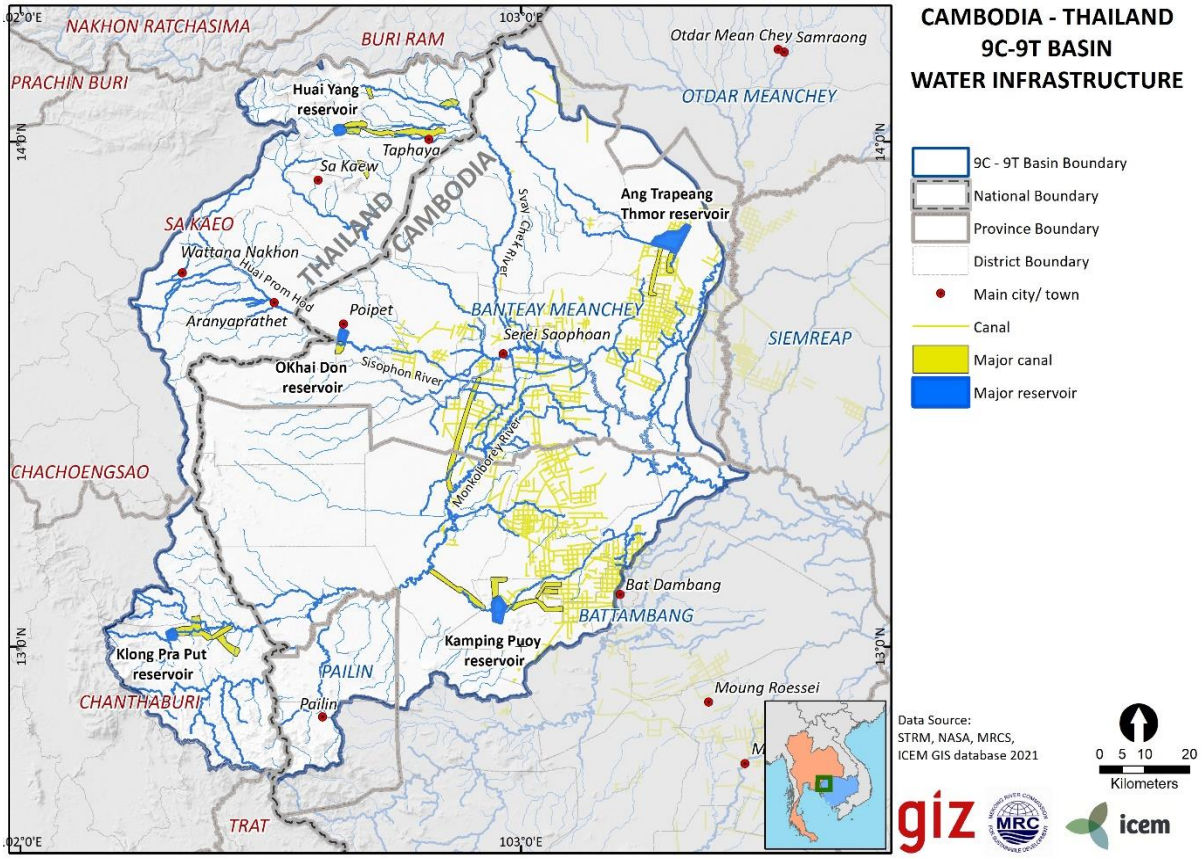
1. Collection of onsite observations, photos and survey information using the Fulcrum Mobile Data Collection App;
2. Survey estimates of on-site dimensions using a laser distance measurer;
3. Onsite written reports based on field observations and discussions with local stakeholders; and
4. Roundtable meetings and discussions with provincial authorities.

This process resulted in identification and discussion of specific sites where demonstration projects could be feasible and preparation of the initial project concepts. Through the collaborative projects, the two countries can coordinate actions to invest in and grow a linked network of ecosystem-based adaptation across the sub-basin.

3.2 Initial watershed assessment and sub-catchment prioritisation process

A watershed assessment was conducted as the starting point for identifying priority landscapes for watershed rehabilitation, existing infrastructure in need of improved resilience, and hotspots for flood and drought. Existing water infrastructure in the 9C-9T sub-basin is shown in Figure 5.

Figure 5: Water infrastructure within the 9C-9T sub-basin



Priorities were identified based on spatial analysis, remote sensing, and ground truthing. The 9C-9T sub-basin was divided into 18 catchments (Table 1: Sub-catchment scoring matrix Figure 6) that were subject to assessment and ranking according to rehabilitation need. Annex 2 of the 9C-9T Flood and Drought Master Plan provides details of this watershed assessment. Highly ranked sub-catchments are identified in Table 1.

Table 1: Sub-catchment scoring matrix

Basin ID	Drought Risk Score	Flood Risk Score	Erosion Risk Score	Biodiversity Conservation Score	Socio-economic Score	Total Score	Ranking
S1344	4	5	4	3	5	21	1
S0810	5	3	5	4	3	20	2
S1443	4	3	4	3	5	19	3
S2536	5	5	1	4	4	19	3
S0624	5	3	2	2	5	17	5
S0517	4	1	3	5	3	16	6
S0583	5	3	4	2	2	16	6
S0908	4	3	4	3	2	16	6
S0326	2	1	3	5	4	15	9
S0722	4	1	5	3	2	15	9
S1017	5	2	3	4	1	15	9
S0576	4	1	2	4	3	14	12
S0340	4	3	3	1	2	13	13
S0569	2	1	3	3	4	13	13
S0795	3	4	1	2	3	13	13
S1002	5	2	3	1	2	13	13
S0553	2	1	3	3	2	11	17
S0293	1	1	3	4	1	10	18

A network of 13 landscapes (Figure 6) targeted for resilience-building measures were mapped as a spatial starting point for future development and implementation. These locations are priority targets for demonstrating the importance of connectivity and the cumulative effects of networks of NbS interventions at the landscape scale. The landscapes were identified based on three overarching selection factors:

- Areas in need of watershed rehabilitation;
- Existing infrastructure in need of improved resilience; and
- Hotspots for flood and drought.

Each of the 13 landscapes was explored by high resolution Google Earth imagery as the basis for field surveys to assess root cause issues and define corresponding rehabilitation measures. Table 2 lists the 13 landscapes and the factors which led to their identification as possible demonstration landscapes to address the serious issues they are facing through a combination of nature based and hybrid measures.

Figure 6: Sub-catchments scoring and selecting

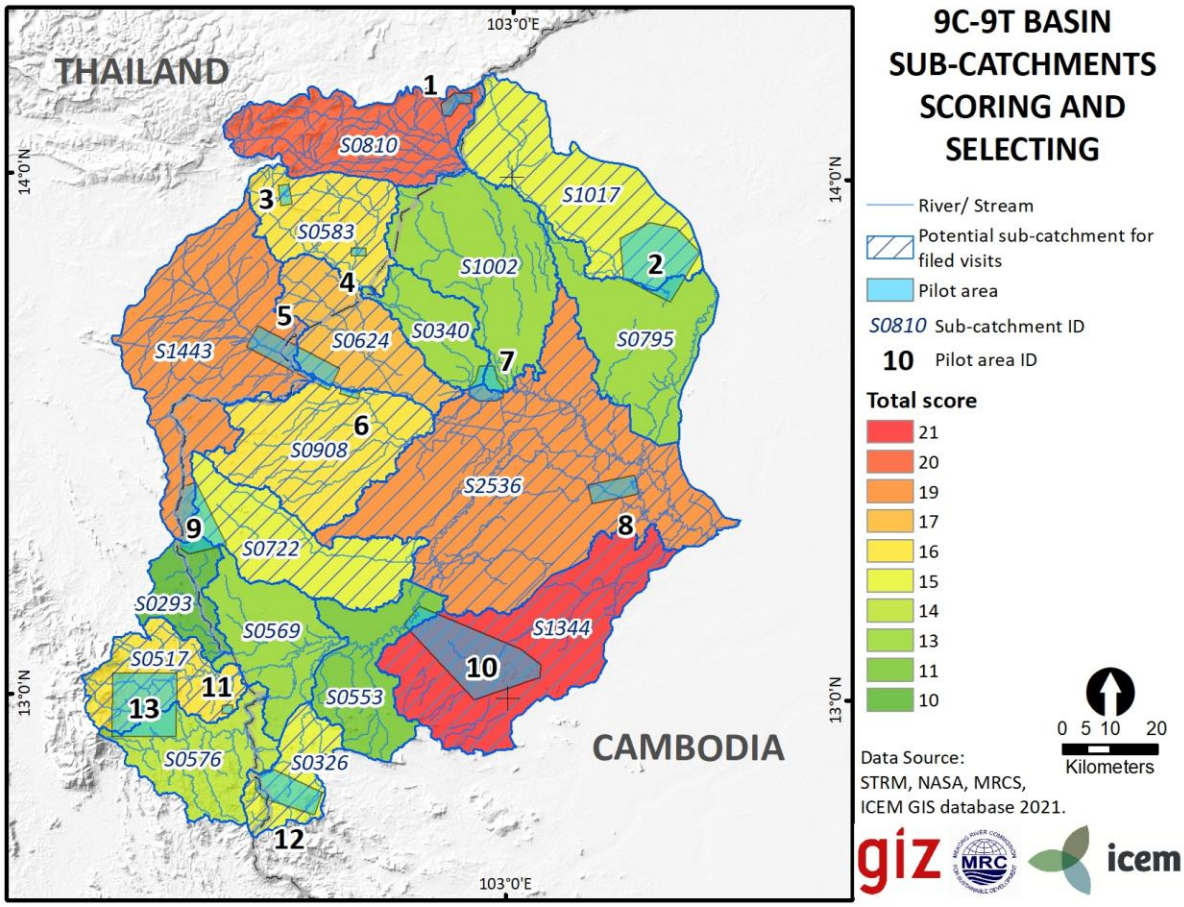


Table 2. Network of 13 landscape areas identified for potential investigation and resilience building demonstration measures in the 9C-9T sub-basin

No.	Country	Sub-catchment	Landscape area	Specific selection factors
1	Thailand	S0810	Klong Sompoi, Klong Taduang and UN reservoirs and watersheds rehabilitation	• Low water availability in the soil • Low infiltration/exfiltration capacity • Soil erosion and sedimentation problem • High potential of crop-Evapotranspiration (indicating potential water stress) • High frequency of drought • Rainfall is projected to reduce in the dry season • Upstream of 1002 sub-catchment which has a very high total score • Reservoirs inside protected areas
2	Cambodia	S1017	Sediment management and watershed rehabilitation at Trapeang Thma Lake	• Low infiltration/exfiltration capacity • Soil erosion and sedimentation problem • High potential of crop-Evapotranspiration (indicating potential water stress) • Increasingly impacted by drought • Rainfall is projected to reduce in the dry season • Forest to agriculture transitions and other land management practices
3	Thailand	S0583	Erosion-sedimentation in Watthana Nakhon District	• Low water availability in the soil • Low infiltration/exfiltration capacity • Intensive soil erosion and sedimentation problem • High potential of crop-Evapotranspiration (indicating potential water stress) • High frequency of drought • Rainfall is projected to reduce in the dry season
4	Thailand	S0583	Riverbank stabilization on Takhian River	
5	Cambodia and Thailand	S1143, S0624	Cross-border waste- and stormwater management through nature-based measures	• Wastewater management issues • Low water availability in the soil • Low infiltration/exfiltration capacity • Medium water retention capacity (increased sealing) • Medium flood risk (projected increasing rainfall in the wet season) • Transboundary flood regulation • High frequency of drought • Rapid urbanisation
6	Cambodia	S0908	Flood retention in Phum Koub Thum and Phum Sokh San	• Regularly flooded area • Increasingly impacted by drought. Rainfall is projected to reduce in the dry season and increase in the wet season

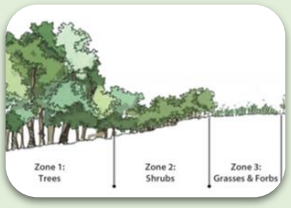
No.	Country	Sub-catchment	Landscape area	Specific selection factors
				• Low water availability in the soil • High potential of crop-Evapotranspiration (indicating potential water stress) • Blockage of natural river channel in Sokh San
7	Cambodia	S2536, S1002	Urban flood management in Serei Saophoan City	• Mining areas, • landslide risk, • urban wastewater pollution
8	Cambodia	S2536	Flooded forests and wetland rehabilitation in buffer zone of Tonle Sap Biosphere Reserve	• High flood risk • Forest to agriculture transitions • Wetland loss
9	Cambodia	S1443, S0722	Forest stepping stone network for connecting remaining forest areas in critical watersheds	• Forest fragmentation issue • Forest loss • Soil erosion and sedimentation problem • Low infiltration/exfiltration capacity
10	Cambodia	S1344	Watershed management at Kamping Puoy Reservoir	• Low water availability in the soil • Low infiltration/exfiltration capacity • Low water retention capacity • High flood risk • High and increasing frequency of drought • Forest to agriculture transitions • Soil erosion and sedimentation • Encroachment into reservoir
11&13	Thailand	S0517	Water conservation and supply for orchard plantations Forest corridors established in critical watersheds	• A critical catchment for downstream water uses and conditions (water conservation and supply for orchard plantations in Pong Nam Ron) • Forest fragmentation issue • Encroachment into protected areas
12	Cambodia and Thailand	S0326	Watershed rehabilitation in Samlaut Multiple Use Area (Cambodia) and buffer zone to Khlong Kreua Wai Chaleum National Park (Thailand)	• Covering Samlaut Multiple Use Area (Cambodia) and buffer zone to Khlong Kreua Wai Chaleum National Park (Thailand) • Encroachment into protected areas. • Forest degradation with knock-on downstream impacts

3.3 Selected priority landscape areas for NbS demonstration projects

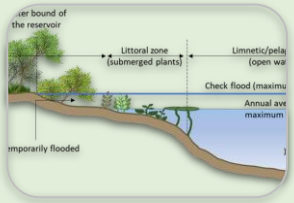
Of the 13 landscapes that were prioritised for resilience building measures, a first phase of six have been selected for more detailed conceptual design and planning aiming for a diversity of ecosystems, infrastructure assets, and a balance of target areas within Cambodia and Thailand (Table 3, Figure 8). These landscapes were selected in consultation with NWGs to achieve a diversity of conditions in each country and NbS intervention potential.

This report sets out six project concepts (one for each selected prioritised landscape) with a network of NbS interventions to build flood, drought and ecosystem resilience. These six projects provide for the demonstration of 15 specific nature based and hybrid solutions laid out in networks across forest, agricultural and urban landscapes as illustrated in Figure 7.

Figure 7: The 15 NbS measures identified in this report for the six priority landscapes



1. Riparian buffer



2. Reservoir zoning

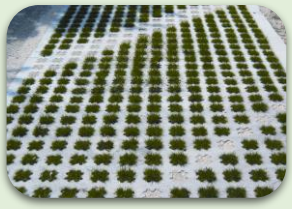
3. Catchment water management plans

4. Drainage combined with nature-based retention

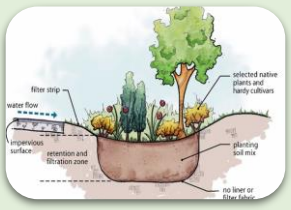
5. Sediment trapping

6. Forest restoration & rehabilitation

7. Retention & infiltration of rooftop runoff



8. Permeable surfaces



9. Retention & infiltration of surface runoff

10. Constructed wetlands

11. River channel widening & rehabilitation

12. River bank stabilization & rehabilitation

13. Sustainable irrigation measures

14. Urban greening

15. Agricultural field buffer

These 15 specific measures comprise a sub-set of those outlined in the 9C-9T NbS Catalogue, further detailed as part of the Basin Atlas. The 15 nature-based/hybrid measures are outlined in detail in Annex 1. Proposed measures include rehabilitation of degraded upper catchments and drainage corridors; restoration and expansion of forest cover and wetlands; canal, river and reservoir rehabilitation including vegetated buffers, sediment trapping and bank stabilization; vegetated buffers on boundaries of agricultural allotments and along roads; and a wide range of NbS in urban areas, including rain gardens, constructed wetlands, expansion of green space and urban forest canopy cover.

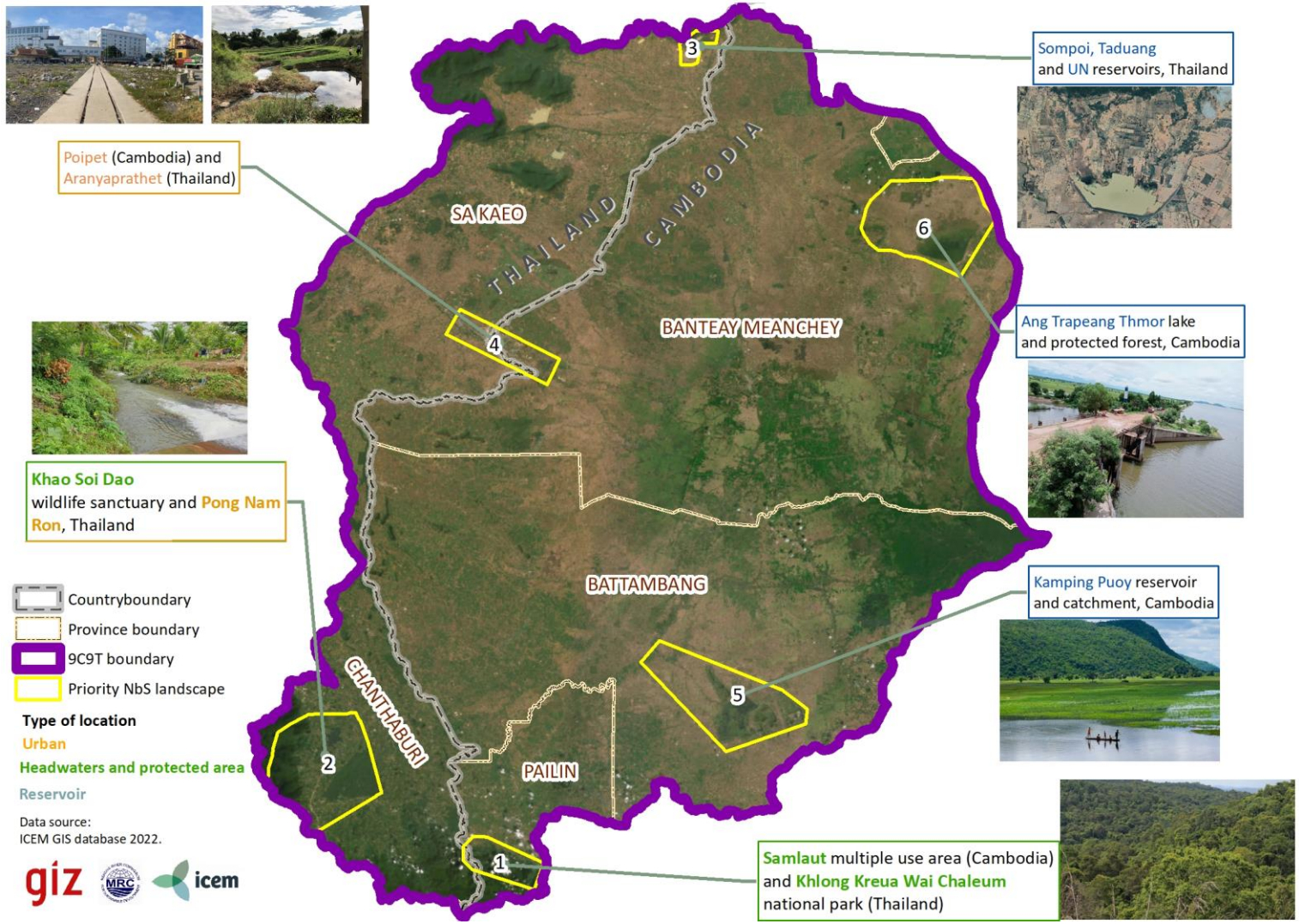
The overall goal is to demonstrate measures that can be replicated and rolled out across the basin's agricultural, urban and headwaters landscapes as a connected network so that their cumulative impact will substantially reduce the risks of flood and drought. These degraded landscapes emphasize the importance of national priorities in both countries for ecosystem restoration, biodiversity conservation, watershed rehabilitation and the joint priority of building urban and rural flood and drought resilience.

The project concepts identify (i) the desired function and benefits from the NbS, (ii) locations that are suitable for the NbS and (iii) potential constraints in applying the measures. These projects with multiple NbS are a starting point in developing the network of nature based and hybrid solutions for the 9C-9T sub-basin. Further development of this network will be progressed as the 9C-9T Master Plan is implemented with national and international funding contributions.

Table 3: Selected landscape areas for detailed investigation and interventions (from upstream to downstream of 9C-9T sub-basin)

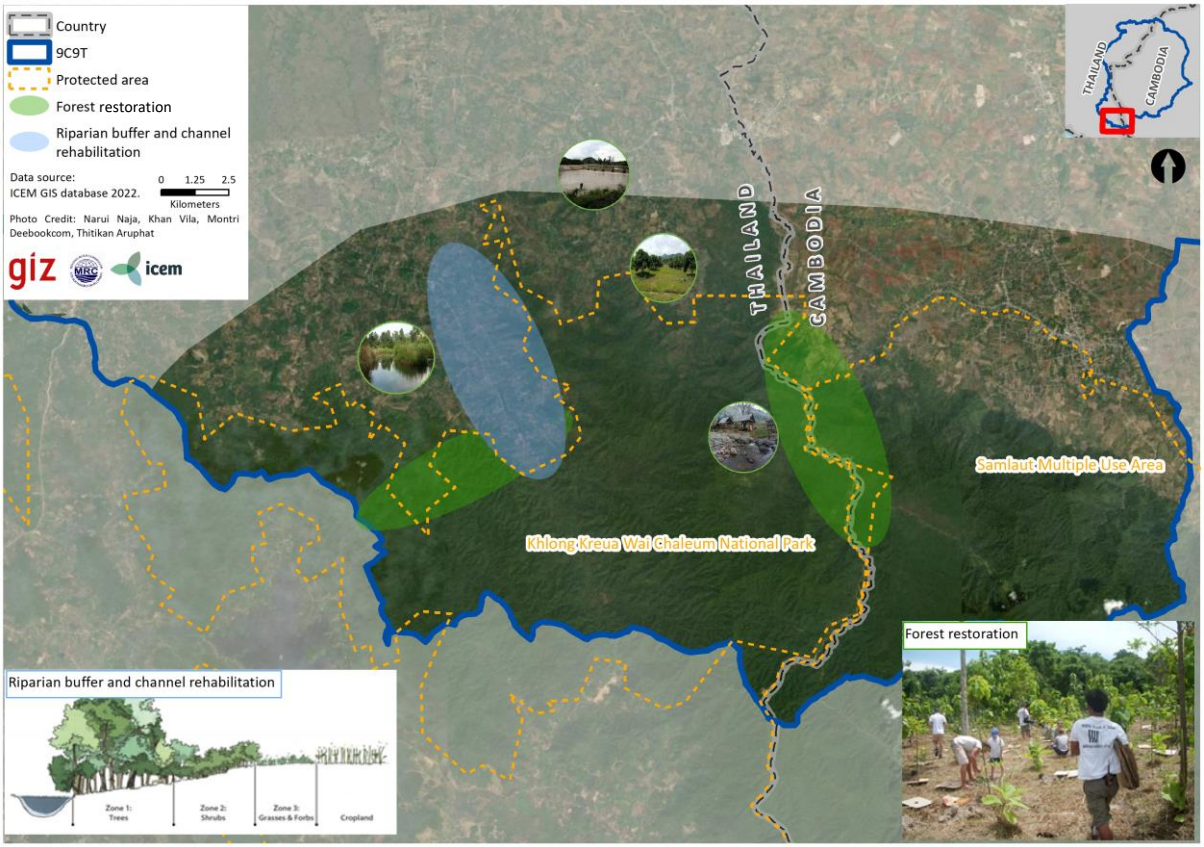
Project No.	9C-9T Masterplan output	Landscape area category	Landscape area location	Country (Province)	Drivers, impacts and selection factors	Proposed interventions
1	2.3.1	Transboundary headwaters and protected areas	Samlaut Multiple Use Area (Cambodia) and Khlong Kreua Wai Chaleum National Park (Thailand)	Cambodia (Battambang) / Thailand (Chanthaburi)	Protected area encroachment, watershed and forest degradation with downstream impacts	Watershed rehabilitation, protected area and buffer zone ecological restoration, protected area management (forest restoration, riparian buffers)
2	2.3.1	Headwaters and protected areas ('sister projects')	Khao Soi Dao Wildlife Sanctuary and Pong Nam Ron	Thailand (Chanthaburi)	Forest fragmentation, protected area encroachment (agriculture and hunting), biodiversity loss	Establishment of forest corridors in critical watersheds, protected area management (forest restoration, sustainable irrigation), Urban waste and stormwater management through nature-based measures (retention of runoff, river rehabilitation, urban greening)
3	2.3.2	Headwaters and protected areas ('sister projects')	Sompoi, Taduang and UN reservoirs	Thailand (Sa Kaeo)	Low water availability, high drought frequency, soil erosion and sedimentation, protected area and buffer area encroachment	Reservoir and watershed rehabilitation and management (riparian buffers, sediment trapping, forest restoration, nature-based drainage, sustainable irrigation and agricultural buffers, catchment water management)
4	2.1.4	Transboundary urban areas	Poipet (Cambodia) and Aranyaprathet (Thailand)	Cambodia (Banteay Meanchey) / Thailand (Sa Kaeo)	Wastewater management issues, low water availability, moderate flood risk, high frequency of drought	Cross-border waste and stormwater management through nature-based measures (urban greening, river rehabilitation, sediment trapping, water retention, drainage improvements and nature-based retention, constructed wetland)
5	2.2.2	Rural reservoirs ('sister projects')	Kamping Puoy Reservoir	Cambodia (Battambang)	High flood risk, forest to agriculture transitions, wetland encroachment, low water availability, soil erosion and sedimentation	Reservoir, wetland and watershed rehabilitation and management (riparian buffers, sediment trapping, forest restoration, reservoir/wetland zoning, catchment water management, sustainable irrigation)
6	2.2.2	Rural reservoirs ('sister projects')	Ang Trapeang Thmor Lake and Protected Forest	Cambodia (Banteay Meanchey)	Protected area encroachment, biodiversity loss, forest to agriculture transitions, soil erosion and sedimentation, increasingly drought frequency	Sediment management, watershed rehabilitation and protected area management (forest restoration, riparian buffers, water management, sustainable irrigation, agricultural buffer, sediment trapping)

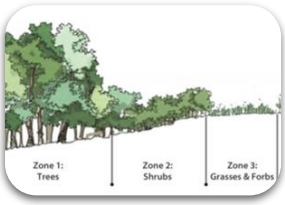
Figure 8: Selected projects for NbS conceptualisation



4 PROJECT 1: TRANSBOUNDARY HEADWATERS AND PROTECTED AREAS – SAMLAUT MULTIPLE USE AREA (CAMBODIA) AND KHLONG KREUA WAI CHALEUM NATIONAL PARK (THAILAND)

4.1 Project Overview





1. Riparian buffer

6. Forest restoration and rehabilitation

Project 1 is a key landscape area for the demonstration of nature based and hybrid solution networks, with selection factors including protected area encroachment and watershed and forest degradation with downstream water security and quality impacts. The project objectives for this landscape include:

- Establishment of measures to foster watershed rehabilitation, forest restoration and protected area and buffer zone ecological restoration; and
- Work together with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated and transboundary approach to watershed rehabilitation and forest restoration is implemented within the both the Multiple Use Area (MUA) and National Park (NP), that aligns with the 9C-9T Masterplan and Action Plan.

Table 4: Project 1 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk • **Outcome 2.3**: Rehabilitated basin headwaters and wetlands, to improve water security and climate resilience through ecosystem-based adaptation interventions • **Output 2.3.1**: Develop and implement at least six (3 in each country) interventions for rehabilitation and effective management of protected areas and upper watersheds in river basin headwaters – to improve and maintain the delivery of ecosystem services, with an emphasis on safeguarding transboundary biodiversity of international importance
Implementing stakeholders	• **Lead agency (Cambodia)**: Ministry of Environment (MoE) • **Lead agency (Thailand)**: Department of National Park, Wildlife and Plant Conservation (DNP) • ***Supporting agency (Cambodia)***: Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Water Resources and Meteorology (MOWRAM) and provincial government • ***Supporting agency (Thailand)***: Office of the National Water Resources (ONWR), the Ministry of Agriculture and Cooperatives, the Ministry of Natural Resources and Environment (MoNRE) and provincial government
Alignment to agency priorities	DNP, an agency of the Ministry of Natural Resources and Environment in Thailand, has a mission towards the conservation, protection, restoration and sustainable management of forest resources and wildlife. Khlong Kreua Wai Chaleum is one of the national parks under its remit. Ministry of Environment is a government ministry of Cambodia with a focus on environmental protection.

4.2 Site description

Project 1 comprises Samlaut MUA (Cambodia) and buffer zone to Khlong Kreua Wai Chaleum National Park (Thailand); a transboundary protected area landscape located on the border of Cambodia (Pailin) and Thailand (Chanthaburi). Samlaut MUA, decreed in 1993, covers an area of 60,000 Ha. Khlong Kruewai Chalearm Phrakiat National Park is a fragmented protected area, covering an area of 26,500 Ha.

The headwaters of this transboundary landscape comprise maximum elevations of over 900 m above sea level (asl). The northern extent of the MUA and national park catchments naturally drain down from the steeper, elevated areas and level off into an agricultural plain, with scattered villages and the Krong Pailin urban settlement on the Cambodian side of the border. Several discrete elevated vegetated areas are also present within the plain on the Thai side.

Samlaut comprises the northernmost range of the Cardamom Mountains and is one of Cambodia's key watersheds, as well as being the last remaining tropical rainforest in north-western Cambodia. It is an essential drainage corridor, with its rivers and streams supplying fresh water and ecosystem services for around one million people in the downstream provinces of Pailin and Battambang. Samlaut's Stung Sangker River provides for local upland crop irrigation, as well as fish stocks and water for the Tonle Sap Lake and its lowland agricultural lands.

The MUA is also an essential ecosystem for biodiversity, providing a critical habitat for endangered species of flora and fauna, whilst providing an international wildlife corridor to support ecological connectivity within the region.

4.3 Flood and drought drivers and impacts

4.3.1 Drivers

Protected area encroachment and lack of enforcement capacity

Geospatial analysis of the landscape area demonstrates significant land cover change and vegetation disturbance over the last 30 years, particularly within the northern extent of Samlaut MUA. Samlaut MUA status permits local communities the right to utilize natural resources in a sustainable manner. Despite this, precious gem/mineral mining, illegal logging, animal poaching and land encroachment continue to threaten the area. A lack of financial support and enforcement has compounded these issues over the years. Agricultural encroachment of the protected area foothills is apparent and several roads dissect the forested areas.

On the border of the 9C-9T sub-basin to the south, the buffer zone between Khao Soi Dao and Khlong Kreua Wai Chaleum National Park is significantly fragmented by linear infrastructure and urbanisation. This division inhibits a connecting wildlife corridor between the two protected areas. In 2020, an agreement was signed between the Cambodia and Thai protected area agencies to collaborate in conserving the international wildlife corridor but has not led to effective action.

Drainage structure, irrigation and reservoirs

The landscape area is an important watershed for the 9C-9T basin and has historically supported several drainage channels in the foothills and terraces below the MUA and NP. Their gradual degradation and replacement with agricultural land has resulted in reduced water storage capacity, increased drought risk and sedimentation.

4.3.2 Impacts

Forest fragmentation and biodiversity loss

Encroachment into the protected areas has led to widespread forest fragmentation and deforestation. This resulted in habitat degradation and impacts to the flora and fauna located within the MUA and national park. In addition, the development of road infrastructure and encroachment has impacted on ecological connectivity with the landscape.

Increased runoff, loss of water storage and degrade drainage channels

Encroachment into the foothills of the MUA and national park, as well as soil erosion, has impacted natural drainage channels, reducing the vegetative cover and natural water storage and supply potential of the landscape. Filling and reducing the depth of streams increases the risk of flash flooding and landslides during periods of high rainfall and high discharge. The degradation of the watershed reduces availability of water during droughts and results in an increase in sedimentation and reduced water quality – and overall loss of soils and soil condition.

4.4 Nature based and hybrid solutions project concept

4.4.1 Concept design of NbS

Measure 6: Forest restoration and Measure 1: riparian buffer strips

Forest restoration in the landscape is critical to ensure the recovery of degraded and fragmented areas and should be planned at the landscape scale, with the objective of re-establishing ecological integrity and transboundary connectivity. Several potential locations have been identified for restoration particularly in areas where there is encroachment into the MUA and national park along its northern boundary (Figure 9). Land ownership and tenure arrangements of these areas has not yet been determined through detailed field visits and site investigation. Opportunities for restoration and connected networks of drainage buffers will be explored during future investigations with national and local authorities. Measures in each location would share the same restoration objectives, as identified in Measure 6 and Measure 1 (Annex 1).

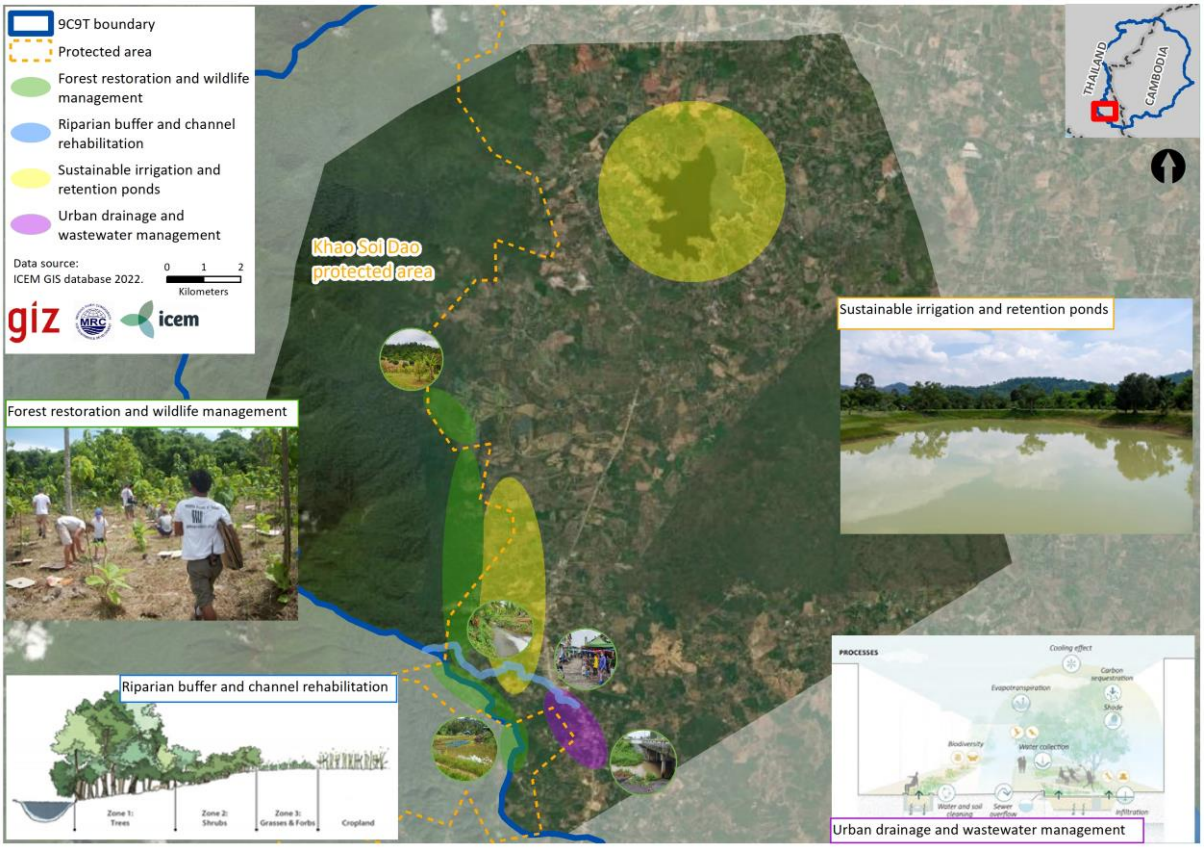
Figure 9: Forest fragmentation and degradation within the landscape area – (a) degradation along international boundary and (b) encroachment into Samlaut MUA

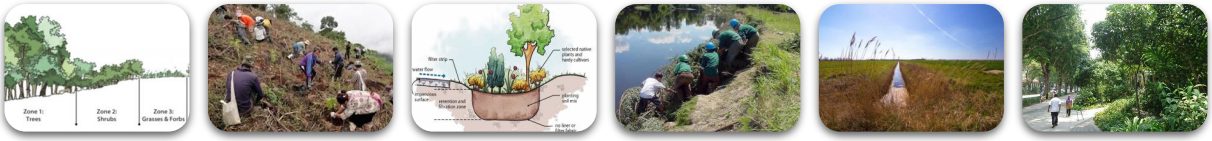
4.4.2 Project benefits

- Restoration of 50 ha of forest areas;
- Restored ecological connectivity between previously fragmented landscapes;
- Increased habitat provision and biodiversity value;
- Improved natural water storage and reduced sediment runoff; and
- Restoration of drainage channels and water retention for agricultural activities.

5 PROJECT 2: HEADWATERS AND PROTECTED AREA – KHAO SOI DAO WILDLIFE SANCTUARY, PONG NAM RON AND PLANTATIONS, THAILAND

5.1 Project Overview





1. Riparian buffer | 6. Forest restoration and rehabilitation | 9. Retention and infiltration of surface runoff | 12. River bank stabilization and rehabilitation | 13. Sustainable irrigation measures | 14. Urban greening

Project 2 is identified as a key landscape, in particular in relation to protected area encroachment, drought and water retention, urban risk and watershed and forest degradation with downstream impacts on farms, urban areas and transport corridors. The project objectives for this area are focused on:

- Defining opportunities for the establishment of measures to foster watershed rehabilitation, forest restoration, protected area and buffer zone ecological restoration, and road and urban drainage interventions;
- Working with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated and transboundary approach to watershed rehabilitation and forest restoration is implemented within the PA, that aligns with the 9C-9T Masterplan and Action Plan.

Table 5: Project 2 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk **Rural** • **Outcome 2.3**: Rehabilitated basin headwaters and wetlands, to improve water security and climate resilience through ecosystem-based adaptation interventions • **Output 2.3.1**: Develop and implement at least six (3 in each country) interventions for rehabilitation and effective management of protected areas and upper watersheds in river basin headwaters – to improve and maintain the delivery of ecosystem services, with an emphasis on safeguarding transboundary biodiversity of international importance **Urban** • **Outcome 2.1**: Outcome 2.1: Strengthened urban flood and drought resilience through innovative climate-sensitive and ecosystem-based planning tools and adaptation interventions • **Output 2.1.4**: Develop and implement protective, hybrid (green and grey) infrastructures to reduce urban flood risks (e.g. urban river channel improvement, bank stabilization and natural flood retention areas) and enhance water quality in two target towns (one in each country)
Implementing stakeholders	**Rural** • **Lead agency (Thailand):** Department of National Park, Wildlife and Plant Conservation (DNP) • ***Supporting agency (Thailand)*:** Office of the National Water Resources (ONWR), the Ministry of Agriculture and Cooperatives, the Ministry of Natural Resources and Environment (MoNRE) and provincial government **Urban** • ***Lead agency (Thailand)*:** Ministry of Interior, Department of Public Works and Town and Country Planning • ***Supporting agency (Thailand)*:** National Water Resources (ONWR), the Ministry of Agriculture and Cooperatives, the Ministry of Natural Resources and Environment (MoNRE) and provincial government
Alignment to agency priorities	DNP, an agency of the Ministry of Natural Resources and Environment in Thailand, has a mission towards the conservation, protection, restoration and sustainable management of forest resources and wildlife. Khao Soi Dao is one of the national parks under its remit The Ministry of Interior is responsible for core areas including local administration, disaster management, road safety, land management and public works

5.2 Site description

The landscape covers the area surrounding Pong Nam Ron urban development and the Khao Soi Dao Wildlife Sanctuary, located in the S0517 and SO576 sub-catchments, near the Thai-Cambodian border at the south-eastern boundary of the 9C-9T sub-basin. The landscape is located in the Pong Nam Ron District, Chanthaburi Province, and comprises a combined protected area and rural headwater, and urban environment. The headwater area is located within the protected area at maximum elevations of 1500 m above sea level (asl). To the east of Khao Soi Dao, the catchment levels off into a plain with agricultural land, a number of small reservoirs, urban settlements and scattered villages. The area naturally drains down from steeper elevations within the protected area into flatter terrain, which has been extensively developed into agricultural land. The landscape is transected by the national 317 highway, from north to south. A large vegetated military zone of approximately 55 km^2, as well as the larger Khlong Phra Phut Reservoir are also situated in the catchment. Pong Nam Ron urban area,

providing for an estimated 10,000 people (2019[8]), is also located in the conduit between the military zone and the PA. The area is a critical headwater for four sub-basins in eastern Thailand, with water also flowing to Tonlé Sap Lake in Cambodia. The catchment is important for downstream ecosystems and water users.

Khao Soi Dao is contiguous with Khao Khitchakut National Park to the south and to the west, and contiguous with Khao Ang Ru Nai Wildlife Sanctuary. The topography of the protected area is made up of two distinct landscapes, with a smaller, low-lying area to the north and a larger mountainous region with perennial streams and waterfalls in the south. Vegetation is dominated by semi-evergreen and evergreen forest at higher elevations, as well as a few pockets of deciduous forest and bamboo. Khao Soi Dao Wildlife Sanctuary supports several endangered species and is the only Important Bird and Biodiversity Area (IBA) in Thailand that supports the globally endangered Chestnut-headed Partridge *Arborophila cambodiana*, a restricted-range species.[9]

5.3 Flood and drought drivers and impacts

5.3.1 Drivers

Agricultural development and protected area encroachment

Forest areas at the eastern boundary of Khao Soi Dao act as a protective barrier against erosion, flood/drought and biodiversity loss. Increasingly however forest areas are being destroyed and replaced with orchard plantations. Site visits combined with remote sensing analysis indicates encroachment into the foothills of the PA, associated with the establishment of small to medium-scale plantations, sprinkler systems and the installation of small reservoirs. The main agricultural product in the Pong Nam Ron area is durian, exported overland to China (through Cambodia and Vietnam). Durian, mangosteen, banana and other crops require the application pesticides and broad-spectrum herbicides that pollute local retention ponds and streams.

Many encroached areas were initially established by local communities, comprising dwellings, orchard plantations or cropland before such locations were declared part of the Khao Soi Dao Wildlife Sanctuary. Such areas are therefore recognised and not illegal.

Drainage structure, irrigation and reservoirs

A key issue in Pong Nam Ron district is drought, so the priority is to retain as much water as possible for the dry season. Water demand and consumption associated with urbanisation, agricultural land (including plantations) and recreational use has risen along with waste water and water abstraction for irrigation. These drivers contribute to the construction of reservoirs, occasionally at the expense of degrading and disappearing natural drainage channels.

The Khlong Ta Liu dam and reservoir, situated within the forested area of PA, was proposed for flood regulation purposes and supports water provision in the region (without the undertaking of an environmental impact assessment). A number of further reservoirs are situated in the lowlands, outside the protected area boundary, to provide agricultural and recreational water resources. Satellite imagery highlights the continuous construction of such artificial waterbodies. Natural drainage channels and streams have been developed over, constraining the natural drainage structure and flood/drainage control of the lowland area, including the expanding Pong Nam Ron urban development.

[8] Source: https://www.citypopulation.de/en/thailand/eastern/chanthaburi/2289__pong_nam_ron/
[9] BirdLife International, 2022. Important Bird Areas (IBA) factsheet: Khao Soi Dao, Thailand. http://datazone.birdlife.org/site/factsheet/khao-soi-dao-iba-thailand

Urbanization and road infrastructure

Although there are no large urban areas situated within Pong Nam Ron District, development along the road that borders the easter boundary of Khao Soi Dao has resulted in increased hard surfaces and a reduction in natural areas. The increase of small to moderately sized urban areas such as Pong Nam Rong have acted as a hub for urbanization, road infrastructure and industrial expansion in the area. Waste management and wastewater treatment facilities have not been able to keep up with the increasing commercial and residential demands. Road infrastructure and paths are located in the transition from the plain into the hilly area. Many lack a drainage structure which would divert water into channels, fields or natural retention areas.

Figure 10: Hardening of the landscape at Pong Nam Ron

5.3.2 Impacts

Increased runoff and loss of water storage in the reservoirs and drainage channel

The expansion of urban areas has reduced nature-based water management and retention opportunities, in turn reducing water infiltration and increasing runoff from the upland watershed in the PA. The area also experiences damaging seasonal flooding.

Insufficient water during the dry season impacts both the agricultural sector and the use of water for consumption. During the dry season, the Pong Nam Ron municipality water source has reduced flow for approximately two months, resulting in competition for water among farmers and local municipalities. Drinking water is supplied for 3 months by trucks.

Wastewater discharge

The lack of waste management and water treatment facilities result in untreated wastewater discharge entering drainage channels and streams within the catchment, passing into downstream areas in Cambodia. Hard standing and grey infrastructure dominates the built-up environment, which also increases wastewater disbursement and potential flash flooding.

Forest loss, fragmentation and biodiversity loss

The increase in urbanization and agricultural development around the Khao Soi Dao protected area has resulted in a reduction in forest cover in the landscape area. In addition, development within the protected area, including the Khlong Ta Liu dam, has reduced vegetative cover and impacted on biodiversity. This loss of forested areas (including in elevated areas) increases soil degradation, erosion and landslide risk, as well as water retention and flood risk in an area that already experiences flooding. Changes to the drainage system has resulted in elephants and other wildlife coming down into the foothills to drink and feed in agricultural areas (Figure 11).

Figure 11: (L) Water retention/irrigation pond (0.21 Ha) and (R) evidence of elephant presence

The national 317-highway road is a significant constraint to ecological connectivity within the landscape – it has been constructed with little concern to maintenance of natural drainage channels as important ecosystem service and amenity assets for the area. On the border of the 9C-9T sub-basin to the south, the buffer zone between Khao Soi Dao and Khlong Kreua Wai Chaleum National Park is severely fragmented by the road and the associated linear urbanisation. This prevents prospects for a connecting wildlife corridor between the two PA's. Opportunities for developing ecological buffer zones or wildlife crossings for roads and highways may exist to reconnect the landscape area.

5.4 Nature based and hybrid solutions project concept

5.4.1 Concept design of NbS

Measure 1: Drainage buffer strip and Measure 12: River bank stabilization and rehabilitation

The degradation of drainage corridors within the landscape is a concern for flood and drought resilience. The rehabilitation of natural drainage channels (and artificial canals linked to reservoirs in the area, including the Khlong Phra Phut Reservoir) is required to reconnect the hydrological landscape and provide effective soil retention, water quality and drainage from the watershed into the agricultural-focused plains below. Figure 12 presents the Ta Ni stream and weir complex near Pong Nam Ron.

Figure 12: Drainage channel from Khao Soi Dao to Pong Nam Ron

NbS rehabilitation of the stream through buffer strips in combination with bank stabilization measures provide an opportunity to improve water retention, water quality and reduce sedimentation.

Riparian buffer strips are linear vegetated areas located alongside streams and other water courses. They provide several ecosystem services and are beneficial for improving water retention, water quality, biodiversity, and reducing pollutant and sediment delivery into drainage channels. The buffer strip either side of the drainage channels are proposed at a width of 30m, in line with good practice design, to ensure the ecological integrity linked to the adjacent protected area (see Measure 1, Annex 1). This would yield improved habitat provision and sediment and pollution trapping potential in comparison to a more restricted 15m buffer.

Potential conflicts associated with necessary land take from adjacent private agricultural land are acknowledged. Extensive stakeholder consultation is required prior to planning and implementation. The establishment and development of the natural buffer strip should complement the existing vegetation present in the drainage areas and comprise a mix of native species with exotic trees beneficial to local livelihoods. This will ensure buffer integrity, maximise ecological resilience and prevent the spread of alien invasive species (AIS).

Measure 4: Drainage in combination with nature-based retention

Surface runoff from haphazard drainage needs to be diverted (and where possible treated) into swales, natural depressions, and drainage channels through NbS measures. The surface of the diversion structures must be adopted to expected traffic and small enough to avoid accidents with pedestrians, cyclists and vehicles. Stormwater runoff conveyance systems (e.g. bioswales) comprising linear ditches collect, infiltrate and treat stormwater runoff before releasing it to the watershed. Vegetation reduces water velocity, allowing it to accumulate in a bioswale, and filters suspended sediments.

There is one location (Thap Sai School) where soil erosion is present, requiring NbS measures to connect a new culvert to the manhole of Highway 317 (Figure 13, L). A vegetative buffer would provide appropriate protection from erosion. Such interventions would require engagement and consultation with the Department of Highways and local authorities. The drainage system of 3193 highway road comprises a combined system (water including rainfall, commercial wastewater and public wastewater). NbS interventions for this area comprise wetland rehabilitation at the Ta Ni drainage channel outlet, with effective natural water treatment prior to discharge downstream (Figure 13, R).

Figure 13: Examples of required drainage improvements (Highway 317 (L), Highway 3193 (R))

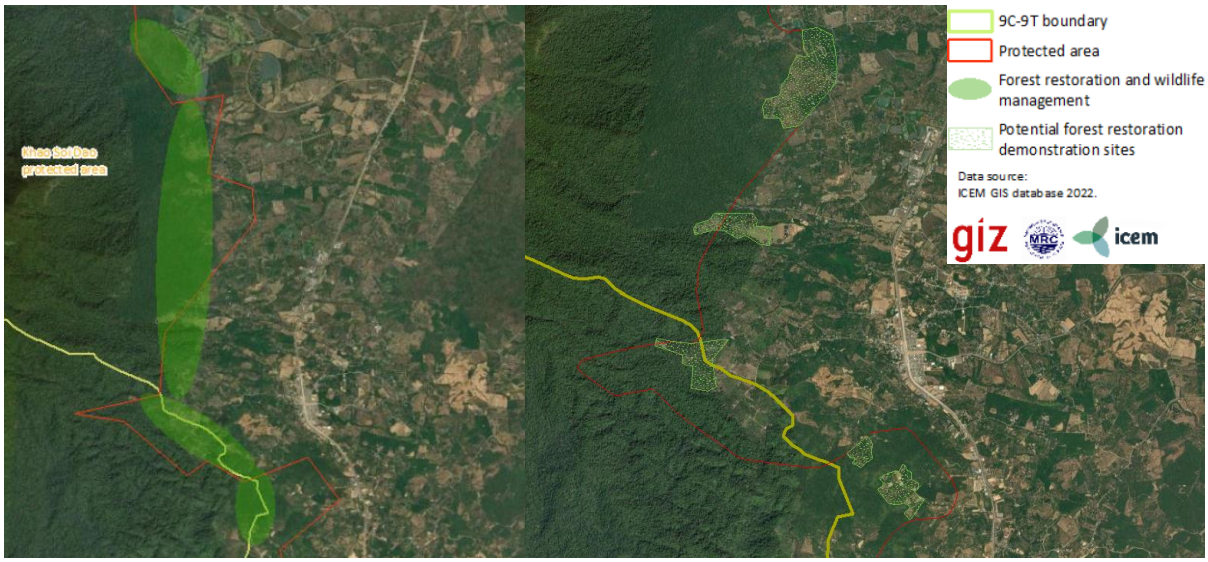
Measure 6: Forest restoration

Forest restoration in the landscape within protected areas and across agricultural and urban areas is critical to ensuring the recovery of degraded and fragmented areas and should be planned at the landscape scale, with the objective of re-establishing ecological integrity and connectivity. This measure is linked to Measure 1 - restoring drainage buffers.

Potential locations have been identified for restoration, particularly in areas where there is encroachment into the protected area along its eastern boundary and in the foothills of Pong Nam Ron. Land ownership of these areas typically comprises private land or land managed by Department

of National Parks, Wildlife and Plant Conservation. These areas currently comprise dwellings, orchard plantations and water retention ponds. Measures in each location would share similar objectives (Measure 7, Annex 1).

Figure 14: (left) protected area forest buffer corridor (right) potential forest restoration sites



Measure 13: Sustainable Irrigation

The establishment of water retention measures, including a network of ponds (Figure 11) in the foothills of Khao Soi Dao Wildlife Sanctuary where orchards are widespread, will support irrigation in the dry season (Measure 13, Annex 1). This should be implemented in tandem with the rehabilitation of drainage channels, reservoirs (including the Khlong Phra Phut Reservoir) and wetland areas, to reconnect the hydrological landscape. Planning and designing such ponds via a network approach can enhance water retention and infiltration benefits. Appropriate wildlife-friendly mitigation/security measures should also be in place to avoid and reduce wildlife conflicts – a challenge already present in the landscape. The creation of ponds for wildlife within the protected area would reduce the need for animals to enter agricultural areas during periods of drought.

Measure 14: Urban greening

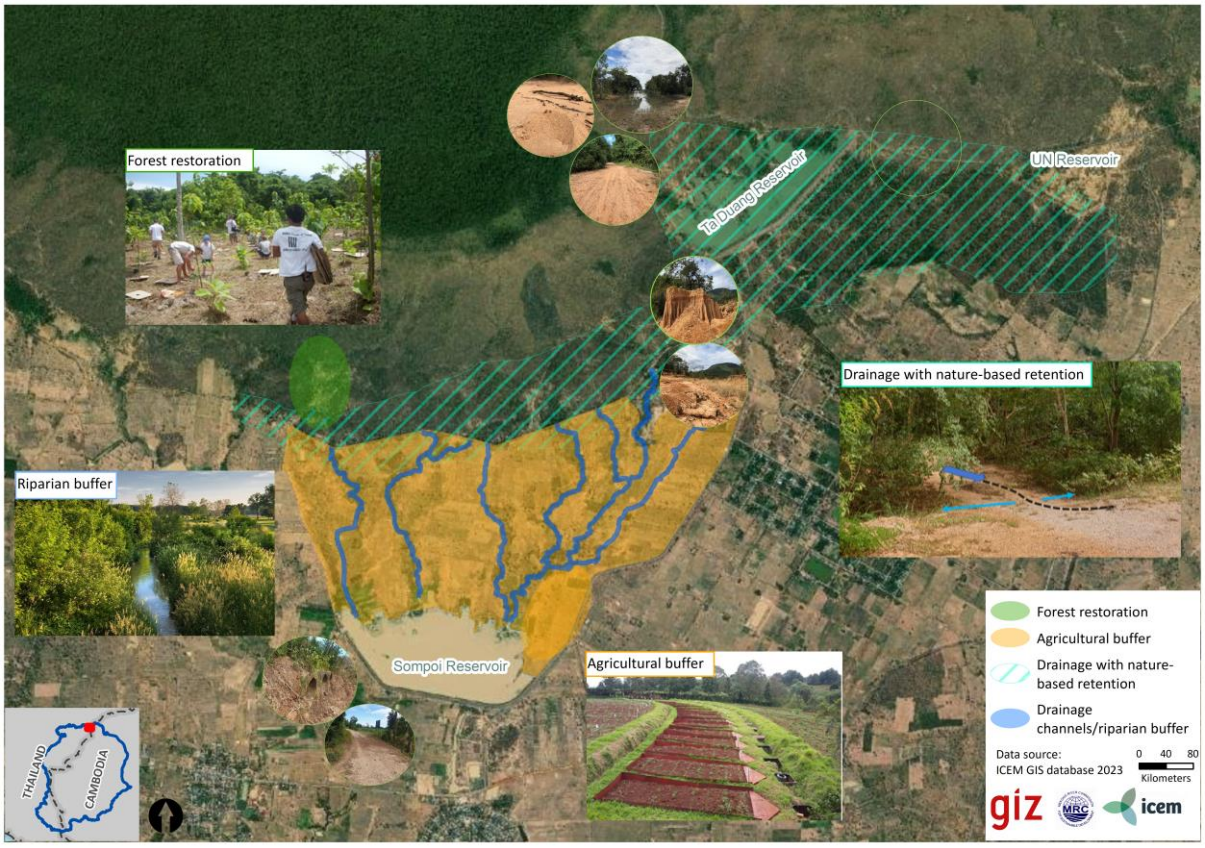
In combination with nature-based retention, urban green spaces should be established in Pong Nam Ron in strategic locations to capture, reduce and store urban runoff. These can be implemented at different scales in both public and private spaces, including the central market. Existing extensive areas of open hardstanding and degraded industrial open spaces should be converted to green spaces. Ultimately the ambition should be to have 30% coverage of green infrastructure in the urban environment, through a range of interventions including parks, gardens, play areas, landscaped areas and tree pits. New green spaces may require changes in land use, resulting in a loss of productive land and impacting local livelihoods.

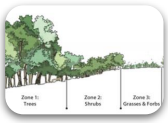
5.4.2 Project benefits

- Restoration of 100 ha of forest areas;
- 30% coverage of green infrastructure in Pong Nam Ron, benefiting 10,000 people;
- Rehabilitation of 4 km of the Ta Ni stream and weir complex;
- Reduced human/wildlife conflict in the buffer zone of the protected area;
- Increased water retention;
- Increased water quality, reduced soil loss and sedimentation; and
- Enhanced habitat for biodiversity.

6 PROJECT 3: HEADWATERS AND PROTECTED AREAS – SOMPOI, TADUANG AND UN RESERVOIRS, THAILAND

6.1 Project Overview




1. Riparian buffer


3. Catchment water management


4. Drainage in combination with nature-based retention


5. Sediment trapping


6. Forest restoration and rehabilitation


13. Sustainable irrigation measures


15. Agricultural field buffer

Project 3 is in a key landscape suffering headwater protected area encroachment, drought, erosion and sedimentation and reduced water quality. The project objectives for this area address those concerns by:

- implementing measures for reservoir and watershed rehabilitation and management, including introducing riparian buffers, sediment trapping, reforestation, agricultural field buffers and water quality management; and
- working with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated approach to protected area, drought and erosion management, aligning with the 9C-9T Masterplan and Action Plan.

Table 6: Project 3 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk • **Outcome 2.3**: Rehabilitated basin headwaters and wetlands, to improve water security and climate resilience through ecosystem-based adaptation interventions • **Output 2.3.2**: Develop and implement at least four (2 in each country) interventions to rehabilitate and manage wetlands in the multiple use areas to strengthen protected area buffer zones and improve ecological integrity for the delivery of ecosystem services (water storage/treatment/habitat)
Implementing stakeholders	• *Lead agency (Thailand)*: Ministry of Agriculture and Cooperatives (MOAC) • *Supporting agency (Thailand)*: Office of the National Water Resources (ONWR), the Department of National Park, Wildlife and Plant Conservation (DNP), the Ministry of Natural Resources and Environment (MoNRE) and provincial government
Alignment to agency priorities	MOAC is responsible for the administration of agricultural policies, forestry, water resources, irrigation and the development of farmers and cooperative systems

6.2 Site description

Project 3 is located in Sa Keo Province, Amphoe Taphaya district and covers the Tambons Thap Thai in the north and Thap Sadet in the south. It is the utmost northern part of the 9C-9T basin. The headwater area is hilly and forested within the Tapraya national park located close to Pang Sida national park, and part of the Phnom Dong Rak mountain range. The hills fade out to the south where agricultural land prevails. The location is home to many reservoirs, which provide domestic water and irrigation. Countless small rivulets drain the area from north to south and become the source for the reservoirs. They continue to form the drainage corridor that finally flows through the Svay Check river to Sisophon in Cambodia.

The striking feature of this area is dispersive soil, which is sandy in nature and thus highly erodible (such as the 'Lalu' landscape presented in Figure 15 – right image). Rain can easily infiltrate and mobilise the loose sand particles. This causes high sediment loads in all rivers in the catchment. Erosion and thus sedimentation is strongest where vegetation has become sparse or entirely removed which is often the case along river-banks and in the buffer to the park following logging and temporary settlements. In addition, although satellite images suggest rather dense vegetation in the hills, the field mission found that the remaining trees and bushes do not have a dense canopy structure and erosion prone areas are common (Figure 15).

Figure 15: Landscape upstream of reservoirs on the southern border of Tapraya national park

The landscape condition determines water supply and condition for all downstream reservoirs and irrigation systems. Three larger reservoirs (UN, Taduan and Sompoi reservoirs) and countless small ponds provide water storage for domestic use and irrigation. The area is part of the Dong Phayayen-Khao Yai Forest Complex, covering 615,500 hectares and comprising five almost contiguous Protected

Areas, of which Tapraya national park is one. From a biodiversity perspective, the national park and forested areas following the mountain ridge from west to east, are a natural wildlife corridor of international importance and an essential upper catchment for Sa Keo Province downstream to Cambodia. However, the Joint Project's GIS analysis from 1990 to 2020 shows a progressive loss of forest, especially in the past 10 years. Forested areas to the north of the reservoirs are managed by the Department of National Park, Wildlife and Plant Conservation.

An in-depth field mission was undertaken to the Sompoi reservoir (see Annex 3 for further details) to identify potential demonstration sites for building flood and drought resilience, incorporating hybrid and nature-based solutions. Thap Thai SAO, LDD and National Park representatives in particular provided an in-depth background to the site. The following sections provide more detailed focus on this reservoir.

6.3 Flood and drought drivers and impacts

6.3.1 Drivers

Erosion and thus sediment local in drainage corridors and reservoirs in this area is largely attributable to the specific soil structure combined with extensive loss of vegetative cover. Other drivers were identified during the field missions and the expert exchange. They are listed in the order of their significance.

Natural features - erodible soil and vegetation with less pronounced canopies

The dispersive soil in this area is the main reason for high erosion and sedimentation rates. In addition, vegetation does not form dense canopies and overall, the immediate upstream landscape is degraded.

A number of individual sites, including Lalu, a popular tourist destination in the region, also contributes to erosion. Lalu is managed by the National Park authority comprises an extensive, bare area of sandy soil and spectacular dissected earth formations formed through steady erosion. Significant sediment build-up and localised erosion occurs dispersing through a system of small ephemeral stream near the National Forest of Thailand office. This results in the transfer of sediment during periods of discharge into the Khlong Sompoi reservoir.

Inadequate drainage structures and vegetated buffers for roads and paths

Roads and paths are located in the transition from the plain into the hilly area. The current system of unsealed roads and paths are a significant part of the erosion and sedimentation problem in the landscape. They all lack adequate drainage structures and vegetated buffers which would divert and filter water into channels, fields or natural retention areas. The presence of small streams and drainage pipes on the roadside of the National Park facilitate the transfer of sediment during periods of discharge towards downstream agricultural areas and then into the Sompoi reservoir.

Missing drainage buffer strips

Vegetated buffer strips have been removed along most streams and drainage channels in favour of gaining more agricultural land, or where present, have been degraded. The benefit of more cultivated land comes with the cost of increasing erosion into rivers and reservoirs. Agricultural practices like furrows in direction of drainage also exacerbates erosion and sedimentation.

Drainage channels were examined during the field mission to the Sompoi reservoir, including the riparian buffer presented in Figure 16. It was noted that the channel and associated buffer does not fully extend down to the Khlong Sompoi reservoir, due to encroachment at the edge of the channel from erosive crop types, including cassava plantations, and a road built over the waterway

The drainage channels are seasonal. During the wet season, water flows rapidly to the Sompoi reservoir due to the steep slopes of the channels. The channels carry runoff from upstream areas in the forest, through culverts under the road, and into the incised downstream drainage channel. Significant volumes of runoff are generated during periods of intense rainfall and plunge pools have

formed below the culvert outlets. However further deepening of this is prevented by an underlying harder layer of laterite.

Figure 16: Example riparian buffer strip leading towards Sompoi reservoir

Missing sediment management upstream of reservoirs

During the wet season, water rapidly flows from the mountains upstream of the reservoirs downstream towards agricultural land, resulting in a high sediment discharge and surface water runoff via small streams into the Sompoi reservoir. Flash floods associated with steep slopes compound this problem, and result in highly turbid waters in the reservoir. The reservoirs are built without sediment trapping measures to filter water on its way into the waterbodies.

It is also understood that the existing small-scale irrigation pond silts up at a rate of 1 m per year due to erosion of the pond banks and upstream overland sediment inputs during the wet season, which settles in the pond. Attempts to reduce bank erosion have included the establishment of vetiver grass around the pond banks. This has been effective to some extent but has not completely prevented bank failures below rooting depth.

The topography and tenure arrangements mean that sediment management would need to be strategically located in close consultation with farmers and local authorities.

Logging

Location 12 within Tapraya National Park was home to United Nations (UN) refugee camps during the Khmer Rouge time in Cambodia. The increases in population in an otherwise relatively isolated area created high pressures on natural resources, including encroachment into the protected area, hunting and logging. The resulting degraded habits still exist to some degree and logging is not uncommon in this area. Past attempts at providing erosion control at the site have included vetiver plantations and restoration of forest landscapes within the national park. One example is located at the Tubtim Siam 03 Project site for reforestation, which was initiated in 1995 comprising an area of 900 rai (144 Ha).

6.3.2 Impacts

The most prominent adverse impacts related to flood and drought are deforestation of headwaters and sedimentation of waterways and reservoirs. Sediment reduces the capacity of rivers and streams

and inhibits natural flow and greatly reduces productivity and water quality in reservoirs and irrigation systems. All reservoirs are located at the base of the hills. They are shallow and a small gain in water level generates a large increase of the water surface. This combination of natural and man-made features creates several problems:

Loss of water storage in the reservoirs and ponds

Sediment settles in the reservoirs and is difficult and expensive to remove. The structure of the outlets of the reservoirs in combination with the shallow bathymetry does not allow for sediment flushing. The consequence is a relatively rapid reduction of reservoir lifetime.

High turbidity in reservoirs and ponds

Turbidity in the reservoirs and ponds is often high due to sediment. This has been causing problems for domestic water supply and irrigation systems, particularly after heavy rainfall while the sediment has not yet settled.

High evaporation losses from the reservoir's water surfaces

The bathymetry of the reservoirs leads to high evaporation losses. A small increase in water depth causes a disproportional increase of the water surface giving rise to high evaporation rates.

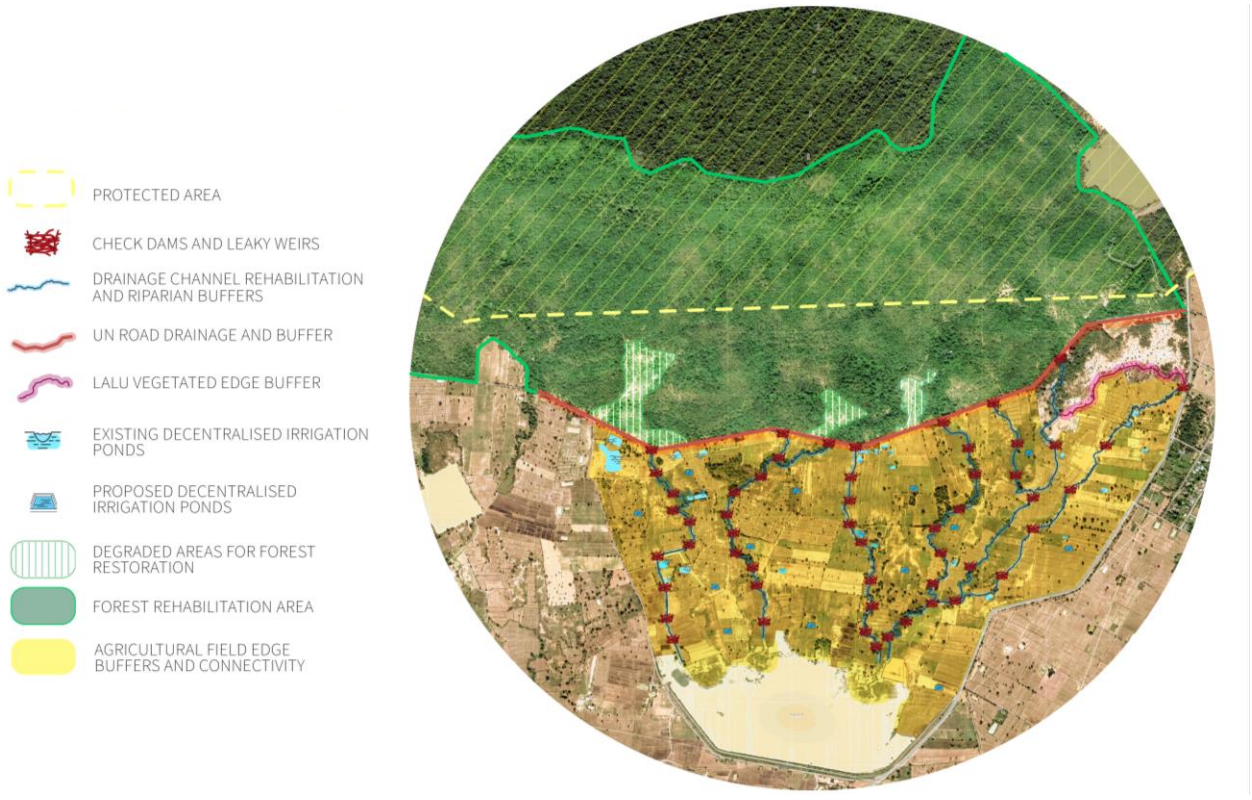
Reduction of flow capacity in rivers due to sediment

Sediment in the rivers is a significant driver for a reduction of flow capacity. Since almost all streams are equipped with structures like weirs, regulated culverts, gates where the sediment settles, the benefit of storage volume is reduced, and the function of the structures is hampered.

6.4 Nature based and hybrid solutions project concept

6.4.1 Concept design of NbS

Figure 17: Proposed NbS measures for Sompoi landscape



Measure 1: Riparian buffers

A number of waterways and drainage corridors have been identified as having the opportunities for riparian buffer establishment and rehabilitation. For example, the natural drainage channel identified in Figure 16 has the potential to be restored to prevent erosion/sediment build up and facilitate its reconnection to the Sompoi reservoir.

Land tenure arrangements here are complex. The waterway is situated on public land – managed by Thap Thai SAO, separated from adjacent private land through its buffer zone. The dimension of this u-shaped waterway was measured as 4m deep, with a top width of 19m and a base width of 16m but showing clear signs of sediment accumulation.

Proposed interventions at this location focus on slowing down and channelling water, supporting infiltration and controlling erosion and encroachment. This includes installing check dams upstream and downstream to prevent further downcutting (see measure 5), something that could be replicated elsewhere in the landscape. With the channel stabilised, the next step would be to consider better management of the channel banks and the prevention of encroachment by cultivation. Solutions focused on negotiation with adjacent land users (farmers) the establishment of riparian buffer strips, and specific measures to stabilise the banks. These measures should extend all the way down to the reservoir. Possibilities for harvesting non-timber forest products (NTFP) from the established buffer could be investigated and discussed with the farmers.

Buffers either side are proposed, with their extent dependant on agreement between Thap Thai SAO and the relevant farmers. The channel banks could be strengthened by bioengineering, for example using native woody species, or by vegetated riprap and other hybrid stabilisation measures.

Measure 4: Drainage in combination with nature-based retention

When NbS and hybrid drainage structures are developed at many places across the landscape as a key strategy in watershed rehabilitation, they contribute in mitigating sedimentation and help reduce flash flooding. Measures can be low-cost and no-regret with multiple benefits of improving water quality and enhancing biodiversity.

Drainage diversion structures for roads, paths and areas suffering from sheet drainage can be combined with nature-based retention measures – i.e. areas of thick vegetation or bioswale channels designed to concentrate and convey stormwater runoff while removing debris and pollution. Generally, these kinds of drainage structures are effective in reducing the speed and volume of surface runoff.

The NbS and hybrid measures here are proposed for the transition zone from the hillside down to the plain where drainage improvement with nature-based retention would best demonstrate its potential. During the site visit to the Sompoi reservoir, existing drainage channels were identified passing under the road and five drainage pipes along the road. Each pipe collects water from the streams to the north in the national park, transferring the flow to the agricultural land downstream and ultimately to the Sompoi reservoir (Further details are provided in Annex 3, field report). The UN Road is under the jurisdiction of the Highways Authority, whilst the land to the north is situated within the National Park.

The more measures implemented the better, beginning at sites with high slopes and dispersive soil. While this demonstration is limited to the immediate areas upstream of the reservoirs, if rolled out more extensively stakeholders can benefit from the cumulative impacts of many natural interventions across the entire headwaters, including within the national park.

Measure 5: Sediment trapping

The establishment of small multiple functioning erosion control and sediment trapping interventions through NbS and hybrid structures offers significant potential within this landscape. Such interventions help to retain sediment before it enters the reservoir to reduce sedimentation, improve water quality and maintain water storage capacity. They are particularly relevant for areas upstream of the UN road, where erosion is significant, and within the drainage channels leading into Sompoi reservoir. Measure 6 provides more details on the sediment stabalisation measures as part of forest restoration efforts.

It was noted that any proposed NbS measures at this location would require engagement and permission from the National Park. In addition, along drainage channels feeding into the reservoirs (see Figure 16 as example), check dams or leaky weirs could be established. These could comprise small wooden log dams built across the channels to lower run-off speed and reduce erosion and gully erosion.

Local stakeholder representatives suggested the provision of 2-5 leaky check dams along a stream to reduce flow and sediment transport during the wet and facilitate the storage of water for use by farmers during the dry season. Although situated on public land, such NbS measures would require engagement and permission from the Thap Thai SAO, with further consultation with local farmers who are active in the area.

Measure 6: Forest restoration

Natural forest rehabilitation is encouraged within the foothills of the Tapraya national park, to the north of Sompoi reservoir. In addition, forest restoration at five seriously degraded locations identified within the Tapraya national park and its buffer, will require a distinctive combination of actions for the park, the buffer and the riparian corridors, because each have differing challenges and opportunities. Yet measures in each location share the same objectives, as identified in Measure 6 (Annex 1). Restoration demonstrations would target degraded areas within the NP.

It is understood that attempts have been made to reforest degraded areas, including planting on elevated bunds, however these failed due to challenges with vegetation establishment. Forest restoration at eroding sites within Tapraya National Park will require a distinct sequence of actions, due to the challenging soil and hydrological conditions.

Initially, steps should be taken to reduce or prevent water flowing overland to specific sites by means of diversion bunds or ditches, with safe outfalls. Second, check dams should be installed to prevent further vertical incision in gullies and to trap sediment. Planting could take place at and behind the check dams. Once the gullies are stabilised, revegetation efforts could extend to the difficult areas of bare soil using pioneer species planted behind simple physical slope modifications such as half-buried branches on the contour.

Native species should be used exclusively, with a planting mix of mixed native woody tree and understorey species, following guidance from the National Park authorities. From satellite and field observations, it is anticipated that each restoration site would be the equivalent of around 3 Ha. Plant nurseries should be established to support native species mix, with a planting regime of mixed native tree and understorey species following guidance from the national park authorities. There are a variety of tree species that have been identified by rangers at the restoration sites that offer potential for tree planting, including *azadirachta indica var. siamensis, peltophorum pterocarpum, Sindora siamensis, Dipterocarpus obtusifolius* and doussie.

Any exotic or invasive species identified at the sites should be replaced with native species, with fencing established to protect re-growth from ungulates and other pressures.

At Lalu, water should be diverted, where possible, away from Lalu to prevent sediment mobilisation and transportation downstream. Opportunities for check dams in upstream drainage channels offer the potential to reduce sediment transfer towards Lalu. Vegetation establishment and tree planting measures to the south of Lalu, may support gradual recolonisation of the area, provide sediment trapping and shade (Figure 17). Lalu is an important site and could provide ecotourism opportunities.

Measure 13: Sustainable irrigation measures and Measure 15: Agricultural field buffers

Due to the sedimentation of the reservoir, drought risk and intensive agricultural practices within the catchment, water conservation irrigation measures are proposed for the three reservoirs in this landscape (see Annex 1, Measure 13). Field trenches and small-scale irrigation ponds provide opportunities for improved water resource management by farmers. Field trenches involve extensive ploughing to the right angle of a field's slope, filtering runoff water, reducing soil degradation and

enhancing infiltration of surface run-off and soil moisture. These should be supported by the establishment of agricultural field buffers (see Annex 1, Measure 15). A network of connected buffers will provide ecosystem services including erosion control, pollination, water retention through water infiltration and slowing surface flow. They can significantly reduce agricultural runoff. Buffer zones are important for ecological connectivity within the wider landscape, connecting and separating landscape features and linking habitats to create wildlife corridors.

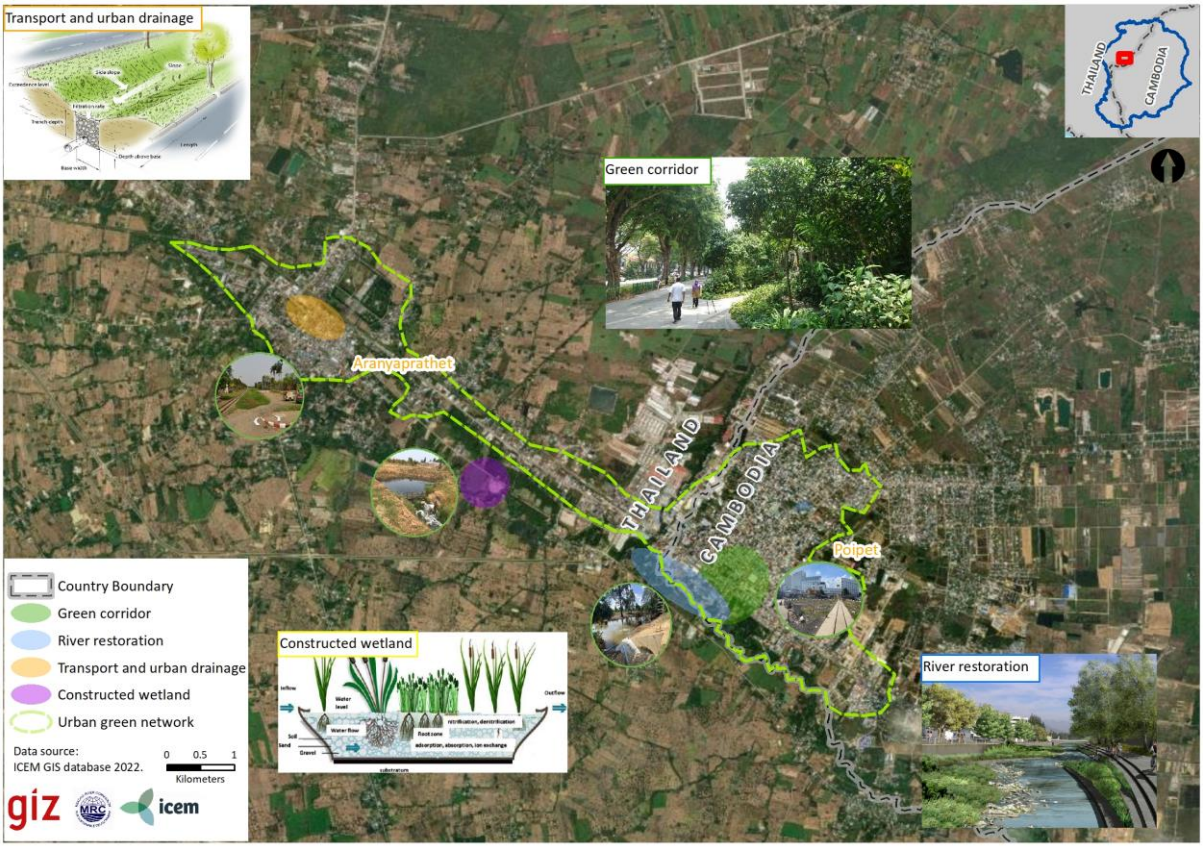
Opportunities exist for expanding the existing network of decentralized irrigation ponds upstream of Sompoi reservoir, to provide greater water security for farmers. The establishment of native grass species or woody species on the pond banks will ensure bank stabilisation and avoid sedimentation. This approach could be applied across the landscape.

6.4.2 Project benefits

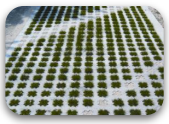
- Restoration of degraded reservoir and catchment, improving water supply functionality;
- Rehabilitation and riparian buffers for 12 km of drainage channels;
- Construction of over 50 new small-scale irrigation ponds, to support decentralised seasonal water security;
- Restored vegetation nodes and corridors within approximately 330 Ha of agricultural land north of Sompoi reservoir, including field buffers;
- Water conservation irrigation measures to support improved irrigation and more sustainable agricultural practices;
- Rehabilitation of 640 Ha upstream forest and drainage system in the Taphraya national park and buffer zone, decreasing sedimentation in the reservoir and increasing ecological connectivity and biodiversity; and
- Restoration and reforestation of over 25 Ha of selected degraded forest sites within Taphraya national park buffer zone.

7 PROJECT 4: TRANSBOUNDARY URBAN AREA FLOODING – POIPET (CAMBODIA) AND ARANYAPRATHET (THAILAND)

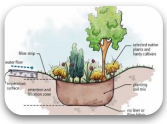
7.1 Project Overview



7. Retention and infiltration of rooftop runoff



8. Permeable surfaces



9. Retention and infiltration of surface runoff

10. Constructed wetlands

11. River channel widening and rehabilitation

12. River bank stabilization and rehabilitation

14. Urban greening

Project 4 was identified as a key landscape, because of the serious water management issues and immediate cross-border implications. The project objectives for this area are:

- Define opportunities for the establishment of measures to foster cross-border waste and stormwater management, urban greening, river restoration, constructed wetland and drainage improvements; and
- Work together with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated and transboundary approach to urban water management is implemented, that aligns with the 9C-9T Masterplan and Action Plan.

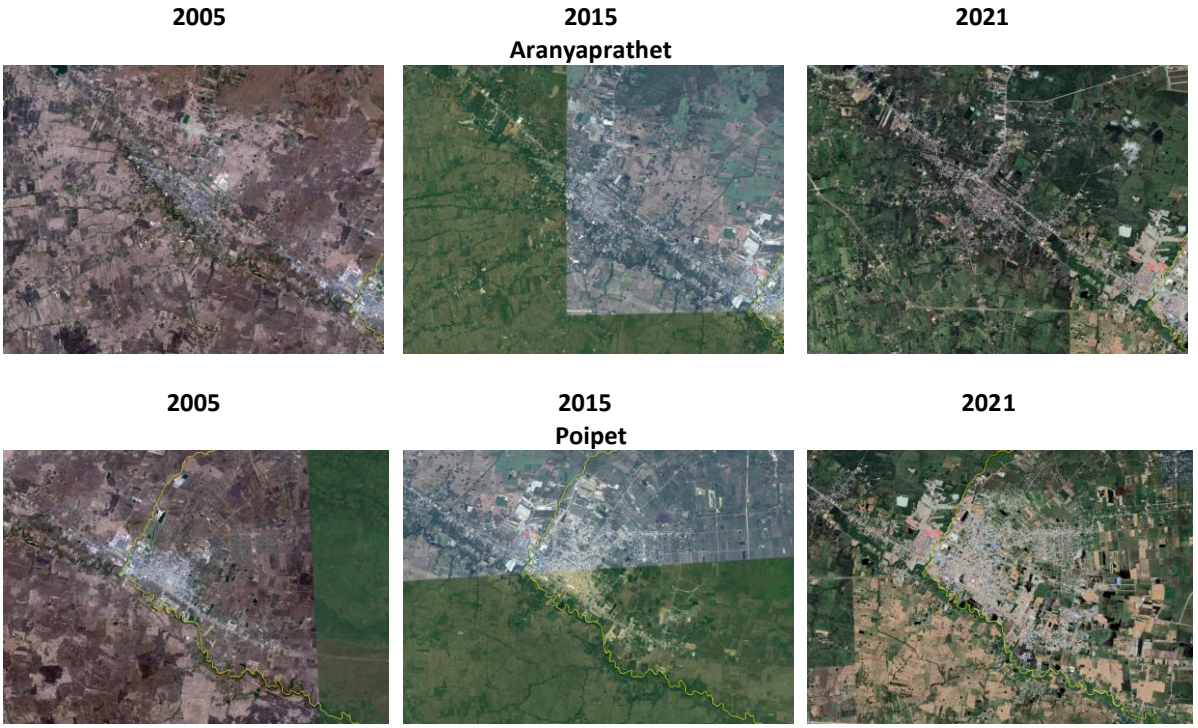
Table 7: Project 4 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk • **Outcome 2.1**: Outcome 2.1: Strengthened urban flood and drought resilience through innovative climate-sensitive and ecosystem-based planning tools and adaptation interventions • **Output 2.1.4**: Develop and implement protective, hybrid (green and grey) infrastructures to reduce urban flood risks (e.g. urban river channel improvement, bank stabilization and natural flood retention areas) and enhance water quality in two target towns (one in each country)
Implementing stakeholders	• *Lead agency (Cambodia)*: Ministry of Water Resources and Meteorology (MOWRAM) and Ministry of Land Management, Urban Planning and Construction (MLUC) • *Lead agency (Thailand)*: Ministry of Interior, Department of Public Works and Town and Country Planning • *Supporting agency (Cambodia):* Ministry of Environment (MoE), Ministry of Agriculture, Forestry and Fisheries (MAFF), and provincial government • *Supporting agency (Thailand)*: National Water Resources (ONWR), the Ministry of Agriculture and Cooperatives, the Ministry of Natural Resources and Environment (MoNRE) and provincial government
Alignment to agency priorities	In Cambodia, MLUC has the mission to lead and manage land use, urban planning, construction projects and land conflict and MOWRAM has the mission to lead flood management in the catchment. In Thailand, the Ministry of Interior is responsible for core areas including local administration, disaster management, road safety, land management and public works

7.2 Site description

Aranyprathet in Thailand and Poipet in Cambodia are neighbouring towns across the international border between the two countries. Both are fast growing cities (Figure 18) with expanding Special Economic Zones, with incoming residents and new development areas and industries. Aranyaprathet is in Amphoe Aranyaprathet district, Sa Keo province and Poipet is situated within the district boundaries of Poi Pet in Banteay Meanchey province.

Figure 18: Rapid development over time at Aranyaprathet and Poipet urban areas



The cities are linked by a railway line and National Highway No.5 in Cambodia which continues as Road 33 in north-west direction through Aranyaprathet. There are railway stations in each city. The channel of the Huai Phrom Hoad River (Thai name) or Ou Chrov River (Cambodian name) acts as the border dividing the two cities, and two countries, and then continues as the upper part of Serei Sisophon River in Cambodia although it encounters many blockages and obstructions due to development before reaching Sisophon city.

Both cities face serious flood problems. Overbank flow inundating residential and industrial areas situated next to the river can be observed almost annually. Poipet is a focal point of support from the Asian Development Bank for solid waste management and drainage. Current proposals are for a new drainage network following the natural topography, discharging stormwater collected towards the Ou Chhrov River[10]. On the Thai side, there are plans to build a large flood diversion canal and a concrete flood wall next to the existing channel, to protect Aranyaprathet with downstream implications.

Taking a transboundary perspective, both cities have similar development potential but also similar problems due to development. However, neither the planned diversion and flood wall on the Thai side nor drainage improvement in Poipet take transboundary issues into account. Coordination between the towns on flood management and water quality is not apparent.

The reasons for the flood problems are manyfold. The Huai Phrom Hoad River, draining an area of approximately 1,443 km², arrives at Aranyaprathet and flows parallel to both towns. A small reservoir upstream of Aranyaprathet functions to regulate the flow in the wet season but does not have the capacity to accommodate annual flood events.

The municipality has developed small scale constructed wetlands to provide some treatment of wastewater, with the wetlands located next to the local landfill site somewhat downstream of Aranyaprathet main city and upstream of Poipet. The wastewater is not treated according to standards, with the wetland flooded regularly during high flow which damages the planting efforts and degrades the effect of water treatment (Figure 19).

[10] ADB, 2022. Feasibility Study for Cambodia: Livable Cities Investment Project (Poipet). https://www.adb.org/sites/default/files/project-documents/52064/52064-001-tacr-en_0.pdf

Figure 19: Constructed wetlands area developed by the municipality downstream of Aranyaprathet – after damage from annual flooding. Constructed wetland (left), plant and grass filtration (middle) and water flow to Phrom Hoad canal (right)

Urban settlements have encroached the flood plain of the meandering river and reduced space for floods. The discharge capacity of the river's cross-sections is too small to accommodate flood peaks that occur regularly. In addition, the cross-sections are not maintained and have become obstructed with debris and vegetation further reducing the flow capacity. Settlements are built directly at the river bank or even partly within the river cross-sections. The health of the river further is challenged by the waste dumped into the river and direct wastewater effluents partly without treatment. A river rehabilitation and restoration effort is needed including a waste management concept to further prevent this international river from being used as a waste dump on both sides of the border.

Field missions have been conducted along with expert exchange on cause-effect issues in both towns. Addressing the repetitive riverine and pluvial flood problems was identified by local stakeholders as of the highest priority. Urban rainwater retention was acknowledged as a necessity given the increasing expanse of impermeable areas, and the expansion of industries and urban development with little spatial planning and controls. Wastewater discharge and solid waste disposal were also recognised as urgent issue that should be addressed.

Measure 12 focuses on flood mitigation by means of river rehabilitation and restoration. The difficulty in rehabilitating the river is its location constituting the border between Thailand and Cambodia. Access is limited especially from the Thai side. Despite the administrative hurdles the necessity to improve the situation is evident and pressing. Indeed, the space for rehabilitating the river is available so NbS and hybrid measures are possible if the two countries collaborate. This project and its various nature based and hybrid measures seeks to improve the flood and water quality situation.

7.3 Flood and drought drivers and impacts

7.3.1 Drivers

Uncoordinated urban development

Uncoordinated and poorly assessed urban development takes place in both cities. It is the major driver of the flood and water quality problems. Poipet is one of the fastest growing cities in Cambodia and subject to a massive inflow of foreign investment. The urban area is expanding into former agricultural lands with little regard to maintenance of the natural drainage corridors. The growing trade flow and number of large entertainment facilities and casinos attracts tourists, real estate ventures and further development like hotels and industry. Large access roads were built on the Thai side connecting Poipet. Water demand has risen as has the volume of waste water following the development.

While urban development took place, stormwater, wastewater, and solid waste management especially in Poipet has not kept pace. The increase of impermeable areas and impediments to natural drainage has increased flash flooding. The river has lost its drainage capacity. Cross-sections are obstructed with debris, waste, and pipes. There is no maintenance of the river cross-sections and extensive encroachment on the river profile. This problem is visible in both cities but is significantly worse further downstream parallel to Poipet with frequent flooding of residential and commercial areas.

The flood problem is worsened by encroachment. Urban settlements reach up to the river bank and into the river channel, especially in Poipet, which will make it difficult to improve maintenance and increase the channels capacity.

Waste problem

The river is used as a waste dump. Waste can be found in the streets, on fields and in particular in the river and along the river banks. Water quality is very poor with an unpleasant odour.

No maintenance of the river

Both the Thai and the Cambodian stakeholders stated that the river cross-section is not maintained. A problem for effective management is the borderline, which follows the river. Poipet is located on the left side in direction of flow with Thailand on the right side.

Inappropriate hydraulic structures

There are several weirs and culverts along the course of the river parallel to Aranyaprathet. The dimension of these structures is not aligned or effectively designed to meet the need giving rise to backwater conditions. Some storm and waste water pipes are in the river parallel to Poipet. Some are damaged. It is unclear what original purpose those pipes served. It is very clear, however, that they obstruct the flow.


Landfill discharging directly into the river

A landfill is situated immediate upstream the Thai/Cambodian border on the Thai side. The land fill drains into the river and gives rise to further deteriorating the water quality.

7.3.2 Impacts

The field mission teams have identified the following issues for the project in Aranyaprathet and Poipet.

Regular flooding

Flooding affects both cities. Flood problems and flood damage occurs almost every year. Especially in Poipet, which is severely affected with residential areas inundated and flood waters baking up.


Poor water quality

The river has bad water quality. Photos taken during the field mission show an alarming level of pollution at the banks and in the river itself. Discharge of untreated waste water is a serious issue in both towns.


Lack of an observation stations and early warning system

The field teams identified the need to install observation stations upstream of Aranyaprathet and Poipet to record water levels and flow and communicate information to both town authorities. This would be an important first step in establishing an early warning system and effective information sharing protocol.

7.4 Nature based and hybrid solutions project concept

7.4.1 Concept design of NbS

7.4.1.1 Urban rainwater retention

Urban rainwater management manifests in two principles: 1) runoff prevention and 2) a functioning drainage system.

Runoff prevention and an adequate drainage system has not kept pace with urban development. Densely built-up areas generate more surface runoff and higher peak flows. These compound an inadequate drainage capacity of the existing drainage channels and the river to cope with new volumes and speed to runoff. The flood problem in Aranyaprathet and Poipet cannot be solved solely by developing upstream flood retention structures since a significant source of the flood problem is within the urban areas. Therefore, retention measures in the upstream catchment, retention improvement of the channel itself (widening and clearing) and decentralized rainwater retention are all needed.

Measure 7: Retention and infiltration of rooftop runoff; Measure 8: Permeable surfaces; and Measure 9: Retention and infiltration of surface runoff

Flood retention measures in built-up urban areas are achievable. Decentralization of runoff prevention is an urban water management concept that needs to be embedded into the urban development and spatial plans for the towns. On-site rainwater retention should be made mandatory for planning permission, infiltration on-site should become a drainage standard, and permeable surfaces should replace hard surfaces wherever possible.

Decentralized retention measures are less prone to failure during significant rainfall events, with fewer consequences than centralized retention structures upstream. In Poipet, two locations have been selected to demonstrate the measures as illustrated in Figure 20: (i) the market in Poipet (Measure 7), and (ii) the transport hub and a strip following the railway (Measures 8 and 9). Both have a high potential for replication in many areas of the town. The two measures present different urban rainwater management measures, which can be combined or applied selectively depending on the location. The most suitable measure for the locations will be further detailed in the engineering design process.

Figure 20: Areas for urban rainwater retention demonstration measures

7.4.1.2 Wastewater treatment

Measure 10: Constructed wetlands

A challenge within the landscape area is presented by landfill site leachates and waste water sewer outflows just south of Aranyaprathet. To improve the existing constructed wetland is proposed to help with mitigating this wastewater problem (Figure 21). A more detailed assessment is needed to determine the feasibility and effectiveness of this measure. It may be that the area of land available for the wetland is not adequate for the volume of untreated waste water now and projected with increasing population and development. For a functioning wastewater treatment, a separated storm- and wastewater drainage system is required. Wastewater is a very serious public health and environmental problem which is being passed on downstream to Poipet so requires concentrated attention and investment.

Constructed wetlands are an alternative wastewater treatment that can reduce suspended solids, biochemical oxygen demand (BOD), pathogens, heavy metals and nutrients. Generally, most constructed wetlands in tropical countries are soil- or gravel-based horizontal flow-systems. Design criteria are the inflow in m^3/d, the quality of the wastewater in terms of concentration, the required treatment related to the outflow concentration, slope of the area, permeability of the soil and associated grain size distribution.

On the conditions that the untreated BOD is 11.8 g/l, and target BOD is 100 mg/l with 30°C water temperature, the required area of a constructed wetland would result to approx. 9,250 m^2 in case the inflow is 850 m^3/d. The larger the daily inflow is and the larger the difference between in and out concentration, the larger is the necessary area. The current area is estimated at approximately 600-800 m^2. The values were taken from the field mission to Aranyaprathet combined with estimates on the inflow rate. The formulas used stem from Tanaka (2011).[11]

[11] Tanaka, et.al., 2011: Wetlands for tropical applications. Wastewater treatment by constructed wetlands. Imperial College Press, London, UK

The constructed wetland should be completed with natural river channel treatments (Measure 11 and 12) and vegetated filtration buffers (Measure 1) around the landfill site.

Figure 21: Proposed constructed wetland site south of Aranyaprathet

7.4.1.3 River restoration and rehabilitation

Measure 11: River channel widening and rehabilitation and Measure 12: River bank stabilization and rehabilitation

The river linking Aranyaprathet and Poipet requires significant rehabilitation as an important component of a major flood and water quality management strategy for the towns and further downstream. This section focusses on the Poipet section of the river to illustrate what needs to be done. River restoration and rehabilitation seeks to develop and improve the river's ecosystem health and to achieve an adequate hydrological function including sufficient flow capacity. Restoration and rehabilitation of a river embraces the development of the following:

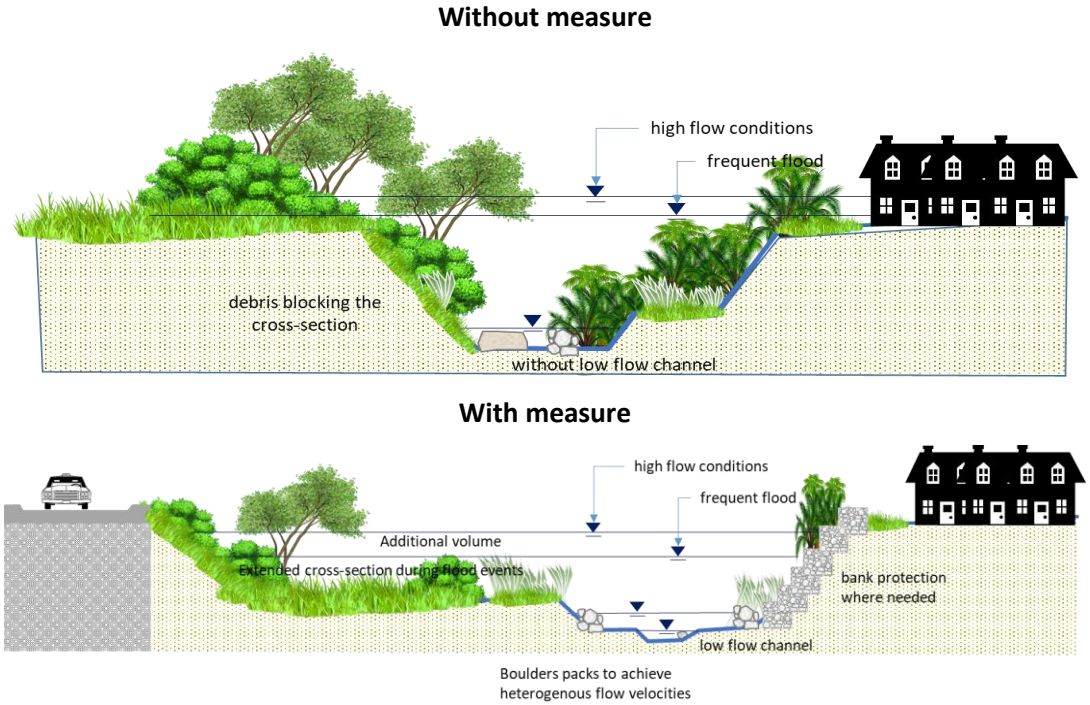
- River cross-sections;
- River bed material;
- River bank stabilization, including vegetated gabions;
- Mixed native species riparian buffers and wetland corridors; and
- Incorporating natural structures to diversify flow velocity and to improve the interconnectivity of the river bed surface with the immediate underground.

Cross-sections are developed with the aim of establishing various flow channels. Each channel has a specific purpose and a specific hydrological and ecological function. A low flow channel aims at ensuring a minimum water depth and flow velocity to preserve a river continuity and wetted

perimeter to maintain ecosystem activities. The normal, medium flow channel is above the low flow channel and is designed to accommodate the range of conditions from low flow up to mean flow. The next level covers flood events up to annual or bi-annual floods (frequent flood). These flood events are considered to be relevant for sediment mobilization and lead to a natural restructuring of the river bed. The top channel is reserved for rare flood events causing high flow conditions. The term rare flood event defines return periods that need to be determined based on available space for the cross-section development, available budget for the measure and a decision on the extent to which settlements should be protected against flooding. The return period selected requires a decision by managers considering hydrological and financial aspects. For flood events exceeding the defined high flow conditions, emergency measures and early warning systems should be put in place.

Two cross sections one without and one with measures are illustrated in Figure 22.

Figure 22: Cross-sections without (top) and with (bottom) measure for Poipet



The starting point for river restoration and rehabilitation is to enable a natural development so that it shifts back into a virtually natural state. That means a sound sediment and nutrient balance, vegetation adopted to site-specific conditions and morphology to unfold its potential to compensate regular flood events within its flood plain.

This ideal development potential must be aligned with socio-economic constraints like available space, existing illegal settlements encroaching on the river, legally binding concessions for water abstraction and other possible restrictions.

2D hydrodynamic modelling of a river for detailing restoration and rehabilitation is state-of-the-art. First, the current situation is surveyed through cross-sections including the river banks and the potentially flooded areas on both sides. The survey must consider the full extent of potential flooding. The distance between the cross-sections depends on the variation of the river. Changes in the cross-sections require a new profile so that a replication of natural conditions can be replicated in the hydraulic model.

The river channel was modelled via a 2D hydrodynamic model with extent (see Annex 2). In order to further promote river restoration and rehabilitation, coarse surveys of cross-sections were conducted during the field missions and used to develop the model, with sample profiles provided in Annex 2. The model applied was HEC-RAS Version 6.0, a free software from United States Army Corps of

Engineers (USACE)[12]. Close up detail of some river stretches in 2D is provided in Annex 2. Both without and with measures were calculated using a flood event that occurred in 2019 with a peak flow of roughly 180 m^3/s (Annex 2).

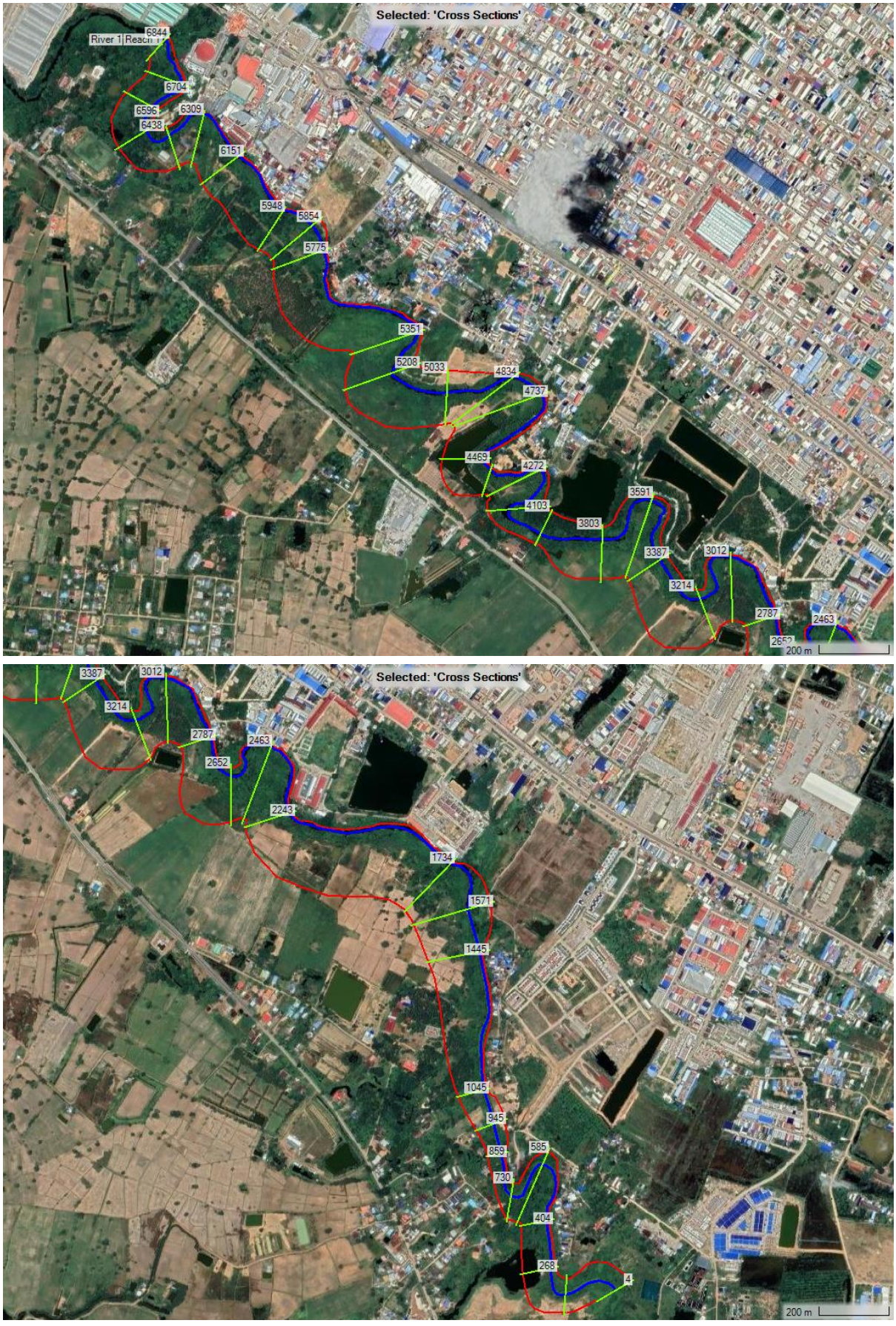
The results indicate the potential for flood mitigation with river rehabilitation and restoration for around 65 Ha of floodplain. The new cross-sections have more space to accommodate floods, thus reduce flow velocities and avoid flooding. The proposed interventions focus on vegetated gabions on the north side of the river where Poipet town is situated (Cambodia side) and floodplain expansion and re-naturalization for a 100m flood buffer zone to the south (Thai side). Further detailing requires adequate hydrological, hydraulic and ecological design where all three components fulfil their desired functions and bring about a healthy river stretch. The ecosystem health, however, depends on accompanying measures like waste management, upstream waste water treatment and others, although flood mitigation could be achieved by primarily looking at the development of the river geometry.

It is acknowledged that the new-cross sections have the potential to encroach onto private agricultural land and sensitive military zones on the Thai side. Extensive consultation is proposed to discuss the potential implications of this intervention. In addition, further studies will assess the cost-benefits of reducing seasonal flooding on these areas – especially as the two towns are rapidly developing as important trading, economic and touristic hubs in both countries.

A similar approach will be taken for the Aranyaprathet stretch of the river of almost 15 km, with greater potential for increased buffer zones on each side of the river. Although hydrodynamic modelling has not yet been undertaken for this stretch of river, similar approaches for flood mitigation with river rehabilitation and restoration are proposed. A possible area of 145 Ha of river rehabilitation and river park are proposed, with a 50m flood and recreational buffer zone on each side of the river channel. This would comprise rehabilitation of the river, including bank stabilisation and mixed native species riparian buffers. Areas of forest and wetland pockets are also proposed along the river park corridor. As in Poipet, further consultation and studies will need to be undertaken to confirm the suitability and viability of the proposed interventions.

[12] https://www.hec.usace.army.mil/software/hec-ras/download.aspx.

Figure 23: (Top) Upper segment: with location of cross-sections used in the model; (bottom) Lower segment: with location of cross-sections used in the model



Measure 14: Urban greening

Nature-based solutions for urban resilience can be applied across spatial scales and settings in and around cities. Figure 20 identifies opportunities for core green corridors in Poipet, to connect the central market, temple area and transport hub with the river corridor to the south (see Measure 14, Annex 1). It is understood that the roundabout area in Poipet of approximately 0.15 ha is becoming an urban green feature with amenity, shading and biodiversity benefits. Other green streets, transport areas, open spaces, landscaped areas, tree pits and gardens should be connected via green spaces and corridors. Overall, it is proposed that Poipet aims for at least 15% urban green cover (approximately 100 Ha of Poipet's 800 Ha total urban area). Accessibility and planning considerations will need to be further identified to facilitate such a development going forward. Surrounding paved surfaces could also drain into the area. The runoff would be retained and treated by bioswales or raingardens (see Measure 7 and 8, Annex 1).

In Aranyaprathet similar opportunities exist to rehabilitate and reconnect existing green areas and also establish green spaces and corridors within the city. This should connect to the urban park to the north, and the adjacent transport hub (Figure 24). The existing park comprises large areas of hardened surfaces, degraded canal networks and homogenous vegetation. These could be improved to form a mosaic and connected network of NbS interventions. A green corridor, comprising tree pits and vegetated areas, should target 30% urban green cover (approximately 200 Ha of Aranyaprathet's 650 Ha total urban area).

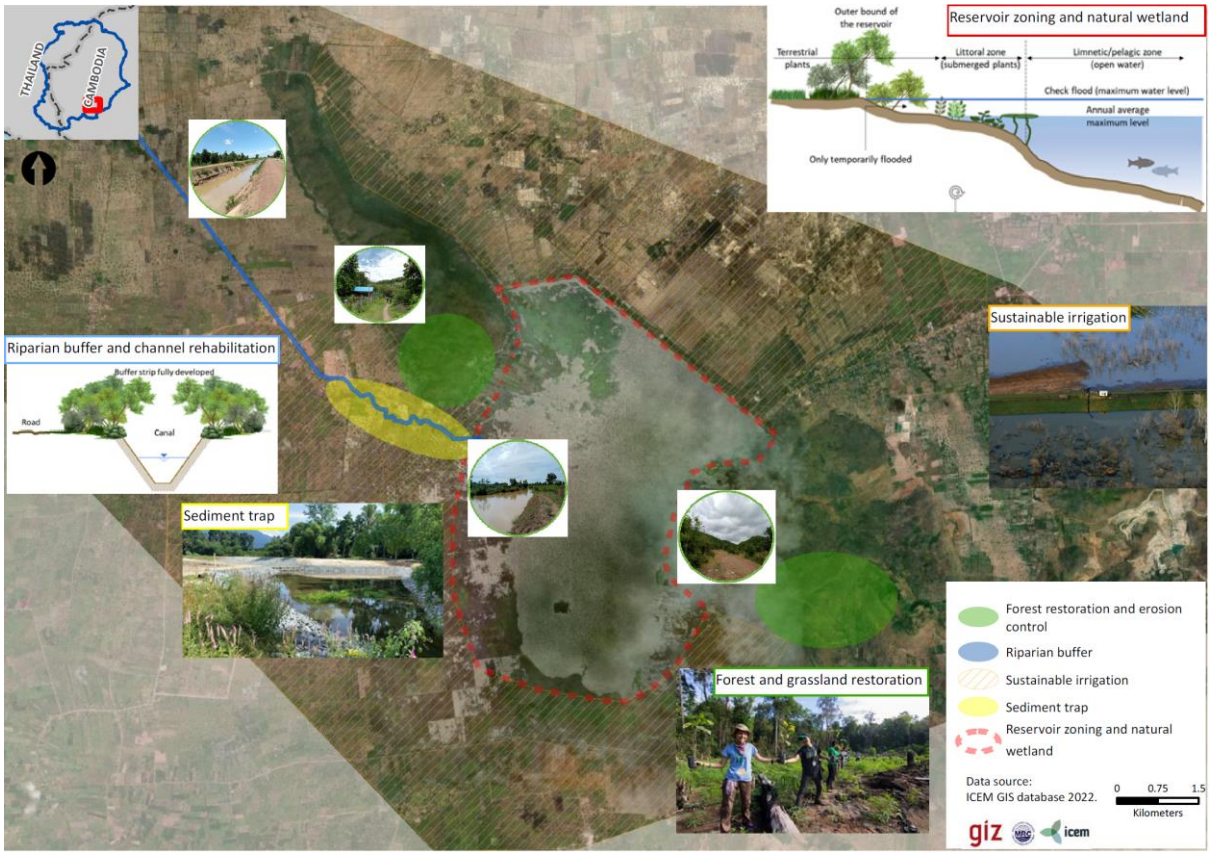
Figure 24: Aranyaprathet city park and transport hub

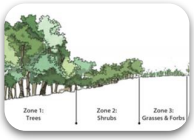
7.4.2 Project benefits

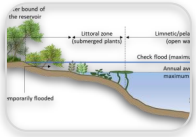
- A significant reduction in flood risk for the two cities post-implementation of channel and bank rehabilitation for almost 7 km in Poipet (65 Ha) and 15 km in Aranyaprathet (145 Ha);
- Establishment of over 45 Ha of forest and wetland pockets;
- Rehabilitation of over 60 ha of existing park land;
- The establishment of new tree canopies, green spaces and green corridors in both cities, comprising over 300 Ha of new green spaces and targets of 15% and 30% green cover targets in Poipet and Aranyaprathet respectively; and
- A significant reduction in runoff and excess drainage, through a network of decentralized urban rainwater retention measures.

8 PROJECT 5: RESERVOIR – KAMPING PUOY RESERVOIR AND CATCHMENT, CAMBODIA

8.1 Project Overview




1. Riparian buffer


2. Reservoir zoning


3. Catchment water management


5. Sediment trapping


6. Forest restoration and rehabilitation


13. Sustainable irrigation measures

Project 5 is a landscape which has a major reservoir, canals and irrigation system as its focus. The project seeks to restore the landscape to protect and prolong the life of those infrastructure assets through a network of NbS and hybrid measures. Problems to be addressed include wetland encroachment, flooding and erosion/sedimentation control. The project objectives for this landscape are:

- Define measures for reservoir, wetland and watershed rehabilitation and management, including riparian buffers, sediment trapping, reforestation, wetland zoning, water management;
- Work together with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated approach to wetland areas, drought and erosion/ sediment management that aligns with the 9C-9T Masterplan and Action Plan.

Table 8: Project 5 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk • **Outcome 2.2**: Strengthened rural flood and drought resilience through ecosystem-based planning tools and adaptation interventions • **Output 2.2.2**: Develop spatial zoning and safeguards across rural landscapes, especially relating to existing and new infrastructure, and implement by installing sediment traps, conducting dredging to maintain capacity, maintenance to prevent encroachment of agriculture into reservoir banks, and establishing vegetated buffers along drainage and transport corridors and along allotment boundaries
Implementing stakeholders	• *Lead agency (Cambodia)*: Ministry of Water Resources and Meteorology (MOWRAM) and Ministry of Agriculture, Forestry and Fisheries (MAFF) • *Supporting agency (Cambodia):* Ministry of Environment (MoE) and provincial government
Alignment to agency priorities	MAFF is responsible for governing activities of agriculture, forestry and fisheries and MOWRAM is responsible for governing activities of flood management in the catchment

8.2 Site description

Project 5 covers the Kamping Puoy Reservoir and its catchment. The reservoir is in Banan district of Battambang Province, while part of the catchment area is located in Rotanak Mondol district. The headwater area is slightly hilly with maximum elevations of 300 m above sea level. The rest of the catchment is a low lying plain with scattered villages and small urban settlements. A few vegetated outcrops are situated in the catchment, some in the immediate surrounding of the reservoir.

The dam was built during Khmer Rouge time between 1975 and 1979 where labourers raised the embankment manually. The dam is now a road. The Kamping Puoy reservoir is of particular significance in terms of water resources because it abstracts potentially large volumes from the Stung Mongkol Borey catchment via a major canal offtake upstream of Bavel – the Ou Doun Pov link canal, thereby diverting water resources between catchments. The canal was initially constructed in 2010-2014, with an ADB funded IAIP (Irrigated Agriculture Improvement Project) supporting its further developing from 2021-2023.

The area naturally draining into the reservoir has been fully developed as agricultural land except the few outcrops with steeper slopes and without suitable soil formation. The water consumption for agriculture is high, regularly causing the streams draining to the reservoir to fall dry. The official map of MOWRAM (2019) shows that these streams vanish before they reach the reservoir. The analysis of satellite images confirms this fact. Water abstraction for irrigation is the main cause for the disappearance of the streams. This means that streams from the headwater area do not contribute to inflow into the reservoir which is replenished by surface runoff from the surrounding area only. In other words, the natural catchment has been greatly reduced. As compensation, a 14 km long diversion canal erected at the Mongkol Borey River brings water to the reservoir. The trapezoidal channel faces serious seepage, erosion, sedimentation and evaporation losses.

The Asian Development Bank (ADB) project CAM 51159-002 (2019), *Irrigated Agriculture Improvement Project Kamping Puoy Irrigation Subproject – Battambang Province* yields additional information. According to the project documentation, the project has the following components:

- Lining of 9 km of the 14 km long link canal connecting Mongkol Borey River with the reservoir;
- Rehabilitation of the main irrigation canal including earthworks, 28 distribution and control structures;
- Rehabilitation of secondary irrigation canals; and

- Strengthening of the reservoir embankment of 6.5 km by providing erosion protection on the upstream slope.

The size of the new irrigation command area is 12,000 ha and lies downstream of the reservoir as seen in Figure 25. According to satellite images (Figure 27), the new irrigation command area seems to be in operation.

Figure 25: General layout of the Kamping Puoy Irrigation Subproject [13]

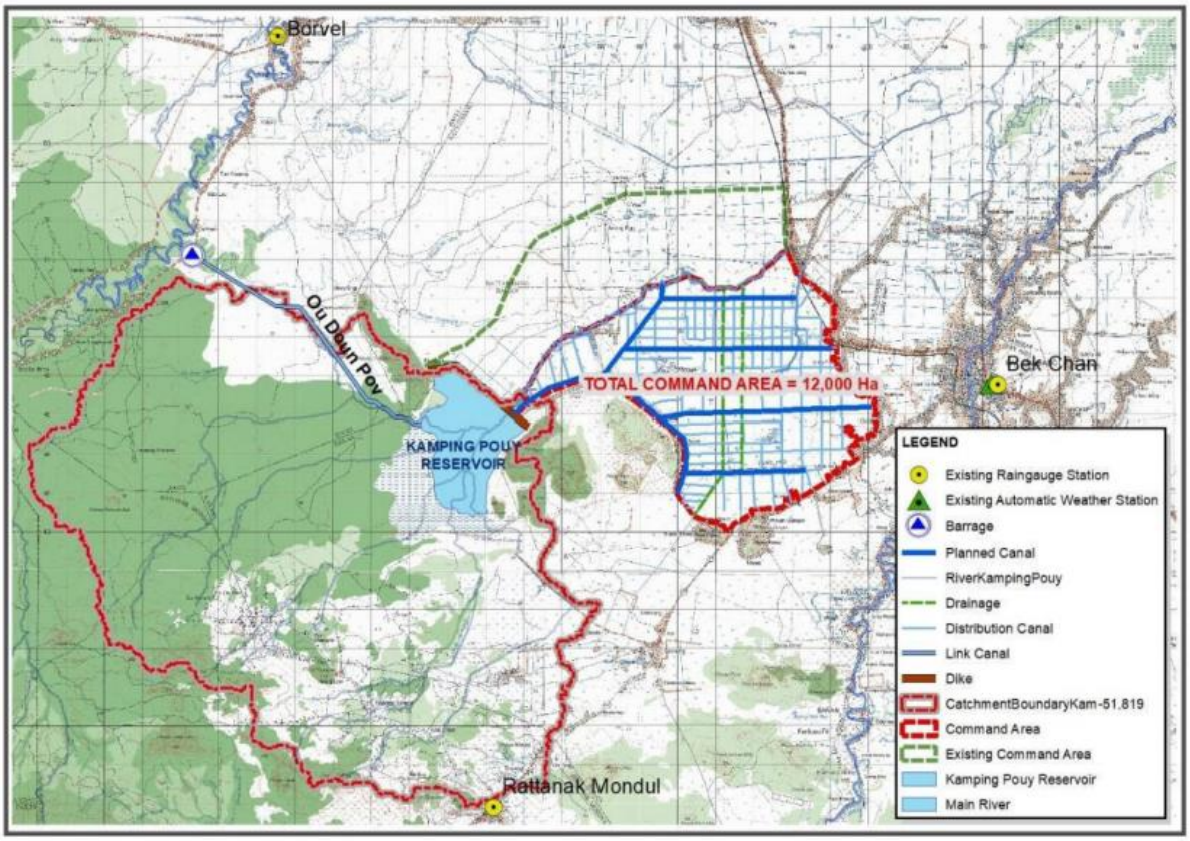
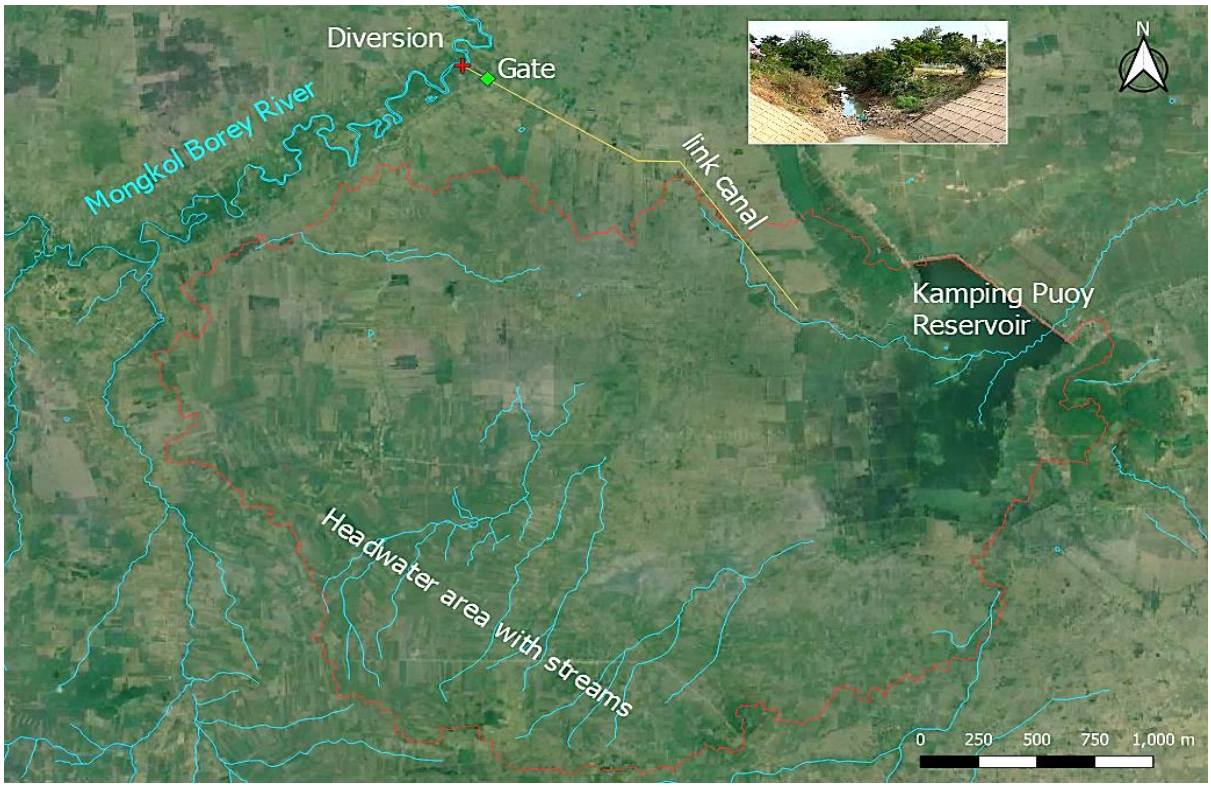


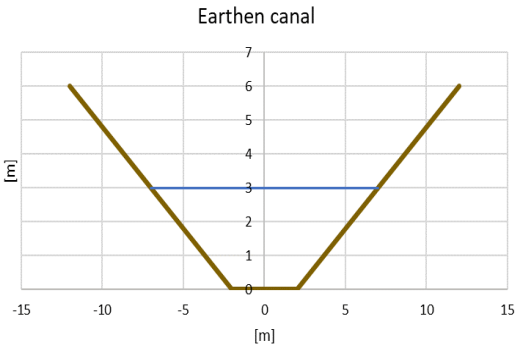
Figure 26 shows the canal 800 m downstream of the diversion close to a regulated gate, which controls the flow in the canal. The estimated geometry is 6m depth, 3 to 4 m at the bottom and maximum of 24 m width at the top.

[13] ADB, 2019: CAM 51159-002 (2019), Irrigated Agriculture Improvement Project, Kamping Puoy Irrigation Subproject – Battambang Province

Figure 26: Canal downstream of the diversion near regulated gate

Figure 27: Catchment area with key hydrological features





With the estimated canal geometry and an assumption of 3 m water depth in the canal, the total volume along the 15 km is approximately 400 000 m^3, which is already a considerable water storage.

With 3 m water depth, the total water surface would be approximately 200 000 m^2. With a daily potential evaporation of 5 mm based on a rather conservative calculation, the daily loss would be approximately 1000 m^3 if the water depth in the canal was 3 m.

The weekly losses would be 7000 m^3 and monthly losses roughly 30 000 m^3. The total loss from evaporation due to operating this canal could be as much as 360,000 m^3 every year depending on the number of days when the canal is filled. Seepage is not counted as losses as the water percolates into the groundwater and is therefore not lost. From an operational point of view, reducing the number of days of operation and if in operation conveying a maximum amount of water seems advantageous to minimise losses. However, there is a disadvantage with such a release policy. The maximum amount of water means high flow velocity and thus high shear stress for both the bed and the banks of the canal. Erosion and hence sediment load will increase and will finally end up in the reservoir. Since the banks of the canal are bare soil and given its length, erosion will be significant.

In conclusion, the canal is an essential part of the water management system of the Kamping Puoy Reservoir and its catchment - it requires rehabilitation attention, as does the reservoir. Assuming that lining according to the ADB project is implemented, rehabilitation of the canal through buffer strips in combination with bank stabilization and measures at the reservoir itself would help prolong the lifetime of the reservoir and dredging intervals of the canal, which in turn yields a direct livelihood and financial benefit. Attention is necessary to design placement of the buffer strips so that dredging is still possible.

8.3 Flood and drought drivers and impacts

8.3.1 Drivers

Lack of integrated water management principles

Water management in this catchment has issues related to cross-sectoral coordination, fair and equitable use of water resources and ecologically sustainably managing water resources in general.

Agriculture, as the main water-dependent sector may need support in practical guidance on how to avoid overexploitation and maintenance of the resource. A possibly unrecognized competition exists between water users located upstream and downstream, which becomes visible only when looking at the entire catchment. Upstream users have direct access to river water and use it to the extent possible within the limits of seasonal availability. Downstream users, however, rely on the supply from the reservoir. Water supply release from the reservoir is fundamentally linked to the downstream interconnected command areas of approximately 19,000 ha.[14] The water related problems arise from fragmentation of the catchment with no integrated management or concern for ecosystem health.

The diversion of water from the Mongkol Borey River expands the problem to another catchment, especially in periods of drought. The potential water use conflicts should be assessed as it will intensify as drought conditions increase due to climate change.

Field interviews with local residents highlighted challenges with flooding and health risks during the rainy season. During the months of September and October extreme runoff discharged from the elevated upstream catchment combined with increased water level in the reservoir results in standing water and inundation surrounding neighbouring villages, such as Andoung Neang village. Flood depths can reach up to 0.7m above the road lasting several weeks.

Encroachment on the reservoir

The field mission and remote sensing revealed that substantial encroachment of the reservoir area takes place during periods of low water levels. When the water level drops, the new land surface is encroached and used for agricultural purposes. The area of the reservoir has shrunk over time. In addition to a possible loss of storage, cultivating crops on areas which might be subject to flooding will transfer organic material, fertilizers and pesticides into the reservoir leading to increased oxygen consumption and eutrophication. The progress over time is illustrated in Figure 28.

[14] ADB-IAIP ADB Irrigated Agriculture Improvement Project

Figure 28: Land use encroachment over time at Kamping Puoy Reservoir

02/2017 *03/2021*

In 2013, the dam faced a critical situation when the embankment was partly cut to release pressure to avoid an uncontrolled break. In contrast to 2013, the reservoir regularly shows very low water levels where many islands appear and the water surface shrinks considerably. Because of different climate conditions from year to year, the water storage in the Kamping Puoy reservoir varies greatly. During dry spells when the water level is low land is exposed.

8.3.2 Impacts

Based on the results of the field mission and the assessments, the impacts on flood and drought are attributable to the following issues.

Contribution of sediment from the canal – design standard

Given the current design of the canal with unvegetated, eroded banks, it is bringing sediment into the reservoir. More effective management of the canal could help reduce erosion and safeguard the Kamping Puoy Reservoir.

Figure 29: Signs of erosion of canal banks and sedimentation

Loss of water storage in the reservoir

The sediment from the canal settles in the reservoir and reduces its life span. This leads to a reduction in flood mitigation functions and decreases in drought resilience.

Overexploitation of river resources in the catchment

The fact that tributary rivers disappear points to overexploitation and indicates a first-come first-serve water allocation approach in the catchment. The Kamping Puoy Reservoir is a critical water infrastructure asset in the catchment with agriculture as the main water consumer. The current situation calls for a review of water management goals and allocation principles within this catchment in the light of existing inequalities in water use. The foundation problem is the serious and continuing degradation of the watershed.

Health concerns

During periods of excessive flooding, residents report challenges with water pollution, illness, cholera and diarrhoea, because of the standing flood water.

8.4 Concept design of nature based and hybrid solutions

Assuming a full implementation of the ADB project, the link canal is equipped with 9 km of lining and is still an earthen canal for about 5 km. The 9C-9T project needs to address three complementary rehabilitation priorities related to the canal:

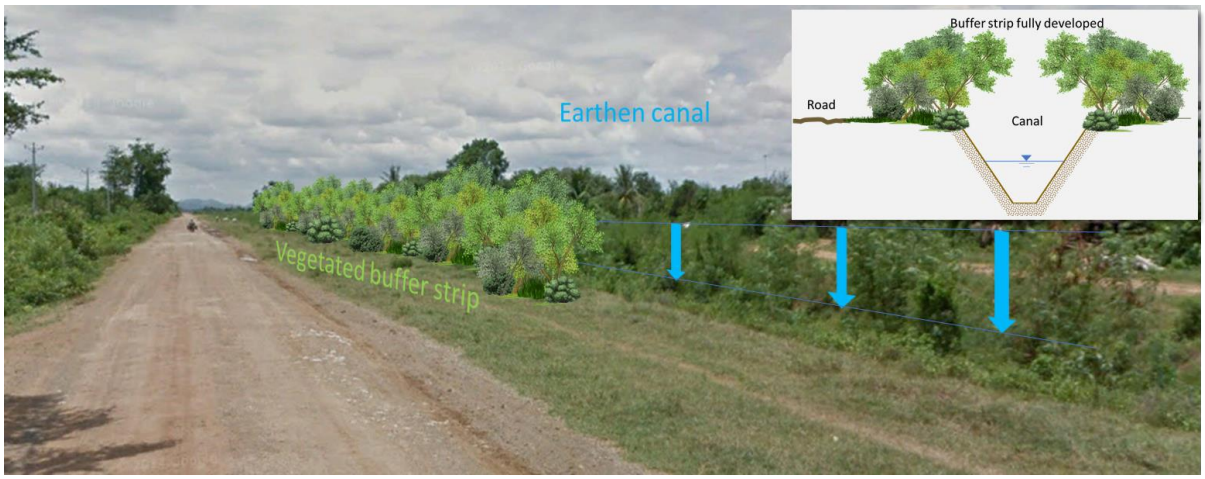
- Development of buffer strips along the canal (Measure 1)
- Sediment traps (see Measure 5)
- Nature-based and hybrid measure to stabilize the canal banks (see Measure 12)

Measure 1: Riparian buffer strip

Using buffer strips along rivers, canals and across agricultural land needs to become standard practice and an essential component of the 9C-9T basin restoration. Buffer strips are measures to retain surface runoff through absorption, plant uptake, deposition and denitrification. By retaining surface runoff, buffer zones reduce the load of sediment, organic matter and nutrients. Trees within the buffer strip can also provide shade and reduce evaporation losses. Figure 30 shows the canal in the catchment approximately one kilometre downstream of the regulated gate. Roads on both sides of the canal are visible following the canal from the gate all the way down to the reservoir. This is an opportunity for NbS application since farming activities are not next to the canal and land ownership problems are less likely. The buffer strips could be developed, interrupted by bridges crossing the canal and considering placement to enable dredging.

A buffer strip either side of the canal is recommended at a width of 15m, in line with good practice design (see Measure 1, Annex 1). Whilst a wider buffer of up to 30m would yield improved habitat provision and sediment and pollution trapping potential, buffer expansion past 15m may prove challenging, due to the need to take from adjacent agricultural land. The establishment and development of the vegetative buffer strip should comprise a mix of native species, to ensure buffer integrity, and maximise ecological health and services.

Figure 30: Buffer strip development along the link canal



Measure 5: Sediment traps

Sediment traps are proposed immediately upstream of the reservoir, near to the inflow channel. The establishment of small multiple functioning sediment traps/pools (through NbS and hybrid structures) offers significant potential within this landscape area. Such interventions would help to collect sediment before it enters the reservoir to prevent sedimentation and decreased water storage capacity.

Figure 31: Potential sediment trap location

Measure 2: Reservoir zoning

The reservoir is steadily diminishing due to encroachment and sedimentation. Boundaries and zones need to be established and enforced. Reservoir zoning is the delineation of a reservoir to its maximum extent defining one or more aquatic zones within this maximum area. The maximum extent is determined by the water level that is associated with the check flood. The check flood is the flood event with a certain return period that the dam must be able to withstand.

An approach to reservoir zoning is therefore proposed below for Kamping Puoy reservoir (Annex 1, Measure 2 for reference). Reservoir zones need to be appropriately defined during later stages with objectives, guidelines and permitted activities:

- A core conservation and recreational zone – established for fish/aquatic habitats and water security;
- An outer sustainable use zone – a seasonal flood area permissible for temporal sustainable agriculture. This is agriculture that adheres to sustainable irrigation practices, without degrading soil quality and using harmful agricultural chemicals.

The variation in the reservoir's extent and volume during the wet and dry season, and associated temporary agricultural encroachment, presents a challenge for implementing zonation. Agriculture is a core livelihood activity surrounding the reservoir and managing water supply and demand along with flood and drought risk is a priority. It is fundamental that local people and communities are suitably acknowledged, engaged and incorporated from the outset of the planning process for this intervention. Agreeing on the zoning and management objectives for each zone (including permissible activities) is an important part of closely involving local communities and other stakeholders in the participatory and sustainable management of the reservoir.

Measure 3: Catchment water management plan

Management of water resources is crucial in conserving ecosystem services. Water management often requires a minimum of controllable infrastructure (e.g. weirs, pumps, gates, and canals) and monitoring. It needs a careful evaluation of water demands, purposes and priorities.

It needs to be a catchment wide approach and integrated water resources management plan. The historic first-come first-serve principle has resulted in imbalances between water users. The construction of the Kamping Puoy was built to store the water from the entire catchment and is now at risk due to the overexploitation upstream. Key water management interventions required include the following (further detailed in Annex 1, Measure 3):

- Regulation and guidelines about sustainable water use associated with Kamping Puoy and its catchment;
- Improvement of water use efficiency associated with Kamping Puoy and its catchment; and
- Hydrological assessment to balance agriculture water consumption upstream and sustainability of the Kamping Puoy reservoir downstream.

A thorough analysis about the current situation, stakeholder analysis, goals, projection of demands are needed to find optimal management rules and a water allocation scheme.

Measure 6: Forest restoration

Opportunities for forest restoration were identified on the steep elevated areas immediately to the east and west of the reservoir. Due to the elevation of these areas, they will require slope stabilisation NbS (see Figure 32 and Measure 6, Annex 1 for example measures).

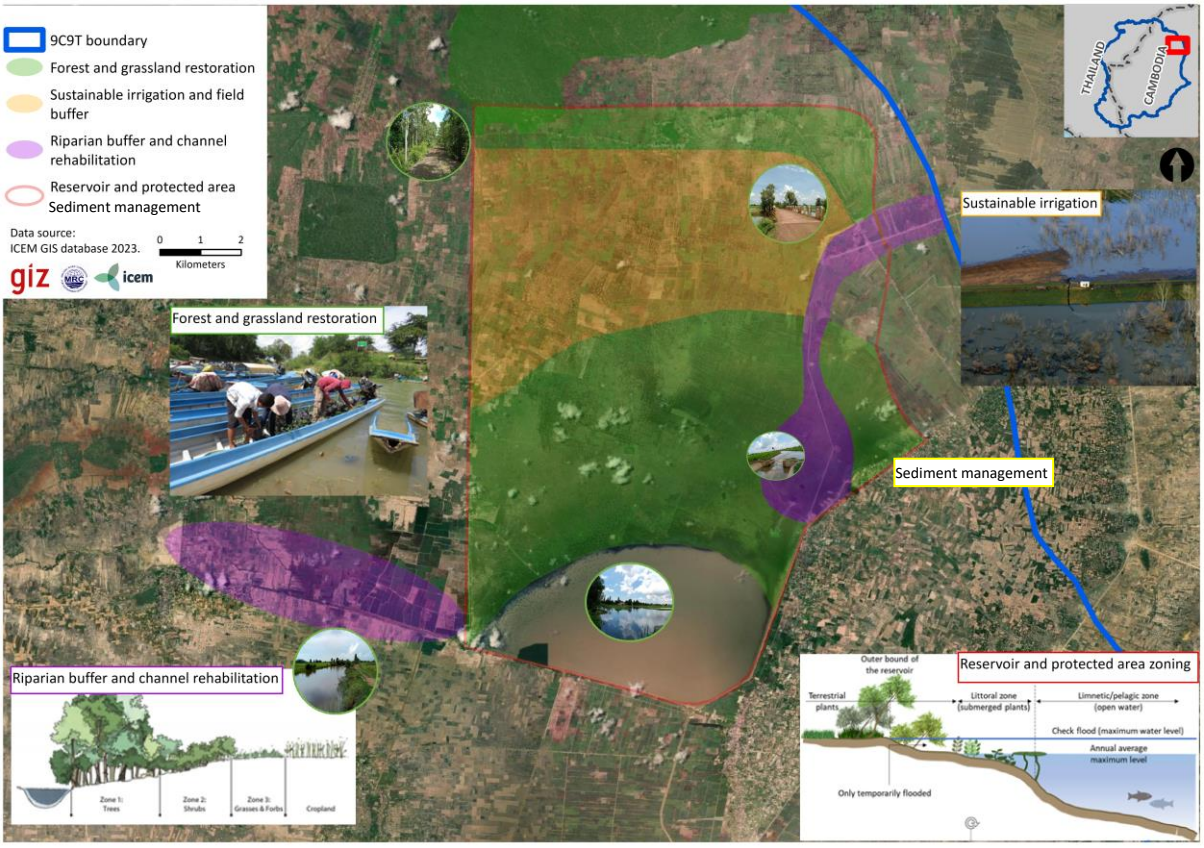
Figure 32: Example forest restoration, with NbS erosion control

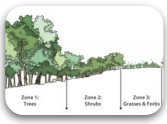
8.4.1 Project benefits

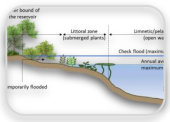
- Canal buffer to retain surface runoff, reduce evaporation losses and reduce the load of sediment, organic matter and nutrients;
- Zoning, regulation and guidelines about sustainable water use and management associated with Kamping Puoy and its catchment;
- Improved water supply and irrigation for the command area of 12,000 ha;
- Restoration and reforestation of degraded elevated areas, to reduce sedimentation and runoff.

9 PROJECT 6: RESERVOIR – ANG TRAPEANG THMOR LAKE AND PROTECTED FOREST, CAMBODIA

9.1 Project Overview




1. Riparian buffer


2. Reservoir zoning


3. Catchment water management


5. Sediment trapping


6. Forest restoration and rehabilitation


13. Sustainable irrigation measures


15. Agricultural field buffer

Project 6 is concerned with protected area encroachment, drought and erosion risk. The project objectives for this landscape are:

- Define measures to foster sediment management, watershed rehabilitation and protected area restoration and biodiversity safeguards, including protected area management, forest restoration, riparian buffers and water management; and
- Work together with the lead and supporting agencies, as well as local and provincial stakeholders to ensure an integrated approach to protected area, drought and erosion management is implemented, that aligns with the 9C-9T Masterplan and Action Plan.

Table 9: Project 6 – Master Plan implementation factors

Item	Description
Alignment to 9C-9T Masterplan	• **Focal Area 2**: Manage urban and rural flood and drought to reduce risk • **Outcome 2.2**: Strengthened rural flood and drought resilience through ecosystem-based planning tools and adaptation interventions • **Output 2.2.2**: Develop spatial zoning and safeguards across rural landscapes, especially relating to existing and new infrastructure, and implement by installing sediment traps, conducting dredging to maintain capacity, maintenance to prevent encroachment of agriculture into reservoir banks, and establishing vegetated buffers along drainage and transport corridors and along allotment boundaries
Implementing stakeholders	• *Lead agency (Cambodia)*: Ministry of Water Resources and Meteorology (MOWRAM) and Ministry of Agriculture, Forestry and Fisheries (MAFF) • *Supporting agency (Cambodia):* Ministry of Environment (MoE) and provincial government
Alignment to agency priorities	MAFF is responsible for governing activities of agriculture, forestry and fisheries and MOWRAM is responsible for governing activities of flood management in the catchment

9.2 Site description

Project 6 covers Ang Trapeang Thmor (ATT) Lake, Protected Forest and catchment, Cambodia. ATT, was established in 2000 by Royal Decree. It comprises 12,650 hectares, is designated as a protected landscape, as well as an Important Bird and Biodiversity Area (IBA), including the ATT Sarus Crane Conservation Area. The site is the single most important non-breeding season feeding area for Sarus Crane globally and supports several other globally threatened species.

The landscape is characterised by a large artificial reservoir, deciduous forests, natural flooded grasslands, inundated forests and rice fields. During the dry season, only the south-eastern corner of the reservoir remains inundated; however, at the height of the wet season, over 80% of the area is inundated. Water levels are typically shallow, and in the wet season, the water depth at the sluice gates is approximately 1.5m, while the maximum water depth of the reservoir is only 3m. The minimum water depth is 0.2m in June through August, during which the ATT water storage is 60 million m^3. When this low water level is reached, any water supply request from the reservoir for irrigation is rejected.

During the Angkorian period, from the 10th to the 13th century AD, a major causeway was constructed through the area, which led to increased water accumulation to the north, mainly of surface runoff. In 1976, an 11 km stretch of this causeway was converted into a dam and a 9 km dyke constructed perpendicular to it. However, the planned irrigation reservoir was never completed, and until recently only the south-eastern corner of the reservoir remains inundated during the dry season.

The development of the dam to the south enabled the creation of a larger reservoir aimed at providing water storage and irrigation, including via irrigation canals, for rice cultivation downstream of the dam. During the 1990s, an influx of refugees from neighbouring provinces and from Thailand increased land pressure on the area. The lake provides opportunities for a range of ecosystem services, includes non-timber forest products (NTFP), fishing grounds and wetland activities. Within the core protected area, no agricultural activity is permitted, including grazing of livestock, however fishing is allowed, although enforcement is a challenge.

A network of 150-200 irrigation ponds have been established by the community to the south of the community forest. These have been developed to provide water and food sources in the dry season. In the wet season, the reservoir extends up to the irrigation ponds and water is deposited. Fish also enter into the ponds during the wet season, providing a spawning ground. Dry-season fish catches weigh in at roughly 60kg in a typically small pond and 100kg in a large pond.

Two key water inflow channels support water availability in ATT reservoir:

(i) The 34km long Sreng canal diversion was recently constructed to support seasonal drought resilience. The canal is the main trunk to link the Sreng River with the ATT reservoir.
(ii) A water inflow channel from the Pon Lay reservoir connects to the southeastern corner of ATT reservoir. Many irrigation channels are connected to the channel in the long stretch between the two reservoirs, extracting water and reducing the water flowing into ATT. During the dry season there is no water in the Pon Lay reservoir and inflow channel.

Two community forests are present within ATT:

(iii) The Konkleng Community Forest, in which there are 180 households and a forest area of 2,873 ha, was officially registered as of 2009 with the state forest administration. The forest community was established in 2000. There are a few NTFPs, including mushrooms and honey, which provide additional, non-agricultural income for the local communities. Agricultural land for the 180 households is located outside of the forest area; and
(iv) There is an additional Community Forest named Prey Daurm Rang in Prasat Vin village. The forest area comprises 400 ha and 100 households, dependant on the forest.

9.3 Flood and drought drivers and impacts

9.3.1 Drivers

Lack of integrated water resource management principles

Sediment management and watershed rehabilitation at ATT are the priority interventions for this landscape. Through consultation, it is understood that the main water management concern for ATT is water allocation between upstream and downstream stakeholders and communities, and the associated management of the reservoir gates. There has been historic conflict between the local villages adjacent to ATT, who have direct access to the reservoir, and other downstream users who reply on water from the reservoir, over control of water resources, including for irrigation purposes.

Figure 33: (top) historic water-related conflict at ATT; (bottom) location of villages in ATT area

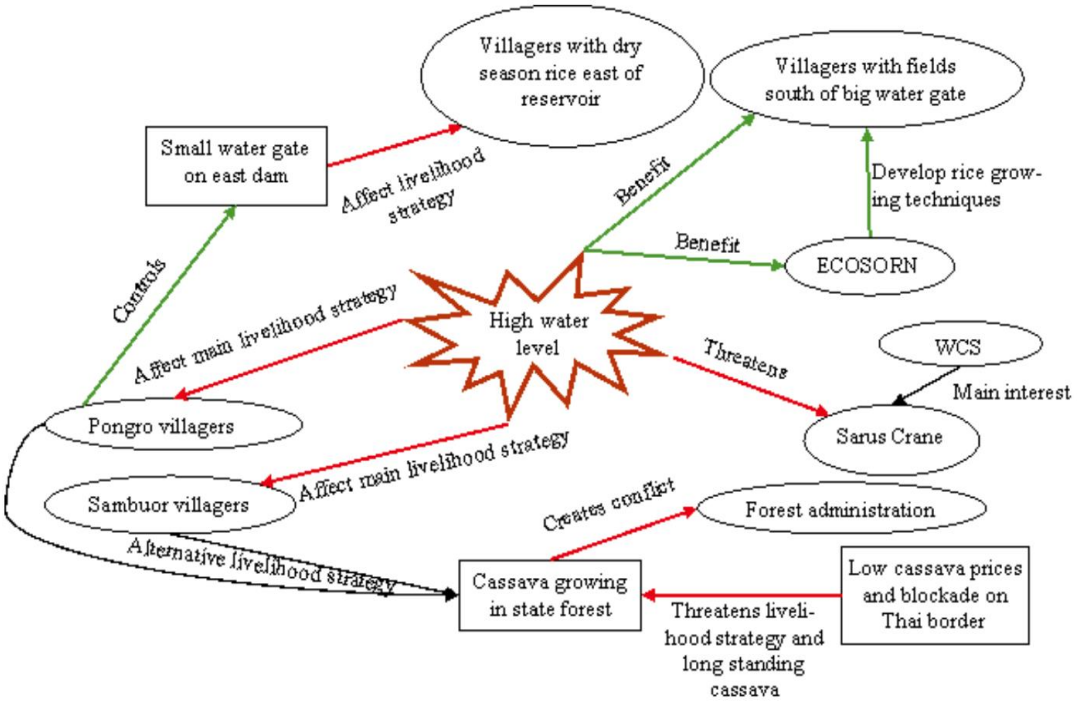
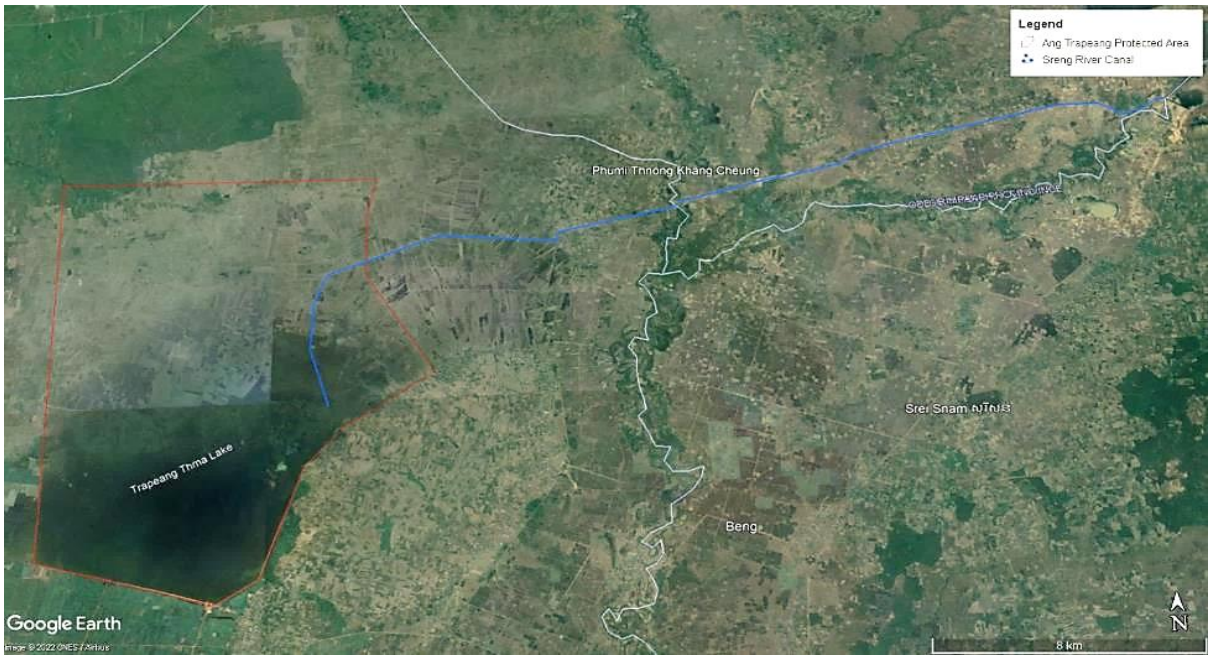


Figure 34: Sreng River canal diversion



The recently constructed 34km long Sreng canal diversion was constructed to support seasonal drought resilience. Cross-sections do not change significantly along the full length. A road network follows on both sides of the canal which is some 9 m in width, connected by bridges at regular intervals. The roads and concrete banks are along the entire length either side of the main waterway (sparsely vegetated in some areas). Adjacent land comprises largely agricultural land, presenting a challenge for extending a vegetated buffer further.

Soil erosion and sedimentation problem

The characteristics of the canals – in particular to the north (Sreng) but also to the south (irrigation canals) – with partially unvegetated, eroded banks, are very likely a source of erosion bringing additional sediment into the reservoir. Vegetated areas have been replaced by agricultural land, increasing erosion into rivers and reservoirs. Agricultural practices, such as furrows in the direction of drainage, exacerbates erosion and sedimentation. Sedimentation in the downstream canals is also caused by water with suspended sediment, discharged from ATT reservoir when water supply is required for rice irrigation.

Encroachment of the reservoir and protected area and forest to agriculture transitions

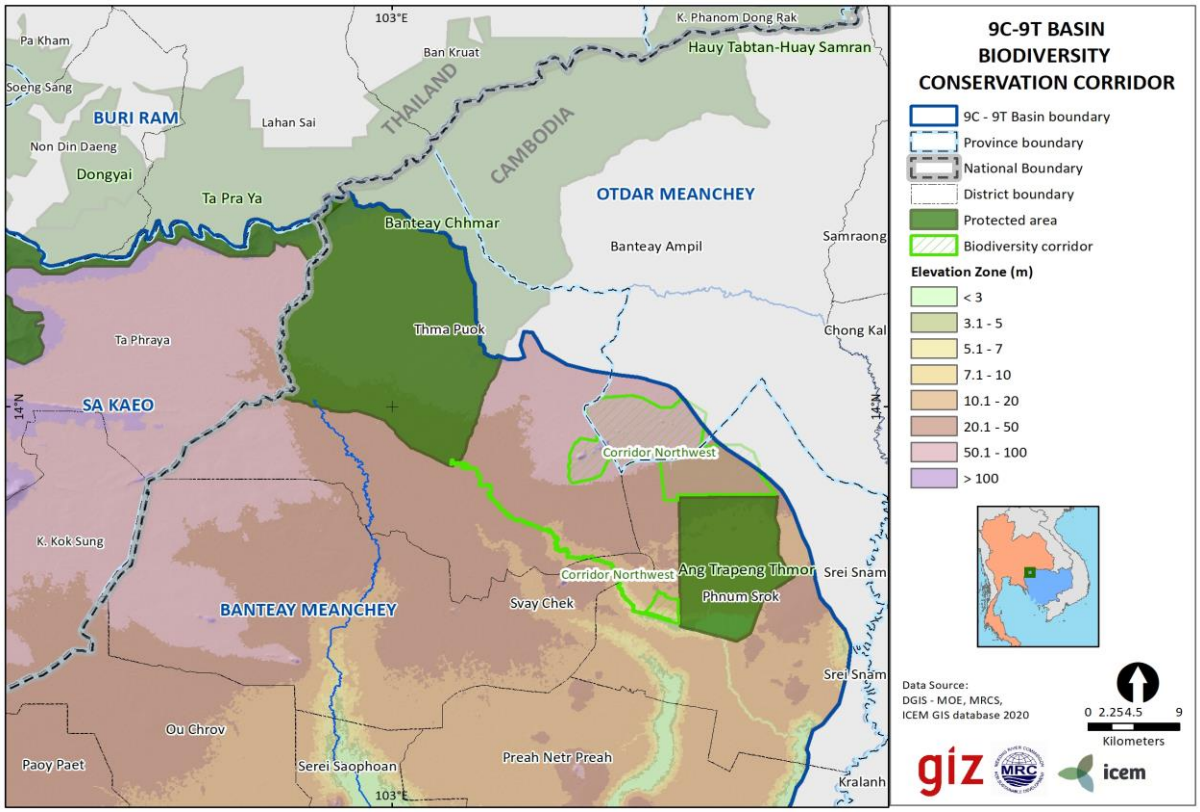
Geospatial analysis of the landscape area demonstrates significant land cover change and vegetation disturbance over the last 20 years, particularly within the northern extent of the protected forest area.

Seasonally inundated areas of the reservoir support grassland expanses, called 'Plong', which is critical feeding habitat for the Sirus Crane. The northern portion of the reservoir is inundated for a short period each year and has been extensively converted to wet rice agriculture. This has resulted in progressive encroachment of the reservoir area during periods of low water level. If the Plong is submerged for more than 5-6 months, then it is likely to be destroyed. Management of the water levels in the reservoir is therefore critical to its conservation. It is understood WCS can engage in operation of the reservoir gates for biodiversity management.

Access restrictions to the protected area by local communities has generated resource management challenges and pressures. Conflicts have arisen around the designation of cultivated lands in/around the PA, leading to historic renegotiation of agricultural vs. biodiversity zones, such as between the International Crane Foundation (ICF) and Pongro and Sambuor villages in 2003.[15] The loss of agricultural land associated with protected area user restrictions has resulted in encroachment of other crops in neighbouring areas, such as cassava cultivation within the largely deforested forests to the east of ATT.

[15] Wan, A. et al. 2009. Dammed protected areas impact on nature and local livelihoods, Ang Trapeang Thmor, Cambodia

Figure 35: Biodiversity conservation corridor connection to ATT (top); ATT Protected Area landscape (bottom)



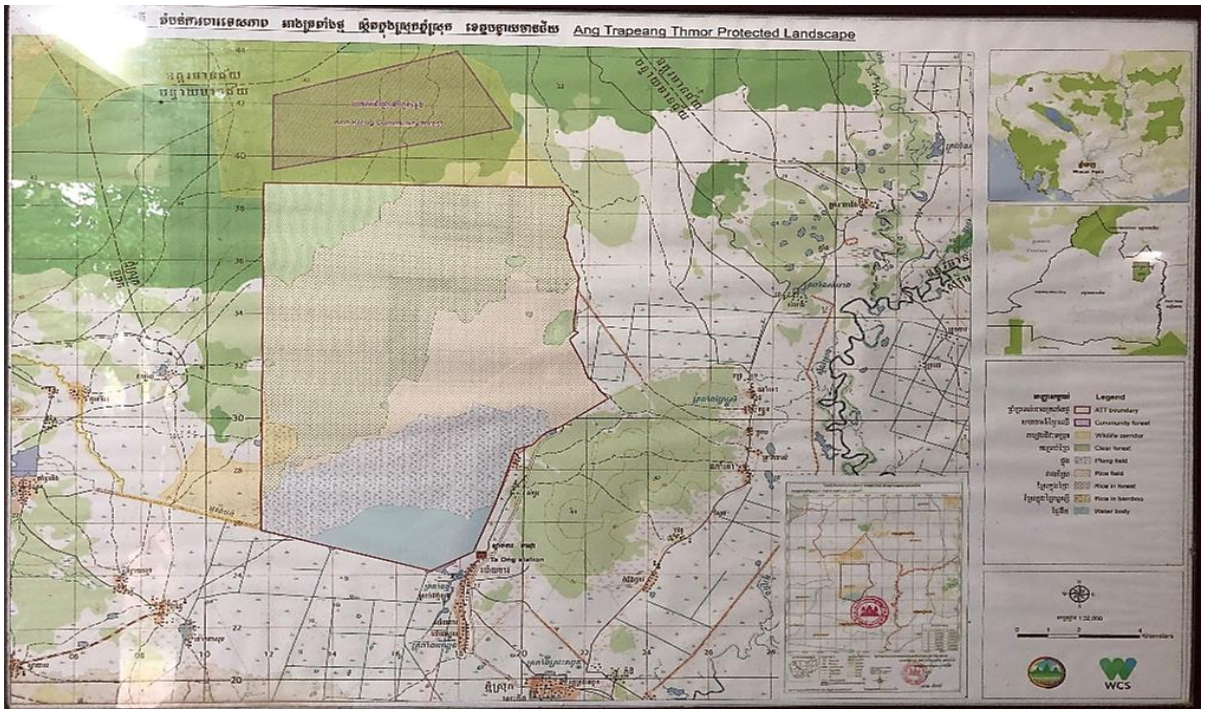
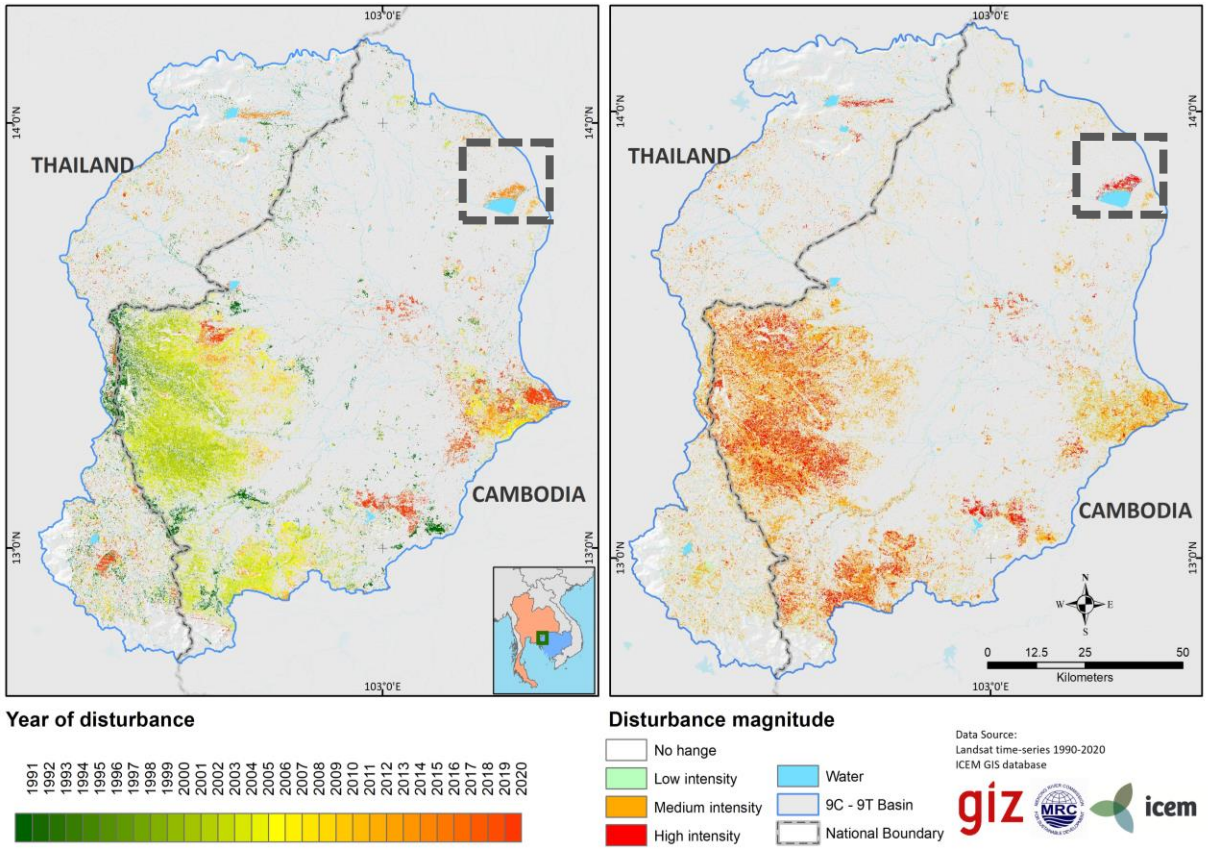


Figure 36: Vegetation disturbance at ATT



Reduced rainfall and drought

The northeast portion of the 9C-9T sub-basin, in which ATT is situated, has been identified as a region of particular concern for drought frequency and risk (Figure 37), to worsen significantly with climate change and a projected reduction in annual precipitation (Figure 38). The area to the east of the reservoir, covered extensively by agriculture, is one of the highest drought risk locations in the 9C-9T.

Figure 37: 9C-9T MODIS Normalized Difference Water Index (NDWI) drought frequency months

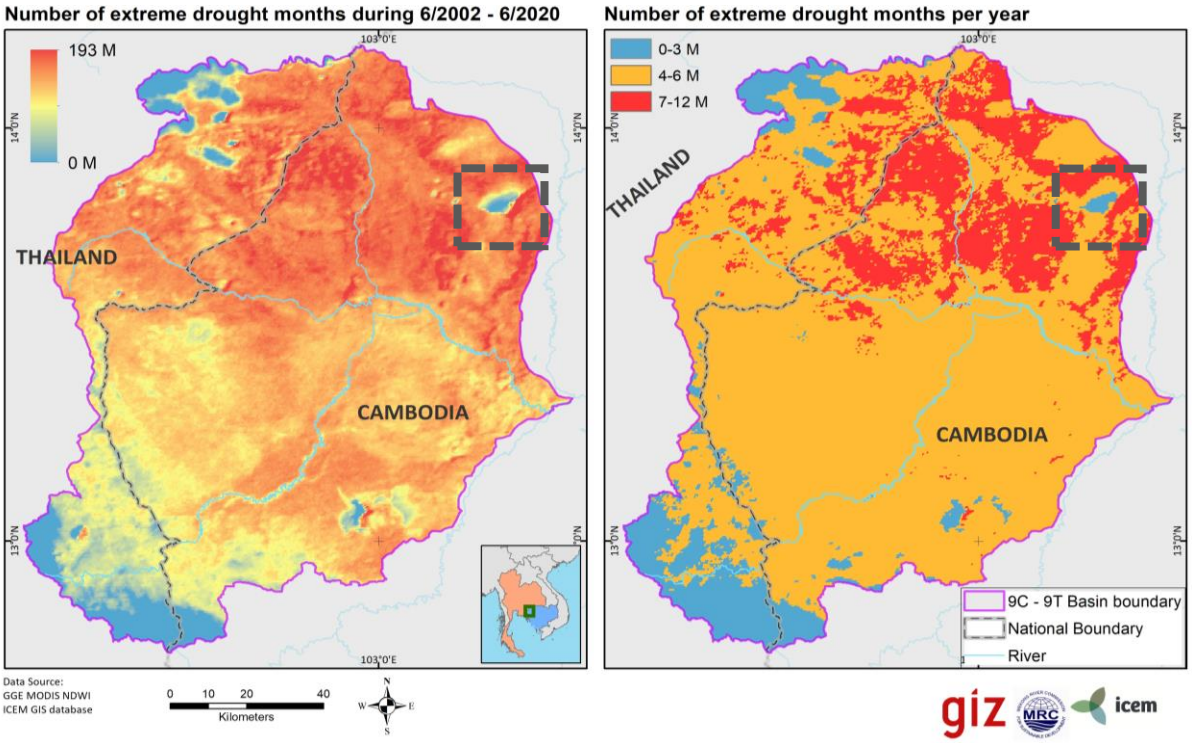
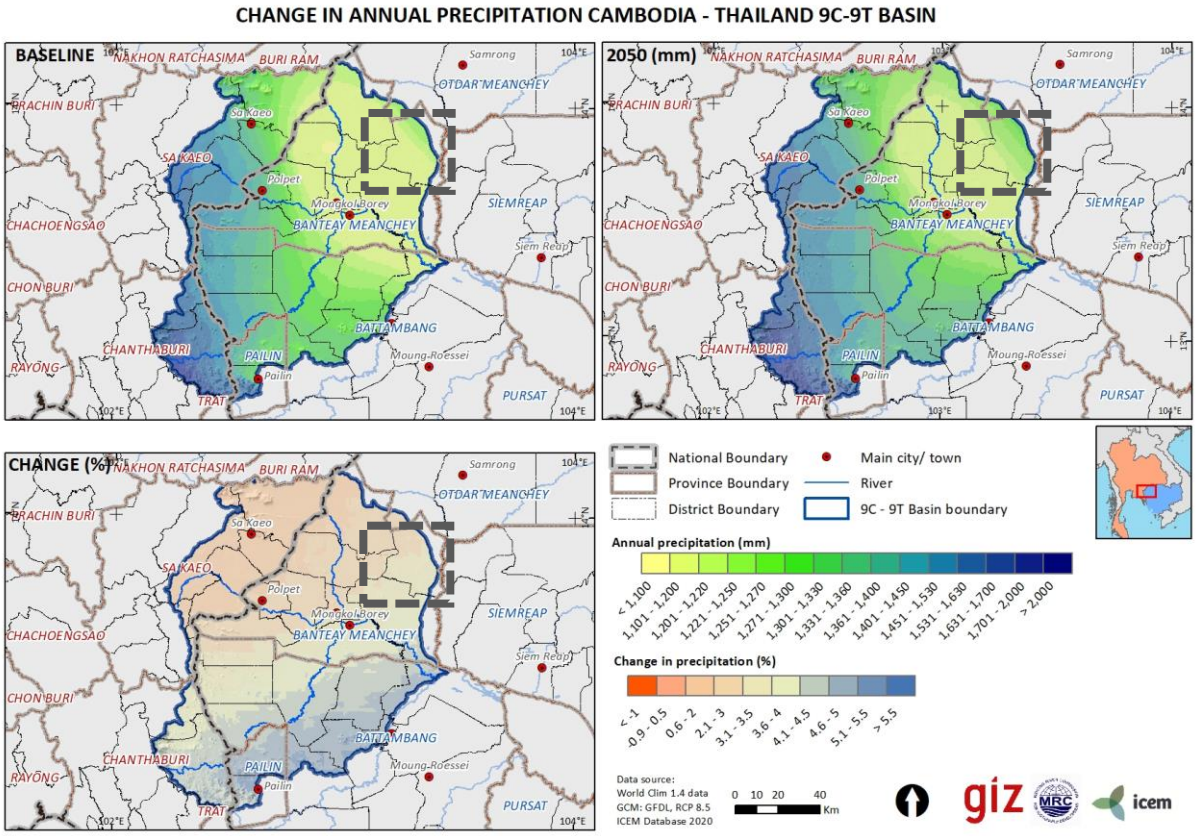


Figure 38: Scenario changes in annual precipitation – baseline vs. 2050



9.3.2 Impacts

Loss of water storage, sedimentation and water quality

Sediment from the canals settle in the reservoir, resulting in a loss of water storage and reducing its life span. This leads to reduced flood mitigation functions and a decrease in drought resilience; a significant risk when coupled with the project future trend of increasing drought/reduced rainfall. The use of chemicals for agriculture also influences the reservoir water quality.

Forest and grassland loss and biodiversity risk

Encroachment of the reservoir and its catchment over time has significantly reduced the forest coverage within the protected forest landscape. There are now only two community forests remaining within ATT; the Konkleng Community Forest, and the Prey Daurm Rang. The Konkleng forest comprises a sparse, dry dipterocarp forest. Historic logging of high value species and forest fires has degraded around 300-500 Ha of the forest. It was noted that the sarus cranes, a critical species for the landscape, roost in the forest at night. Approximately 100 deer are present in the forest, however are at risk of poaching by military personnel during the night.

The competing water resource dynamics also impact on ecosystem services in the catchment. When the flood water level in ATT reservoir is elevated for extended periods, the 'Plong' grasses become oversaturated and destroyed. Despite the grass stem length increasing in a response to the flood waters, the stems are so fragile that they are destroyed by strong water flow. MOWRAM may be planning to increase the retention volume of the reservoir from 80 to 200 million m^3, resulting in a more extensive inundation area, threatening remaining grasslands.

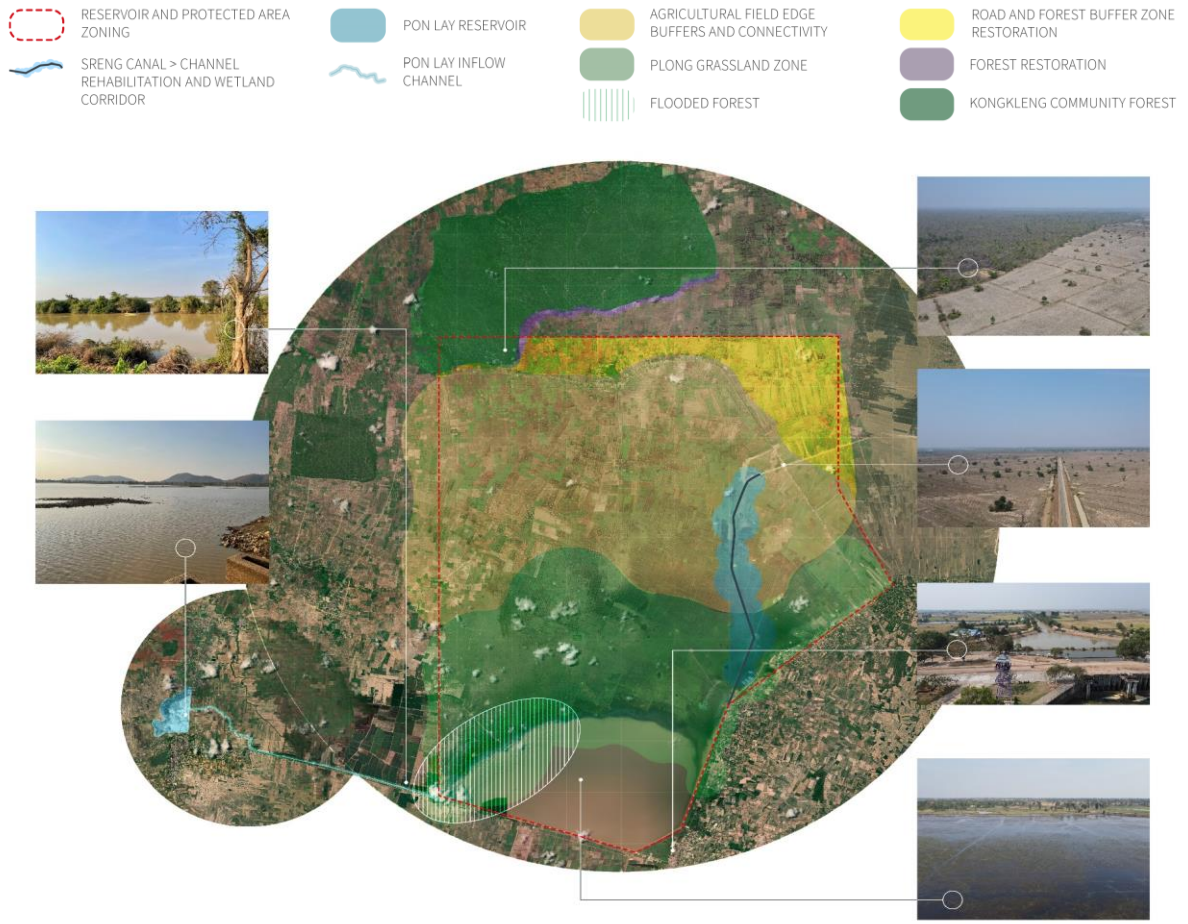
The Plong grassland zone is a significant feeding location over 200 species of birds, and other wildlife. The birds are largely present in the dry season from January - May. Their feeding ground is threatened by chemical fertilizers, herbicides and pesticides used by farmers. The rice fields had been cultivated for decades prior to ATT management. Previous attempts to relocate agricultural land outside of the ATT reservoir and protected area have failed due to a lack of available compensation and land.

Those development trends present a risk to the resident flora and fauna – land and aquatic – and results in a fragmented habitat and loss of biodiversity, significantly undermining the value of the protected area ecosystem.

9.4 Nature based and hybrid solutions project concept

9.4.1 Concept design of NbS

Figure 39: Proposed NbS interventions for ATT landscape



Measure 1: Riparian buffer

The Sreng canal inflow could present locations for possible NbS interventions, including the planning and design of riparian buffers and a natural canal and wetland system. Such interventions could be undertaken solely within the 9C-9T boundary area (approximately 10 km), after the outlet where the canal meets the natural channel (Figure 39). Even so, a larger intervention would create more impact. During the field mission, it was noted that Cambodia National Mekong Commission (CNMC) and Provincial Department of Water Resources and Meteorology (PDOWRAM) raised concerns regarding the plantation of trees next to canals (i.e. riparian buffers) due to MOWRAM regulations.

A vegetated strip and wetland corridor either side of the natural channel is recommended at a width of a minimum 50m wherever practicable, in line with good practice design (see Measure 1, Annex 1). This area would comprise a 7 km wetland corridor with regular expanded pockets as proposed overflow zones during wet season. No agricultural encroachment should occur. The vegetative buffer strip should comprise a mix of native species to ensure buffer integrity. Community representatives explained that acacia trees have been planted extensively throughout the ATT landscape, along roads and fields, in order to harvest wood, create shade and reduce erosion. Concerns were raised about nutrients losses, including reduced rice yields next to the acacia trees. The community members suggested to introduce and plant the Neem tree (*Azadirachta indica*, khmer: sdaw) as a native and affordable alternative as potential buffer vegetation.

The Pon Lay reservoir connects to the south eastern corner of ATT reservoir (Figure 40). Many irrigation channels are connected to the channel in the long stretch between the two reservoirs, extracting water and reducing the water flowing into ATT. During the dry season there is no water in the Pon Lay reservoir and inflow channel. Opportunities may exist for NbS interventions, including the design of a natural canal system, with no dry season flow.

Figure 40: Pon Lay reservoir and area

Dredging: Due to erosion and sediment problems the Pon Lay canal and reservoir requires regular dredging. With the addition of the buffer strips, the sediment problem could substantially be improved and dredging interval prolonged. The option of canal bank stabilization would also reduce erosion. Dredging has the potential to disturb the riverbank and aquatic ecological networks, whilst it is being established. These impacts must be factored in when planning the buffers and dredging schedules.

Measure 2: Reservoir and wetland zoning

Reservoir zoning is the delineation of one or more aquatic zones within a reservoir at its maximum extent (further detailed in Measure 2, Annex 1). Zoning is an essential management tool in the case of this reservoir, which has such important biodiversity values. Zoning would be guided by good practice Biosphere Reserve categories.[16] Consequently, three core zones are proposed for the reservoir, to be further assessed with fine tuning of boundaries:

- Core zone – strict protection and conservation of habitats and water security;
- Buffer zones – for ecologically sustainable activities such as eco-tourism, environmental education and local knowledge and traditions with limited interference; and
- Transition zone – reduced restrictions for sustainable activities, ecosystem service use and socio-culturally sustainable economic and human activity. This could include a seasonal flood area permissible for temporal sustainable agriculture; agriculture that adheres to sustainable irrigation practices, without degrading soil quality and using harmful pesticides.

The variation in the reservoir's extent and volume during the wet and dry season, and associated temporary agricultural encroachment, presents a challenge for implementing zonation. Agriculture

[16] UNESCO (2021). Technical Guidelines for Biosphere Reserves. https://en.unesco.org/news/technical-guidelines-biosphere-reserves-new-tool-mab-programme.

and fishing are core livelihood activities at ATT and managing water supply and demand along with flood and drought risk is a priority. The local community needs to be suitably acknowledged and engaged from the outset of the planning process for this intervention.

Agreeing on the zoning and management objectives for each zone (including permissible activities) is an important part of closely involving local communities, conservation organisations and other stakeholders for the participatory and sustainable management of the reservoir. As there are activities already present in/around the reservoir, including in sensitive areas, future discussions will need to assess and propose management interventions for these. All illegal activities should be prohibited after the approval of the zoning plan.

Measure 3: Catchment water management plan

Water management practices should follow a similar approach to that proposed for Kamping Puoy reservoir. The water management plan should consider the entire catchment of ATT. Key water management interventions include the following (further detailed in Measure 3, Annex 1):

- Regulation and guidelines about sustainable water use associated with ATT and its catchment;
- Regulations and guidelines on the management of ATT reservoir relating to protected area management and biodiversity safeguards;
- Improvement in water use efficiency associated with ATT and its catchment;
- Hydrological assessment to balance agriculture water consumption upstream and sustainability of the ATT reservoir downstream.

A thorough analysis of the current situation, stakeholder analysis, and projection of demands is needed to find optimal management rules and an acceptable water allocation scheme. Currently there is no effective cross sectoral management structure or process which brings together the needed national sectoral agencies and local authorities.

Measure 5: Sediment trapping

Check dams and leaky weirs are proposed upstream of the reservoir, within former/relic drainage channels that have been steadily encroached and degraded. A number of former channels have been identified that are in need of rehabilitation. Riparian buffers should also be established if these channels are to be restored to their former state. The establishment of small multiple functioning check dams and leaky weirs offers significant potential within this landscape. Such interventions would help to trap sediment before it enters the reservoir to prevent sedimentation and decreased water storage capacity.

Measure 6: Forest and grassland restoration

Despite the fragmented and degraded ecosystem to the north of the reservoir with only a fraction of the original forest remaining, opportunities exist for developing nodes, stepping stones and corridor networks of dry and flooded forest (identified on project overview map).

Opportunities also exist to restore over 200 Ha of degraded forest to the southern boundary of Konkleng Figure 39). This network should connect Konkleng to the agricultural and wetland zone downstream.

Flooded forests, of which there are 700 Ha to the southwest of ATT, are an important component of wetland ecosystems, providing fish nurseries and habitats as well as carbon storage. These areas should be restored. In addition, aquatic vegetation as part of wetland restoration needs to be established alongside the reforested areas providing important natural wastewater treatment functions.

Opportunities exist to identify possible wetland zones and support the rehabilitation of the Plong grassland, comprising almost 3,000 Ha. Rehabilitation and restoration of forest and grasslands within

the protected area will provide erosion control, water regulation, habitats and other ecosystem services.

Measure 13: Sustainable irrigation measures

Due to the drought risk and extensive agricultural practices within the reservoir catchment, sustainable irrigation measures are proposed for ATT (see Annex 1, Measure 13). Field trenches and small-scale irrigation/fish ponds (including within the reservoir zone) provide opportunities for improved water resource management by farmers. The small-scale irrigation and fish ponds should be established with natural wetland species, forest/vegetation buffers and bank stabilization with mixed native species. The proposed location of the ponds would be identified by the local community.

Field trenches involve ploughing to the right angle of a field's slope, filtering runoff water, reducing soil degradation and enhancing infiltration of surface run-off and soil moisture.

Measure 15: Agricultural field buffers

Agricultural buffer zones along and within croplands – of which there is over 6,700 Ha within the ATT protected area boundary – can complement and add to natural vegetated corridors across the landscape (Figure 39). Agricultural buffer strips using native vegetation, also offer opportunities to improve ecological connectivity, reduce sedimentation and enhance infiltration. Field buffers should focus on restored forest nodes and corridors within agricultural land. Examples include field edges south of the road towards Konkleng Community Forest and a vegetated road buffer to north, extending to the boundary of the protected area and Konkleng, where possible.

9.4.2 Project benefit

- Regulation and guidelines about sustainable water use associated with ATT and its catchment;
- Establishment of reservoir zones to ensure effective reservoir management, habitat conservation, water security and support for ecologically sustainable activities;
- Improvement in water use efficiency associated with ATT and its catchment;
- Multi-functioning sediment trapping interventions to prevent sedimentation and decreased water storage capacity of the reservoir;
- Conservation and rehabilitation of over 3,000 Ha of degraded forest within Konkleng, 700 Ha of flooded forest and 3,000 Ha of grassland area within the ATT protected area, bringing nature back;
- Reforestation for over 200 Ha of community forest;
- Natural buffer development for 7 km of existing degraded natural channels, including wetland corridors;
- Construction of over 200 new decentralised irrigation/fish ponds, to provide improved seasonal water and food security;
- Restored forest nodes and corridors within approximately 6700 Ha of agricultural land within the protected areas, including field buffers and road buffers;
- Sustainable agricultural measures to reduce encroachment, support and more effective cultivation and water management in the ATT catchment.

ANNEX 1: NATURE-BASED SOLUTIONS MEASURES

Annex 1 provides an overview of 15 specific nature-based and hybrid measures that have been identified for the six landscapes to build flood, drought and ecosystem resilience. These comprise a sub-set of the wider NbS and hybrid measures identified for the entire 9C-9T basin. The 9C-9T NbS Catalogue, provided as part of the 9C-9T Basin Atlas decision support tool, presents concise good practice summaries of over 50 measures applicable to the basin[17].

Each of the 15 nature-based and hybrid measures contained in Annex 1 detail the following information:

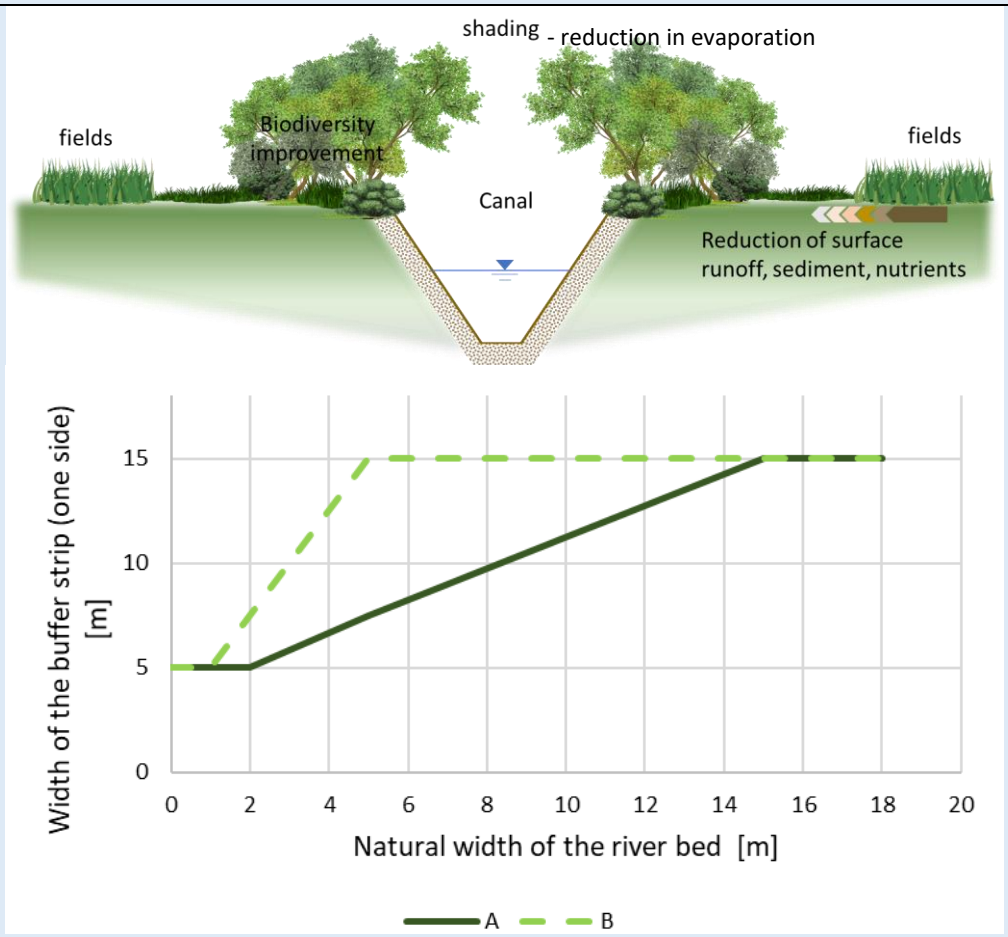
- Relevant locations and applications for the measure;
- A description of the measure;
- Details of complementary measures;
- Opportunities for replicability;
- Effects (on-site, upstream and downstream);
- Relevant stakeholders;
- Structural work/requirements;
- Work plan and cost estimate; and
- Maintenance requirements.

[17] 9C-9T Basin Atlas https://9c9t.mrcmekong.org/9c9t

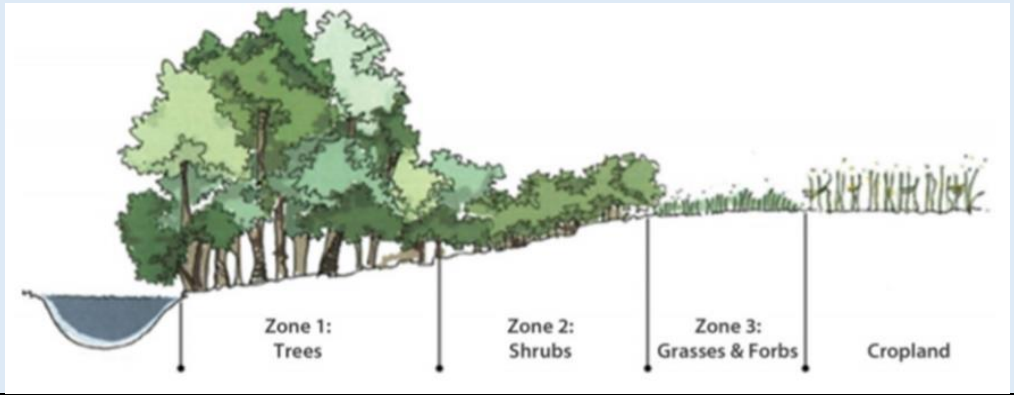
Measure 1: Riparian buffer strip

ID	1	Measure	RIPARIAN BUFFER STRIP
Location		Along streams, rivers, canals, drainage channels, reservoir and between fields	

Illustration



Design principles: A buffer strip including a grass only strip increases the width in which fertilizers and pesticides are not allowed. The relationship between width of the riverbed and width of the buffer strip is shown below. The two curves indicate A) the minimum width of buffer strips which assures the maintenance of ecological functions and B) the width which ensures biodiversity conservation. The curves provide recommendations and were adopted from Furer et al. (2009)[18], with 15m identified as suitable as a basic buffer.



[18] Furer et al. (2009). Pufferstreifen – richtig messen und bewirtschaften. KIP & PIOCH (ed.), Lindau and Lausanne, Switzerland

<table>
<tr><td>ID</td><td>1</td><td>Measure</td><td colspan="3">RIPARIAN BUFFER STRIP</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">The buffer area will comprise a number of core zones, to facilitate its establishment and resilience over time, as illustrated above. Zone 1, adjacent to the river, comprises larger trees and shrubs and provides shade and bank stability. No harvesting or agricultural activities should typically take place within this zone. Zone 2 protects water quality, filters runoff and supports the uptake of nutrients and pollutants, as well as providing a habitat corridor. With a diverse mix of native trees and shrubs, forest management or tree harvesting in this zone should not compromise zonal integrity. Zone 3 is located adjacent to productive land, such as agricultural land and consists of native grasses and shrub cover to filter runoff that transports sediment, nutrients and pesticides from cropland, urban areas or degraded/eroded habitats. This is often a critical zone when control of these elements is necessary[19].

Riparian zones[20] or buffer strips are considered beneficial to reduce evaporation and to improve water quality. Runoff carrying sediments and nutrients are cleaned, retained and released with considerably less solids and pollutants. It is a common approach, widely accepted and regarded as no regret measures due to its positive effects on biodiversity. Access to the channel is hindered and dumping waste along channel banks or into the channel is hampered. Buffer zones should be established for the entire length of the channel rather than in few scattered sections. The more urban areas near the canal, the more buffer zones can contribute to keeping the channel in a good state. Farming in a buffer zone should not be allowed and restrictions with respect to fertilizers and pesticides need to be established.

Since dredging is still necessary but with prolonged intervals, the design of the buffer strips must take this necessity into account allowing for entry and exit points.

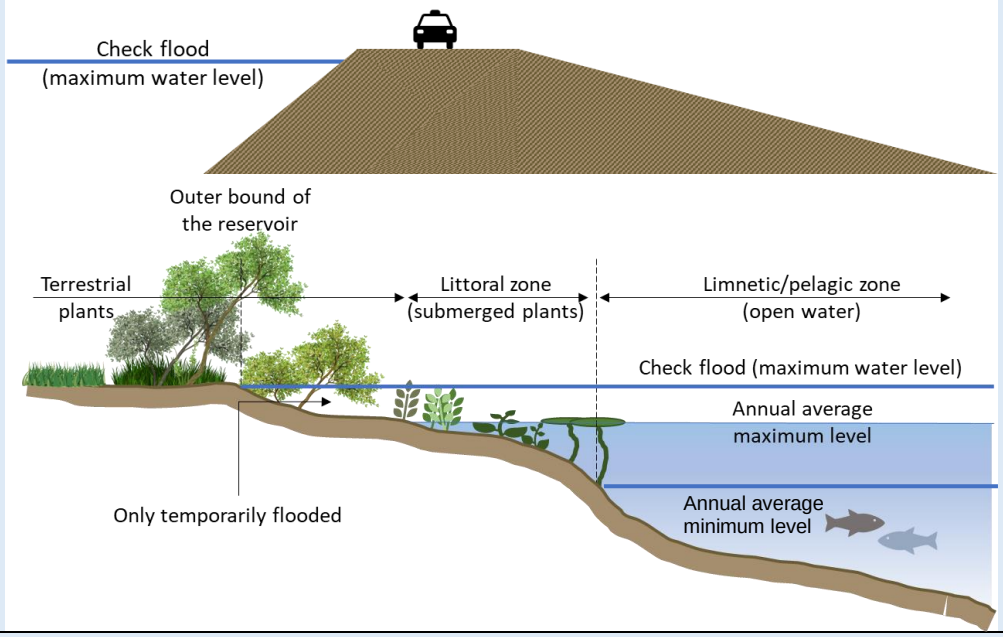
The efficiency depends on the runoff volume, topography and attributes of the buffer strip like age, plant density and in particular width. Studies have shown that buffer strips with a good mix of vegetation can have efficiency rates in reduction for nitrogen between 50 % to nearly 100 %, and for phosphorus between 40 % and 90 %. Pesticides are retained with rates between 40 % to 90% and sediment reduction of 45 % to 100 %. Improvement in biodiversity, connectivity of habitats, vegetation extent and shading, all depend on the buffer width. Moderation of stream temperature can be expected with shading and with buffer zone width of 15 m either side of the canal. Other ecosystem services like food production, improvement of in-stream and terrestrial biodiversity require a larger width of 30 to 200m.[21]</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Channel bank stabilization and bed restoration (Measure 12), agricultural field buffer (Measure 15)</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High. Can be replicated at all water bodies (including rivers, drainage channels and canals)</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td>upstream</td><td colspan="2">downstream</td></tr>
<tr><td>Water quality enhancement
Stabilisation of channel/canal banks
Filtration of solids from adjacent areas
Nutrient reduction
Evaporation reduction
Enhancement of biodiversity
Biological corridor</td><td>none</td><td colspan="2">Water quality enhancement
Sediment reduction
Possibility for increased inflow due to evaporation reduction</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and local government, land owners, farmers and local groups and communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Planting
Landscaping measures (depending on topography)</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Design of measures in collaboration with hydrologists, planners and ecologists/biologists
Selection of various native plants and trees
Involvement of land owners
Sizing in terms of width of the buffer zone
Planning of entry and exit points for dredging
Land compensation measures if land is in private hands</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Control and restoration of structures and plants, especially after flood events</td></tr>
</table>

[19] Drugge, J. and Doty, S.L. (2019). Riparian buffers in agricultural areas. https://www.fao.org/forestry/49973-0c493ebbcffcad591e63d1238f4ada0e1.pdf

[20] Agouridis, C.T., Wightman, S.J., Barton, C.D., and Gumbert, A.A. 2010. Planting a riparian buffer. Cooperative Extension Service, University of Kentucky College of Agriculture, Lexington, KY. 8p

[21] Tredanari, A. (2011): The effect of buffer strip width on cost efficiency: a Swedish case study. Swedish University of Agricultural Sciences, Department of Soil and Environment.

Measure 2: Reservoir zoning

ID	2	**Measure**	RESERVOIR ZONING
Location		Reservoirs, lakes and wetlands	
Illustration			
Measures		The purpose of reservoir zoning is to safeguard the water infrastructure from encroachment and to establish different zones for nutrients uptake, sediment deposition, fish and aquatic habitats. Robustly-designed and scientifically-grounded zonation can effectively support the allocation of management and monitoring efforts, reconcile stakeholder/land use conflicts, define required enforcement and establish appropriate safeguards and protocols. Reservoir zones need to be well defined, with robust goals, guidelines and details on permitted activities. The diagram illustrates these zones, whereby the outer boundary of the reservoir varies interannually between average wet season, average dry season, lowest water levels (drought) and maximum water levels (check flood). The most important zoning functions are: Littoral zone: • Nutrient trap • refuge from predators • nursery for fish Limnetic/pelagic zone: • Nutrient uptake • Sediment stabilization • Habitat for fish and reptiles • Oxygen production Littoral zones are important components of reservoirs with rich functions to maintain the health of the reservoir's ecosystem. Plant species selection is necessary at places where the littoral zone is degraded. Natural succession will take place once the zones are protected and vegetation has been re-established. It should be noted that for many reservoirs, seasonal flooding or droughts affect the zones and encroachment levels of the reservoir. To prevent encroachment requires the identification, mapping and demarcation of the outer bounds of the reservoir and the imposing of regulations for non-compliance. Where possible, zonal boundaries should be selected so that they are easily recognisable and clearly identifiable on the ground (e.g. making use of natural/man-made features), for ease of monitoring, maintenance and compliance. Where the reservoir contains areas of key biodiversity or endangered species, no-go/encroachment conservation zones can be established to avoid habitat and biodiversity loss, with recreational and productive activities prohibited. Other potential zone designations may be established for recreational, tourism, fishing, agricultural, flooding or water conservation purposes.	

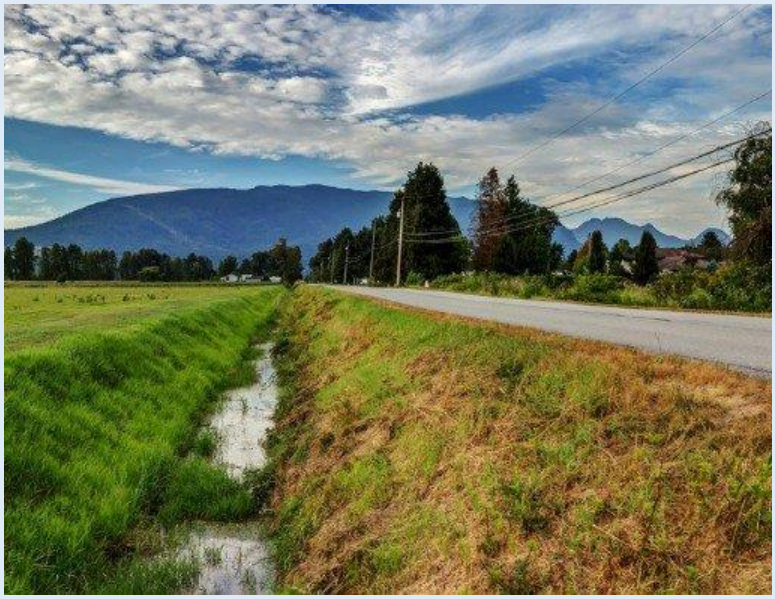
<table>
<tr><td>ID</td><td>2</td><td>Measure</td><td colspan="3">RESERVOIR ZONING</td></tr>
<tr><td colspan="2"></td><td colspan="4">Where relevant, water and fish management plans should be developed to identify core zones, criteria, management and maintenance needs and targets, stakeholders to be involvement and possible interventions.
A range of stakeholders should be involved in the zoning decision-making process, from local communities, to conservation groups, to provincial authorities.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Measure 3, catchment water management plans</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">Low</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Safeguard of the reservoir
Nutrient trap
Water quality improvement
Sediment trap
Fishery</td><td>Backwater
Reduction of flow velocity</td><td>Possibility to moderate the reservoir from a highly eutrophic to a mesotrophic state.</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and local government, management institutions, local businesses, land owners, farmers, communities and conservation groups</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Planting at places where the littoral zones are disturbed or degraded
Removal of structures, if any, where encroachment took place</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Drone flight during a period with low water levels
High resolution Digital Elevation Model (DEM)
Delineation and demarcation of the outer bound
Water and fish management plan
Awareness raising campaign and enforcement</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">No maintenance once the natural succession is in place and input of nutrients does not change.</td></tr>
</table>

Measure 3: Catchment water management plans

<table>
<tr><td>ID</td><td>3</td><td>Measure</td><td colspan="3">CATCHMENT WATER MANAGEMENT PLANS</td></tr>
<tr><td colspan="2">Location</td><td colspan="4">Entire catchment of a reservoir or river.</td></tr>
<tr><td colspan="2">Illustration</td><td colspan="4">-</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">• Regulation and guidelines about sustainable water use and allocation
• Improvement of water use efficiency
• Hydrological assessment to balance agriculture water consumption upstream and sustainability of the reservoir downstream.

Water management is not restricted to one sector and combines requirements from different purposes like drinking water, irrigation, environmental flows and flood control. A thorough analysis about the current situation, stakeholder analysis, goals, projection of demands are needed to find optimal management rules and a water allocation scheme. Rules found within an evaluation and optimisation process are developed in an iterative process. After a first analysis and establishment of initial rules, experience and concerns from stakeholders feed into the evaluation procedure. Final and agreed operation rules must be disseminated, and training and awareness raising provided. Stakeholders involved need to act on the rules and water authorities monitor compliance and ensure enforcement. With all parties involved, an understanding of overarching principles of integrated water resources management (IWRM) can be accomplished. IWRM approaches will secure the sustainability of the reservoir as well as the other water infrastructure measures in the watershed.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">All measures</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High, all catchments of reservoirs or rivers with different water users.</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td colspan="2">upstream</td><td>downstream</td></tr>
<tr><td>Operationalises water abstraction
Institutionalises water management
Handles demands reliably and equitably due to agreed regulations
Identifies water infrastructure for operational purposes.</td><td colspan="2">Provides reliability and accountability for water users.</td><td>Provides reliability and accountability for water users.</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">All stakeholders</td></tr>
<tr><td colspan="2">Structural work/ Requirements</td><td colspan="4">Inventory of current water abstraction and allocation practice
Inventory of monitoring and monitoring equipment
Evaluation of operation rules with stakeholder involvement
Dissemination and training
Monitoring scheme and maybe restoration of monitoring equipment</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Review of current practice
Intensive stakeholder analysis and involvement
In-depth hydrological analysis
Implementation of operation rules
Identification of suitable abstraction points and monitoring sites</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Review of operation rules each 5 to 10-year period or after unprecedented events.
Review of monitoring equipment and organisation on an annual basis.</td></tr>
<tr><td colspan="3">Pros</td><td colspan="3">Cons</td></tr>
<tr><td colspan="3">Enhances supply safety
Creates clear and sustainable water management rules
Creates reliability for all stakeholders
Sets a framework for monitoring, evaluation and verification
Improves collaboration between operator, water authority and stakeholders
Requires commitment by operators, water authorities and stakeholders
Requires consequences if case of non-compliance</td><td colspan="3">Increased effort in monitoring
Requires review and re-establishment of rules when conditions and assumptions change.
Requires enforcement in case of non-compliance, which could call for additional personnel and supervision authority.</td></tr>
</table>

Measure 4: Drainage combined with nature-based retention

ID	4	**Measure**	DRAINAGE COMBINED WITH NATURE-BASED RETENTION
Location	All roads, dirt roads, paths, drainage routes.		
Illustration	  © Life Unio  © East Sussex Highways		

ID	4	**Measure**	DRAINAGE COMBINED WITH NATURE-BASED RETENTION

© Michal Paulus

© United States Forest Service

Measures

The surface runoff of drainage routes is diverted into swales and natural depressions to reduce runoff and sedimentation downstream.

Lateral drainage structures

Cross slope, small lateral ditches with or without a grid on top or depressions perpendicular to the flow direction are easy to build and low-cost measures. They need to be repeated in regular distances. The distance between two measures should be smaller with increasing slope to break the energy of water flow.

The pictures illustrate various possibilities. The measure depends on the slope and the surface material of the drainage route.

Concrete U-shaped structures should be used in combination with compacted surfaces or tarmac. The opening can be smaller than the bottom to prevent large material from falling in and blocking the structure. All lateral structures need to be tightly placed into the space. The attachment to the underground depends on the expected load and is usually made of concrete. A depression with car traffic is best built with cobblestones in a concrete matrix. The distance between each structure depends on the slope of the road.

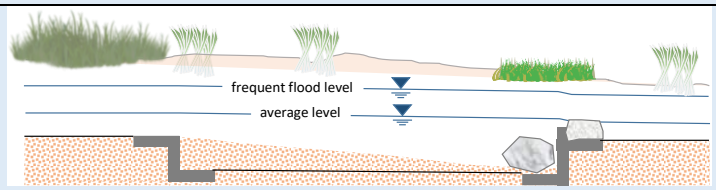
The surface of the structures must be adopted to expected traffic and small enough to avoid accidents with pedestrians, cyclists, vehicles. U-shaped structures can be equipped with grills if need be.

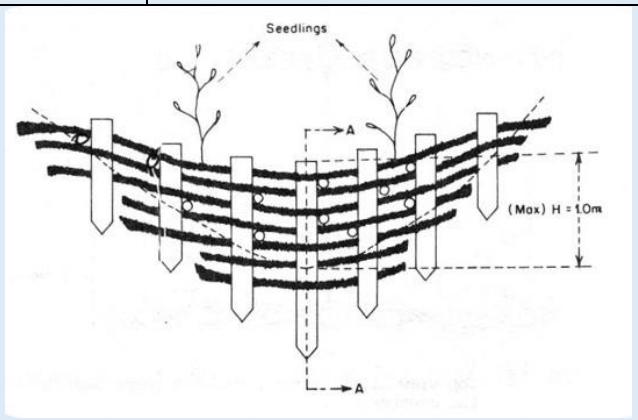
Bioswales

Side ditches can also provide alternative features where desired or where transverse measures are not appropriate. Bioswales are stormwater runoff conveyance systems comprising linear ditches filled with

<table>
<tr><td colspan="2">ID 4</td><td>Measure</td><td colspan="3">DRAINAGE COMBINED WITH NATURE-BASED RETENTION</td></tr>
<tr><td colspan="2"></td><td colspan="4">vegetation, compost and/or riprap. They collect, infiltrate and treat stormwater runoff before releasing it to the watershed or storm sewer. The vegetation reduces water velocity, allowing it to accumulate in a bioswale, and filters suspended sediments.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Measure 9: Retention and infiltration of surface runoff</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High. Can be implemented almost everywhere.</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Surface water is diverted off a road
Limited soil erosion
Less damage to unpaved roads</td><td>none</td><td>Less surface runoff
Reduced sedimentation of the reservoir</td></tr>
<tr><td colspan="2">Structural work/ Requirements</td><td colspan="4">Digging of a ditch or depression
- Construction depends on designed drainage structure
Compact and attach the immediate surrounding</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Design of measures in collaboration with hydrologists, transport planners and ecologists/biologists
Site inspections with survey of slopes, material of roads
Screening for suitable adjacent space for retention.
Construction during dry season</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">U-shaped structures must be emptied regularly.</td></tr>
</table>

Measure 5: Sediment trapping

ID	5	**Measure**	SEDIMENT TRAPPING
Location		Upstream of reservoir or ponds (sediment trap). At confluences of tributaries or along a river with the possibility to widen the riverbed (sediment trap). In seasonal channels and gullies (check dam and leaky weir). *A prominent feature along rivers with intense land cultivation is a high discharge from agricultural areas. With high loads of nutrients and sediments, each tributary carries considerable loads, depending on size and land use of its catchment. Hence, confluences are suitable locations to generate small multiple functioning sediment pools. Another advantage at confluences is that large areas are covered with comparably few measures. Moreover, inundation of adjacent areas is very likely an already regular feature which in turn indicates that crop in the near surrounding might be adapted to wet conditions or even inundation.*	
Illustration		  Hybrid, technical trap  Natural trap	

ID	5	**Measure**	SEDIMENT TRAPPING
		 Check dam	
Measures		Sediment traps Sediment traps or sediment pools can be conventional hard engineering or nature-based structures. They need little maintenance compared to other hard practices that treat sediment-laden runoff. Here it is considered as a NbS/hybrid measure. With homogeneous river reaches in place, widening and deepening of cross sections along a certain distance has the potential of positively affecting flow characteristic and allows for settling of sediments in association with river bed and bank development. River bank vegetation and habitat generation can be enabled by simple means like boulder clusters, vegetated rip rap, boulder revetments, log wads or root wads. Grey measures placed at outlet of the pool provide river bed stabilisation and enhance erosion control. When pools are small, dead trees and boulders, attached to each other and placed across a channel bring similar effects and replace grey measures. The effect of a sediment traps depends on its length, depth, grain-size distribution and the design flood against which a sediment trap is designed to. The key question is which part of the particle size distribution can settle given the geometry of the pool and flow velocity. When designed, installed, and maintained appropriately, sediment traps can have an efficiency of between 60 and 80 %. The required surface area of a sediment trap will typically range from 4-10% of the area draining into them, dependant on various factors including terrain, shape, depth, sediment type/size and other factors[22].After an extended period of time trapping sediment, the ponds/traps will likely fill up with sediment, requiring management- build up should not exceed 50% of the wet storage depth. Dredging of traps is required to dispose of accumulated sediment. Where dredging cannot be accomplished mechanically from the shore, it may be necessary to remove sediment using hydraulic dredging methods. Overall, the lifespan of a sediment trap can vary considerably depending on the context and setting, ranging from 2 – 20 years[23]. Check dams A check dam (also called gully plug) is a small, temporary or permanent dam built across a drainage ditch, swale, or channel to lower run-off speed. By reducing the original gradient of the gully channel, erosion and gully erosion are prevented and sediments and pollutants settle. The dam allows groundwater recharge and possibly retains soil moisture due to infiltration. Nature-based check dams can be built from wooden logs or stone. Depending on the topography, amount of precipitation, material and financial resources available, there are several methods to construct a gully plug. Tree seedlings, as well as shrub and grass cuttings planted in gullies, can grow without being washed away by flowing water. Thus, a permanent vegetative cover can be established in a short time. Temporary structural measures such as woven-wire, brushwood, logs, loose stones and boulder check dams are used to facilitate the growth of this permanent vegetative cover. Check dams can be constructed using locally available labour and materials, involving the community in their construction. They can often be applied in a quicker timeframe than traditional civil engineering works and should be regularly inspected and maintained.	
Complementary measures		Drainage structures (Measure 4), buffer strips (Measure 1). Landscaping measures to shape the target area might be required to account for enough space and to achieve reduction of flow velocity. Preferred flow paths can be established with small embankments around target area	

[22] https://stormwater.pca.state.mn.us/index.php?title=Sediment_control_practices_-_Sediment_traps_and_basins#:~:text=Sediment%20traps%20and%20basins%20are,being%20released%20from%20the%20site.

[23] https://www.solanorcd.org/images/sediment-traps.pdf

<table>
<tr><td>ID</td><td>5</td><td>Measure</td><td colspan="3">SEDIMENT TRAPPING</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High. Can be implemented almost everywhere</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Sediment trap
Nutrient trap (only with plants in the pool)
Habitat for fauna and flora
Water retention in dry season
Reduced flow velocity</td><td>Backwater
Reduction of flow velocity</td><td>Sediment reduction
Nutrient reduction
Extension of sediment removal intervals
Improved water quality</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial government, engineers, land owners, farmers and local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Land survey
For sediment traps, the immediate cross section at the confluence requires probably structural fortification
Landscaping and planting
Surveying, sediment grain size distribution, design floods, design water levels, soil reconnaissance</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Design of measures in collaboration with hydrologists, engineers, planners and ecologists/biologists
Digging of a ditch or depression
Placing of the structure
Compact the immediate surrounding</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Regular inspection (cyclically and after significant rainfall/flood events)
Bathymetric study to calculate the volume of water within pond and requirements for dredging (for sediment trap)
Regular sediment removal and possibly replanting
Rehabilitation of embankments (for sediment trap)
Rehabilitation of cross sections immediate downstream</td></tr>
<tr><td colspan="3">Pros</td><td colspan="3">Cons</td></tr>
<tr><td colspan="3">Effective sediment and nutrients trapping at few points covering a large area
Easy to build
None or only little grey measures necessary
Enhances water quality downstream
Provides wet conditions at the site and surrounding for a longer period of time over the year
New flow paths during floods can be provoked</td><td colspan="3">Needs maintenance and care after each flood season
Stagnant water might give rise to mosquitos and water borne diseases (fish can be added to the ponds as a counter-measure)
Space required, probably affecting land ownership
Increase of evaporation</td></tr>
</table>

Measure 6: Forest restoration and rehabilitation

ID	6	**Measure**	FOREST RESTORATION AND REHABILITATION
Location		National parks, forest, buffer zone and riparian corridors	
Illustration		The illustrations here are from the IUCN restoration project in 2015-6 in Ta Phraya National Park and its buffer.   Source: IUCN 2016   Forest restoration and conservation is a joint responsibility of local communities and government agencies   	

ID	6	Measure	FOREST RESTORATION AND REHABILITATION

Measures	This measure involves rehabilitation of forests within the national park and its buffer zone upstream of reservoirs, in addition to vegetating buffer strips either side of the main riparian corridors leading to the reservoirs. The six internationally recognized principles of forest landscape restoration (Besseau et al. 2018) are: 1) Focus on landscapes 2) Engage stakeholders and support participatory governance 3) Restore multiple functions for multiple benefits 4) Maintain and enhance natural forest ecosystems within landscapes 5) Tailor to the local context using a variety of approaches 6) Manage adaptively for long-term resilience. The purpose of forest restoration is to restore a degraded forest to its original state – that is, to re-establish the presumed structure, productivity and species diversity of the forest originally present at a site. The purpose of forest rehabilitation is to restore the capacity of degraded forest land to deliver forest products and services. Forest rehabilitation re-establishes the original productivity of the forest and some, but not necessarily all, of the plant and animal species thought to be originally present at a site. The rehabilitation

<table>
<tr><td>ID</td><td>6</td><td>Measure</td><td colspan="3">FOREST RESTORATION AND REHABILITATION</td></tr>
<tr><td></td><td colspan="5">activities using NbS methods would be applied to the buffer areas between the national park and the reservoirs and to the riparian corridors.

Both forest restoration and rehabilitation will be implemented on sites where forest loss has caused a decline in the quality of environmental services including those for the downstream reservoirs and roads. They aim to strengthen the resilience of forest sites and landscapes and thereby increase the security of downstream livelihoods and infrastructure. They have multiple benefits but must conserve biodiversity and restore ecological functions.

The restoration and rehabilitation measures will be a distinctive combination of actions for the reforested area, the buffer and the riparian corridors because each have differing challenges and opportunities. Yet measures in each location share the same objectives: (i) the conservation of soil and water and the permanence of carbon pools in forests, which have a bearing on the productivity, health and condition of the forests themselves; (ii) the maintenance (at the landscape scale) of downstream benefits, such as water quality and flow and reduced flooding and sedimentation; and (iii) the conservation of biodiversity, which is essential as a buffer against changing environmental conditions and as a genetic resource for tree breeding and improvement.

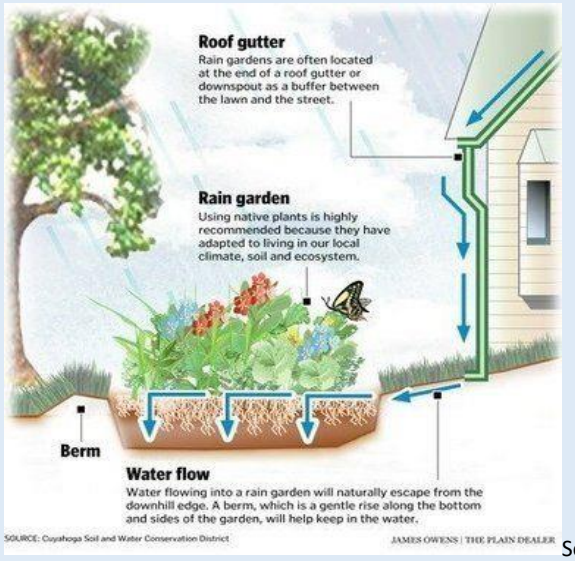
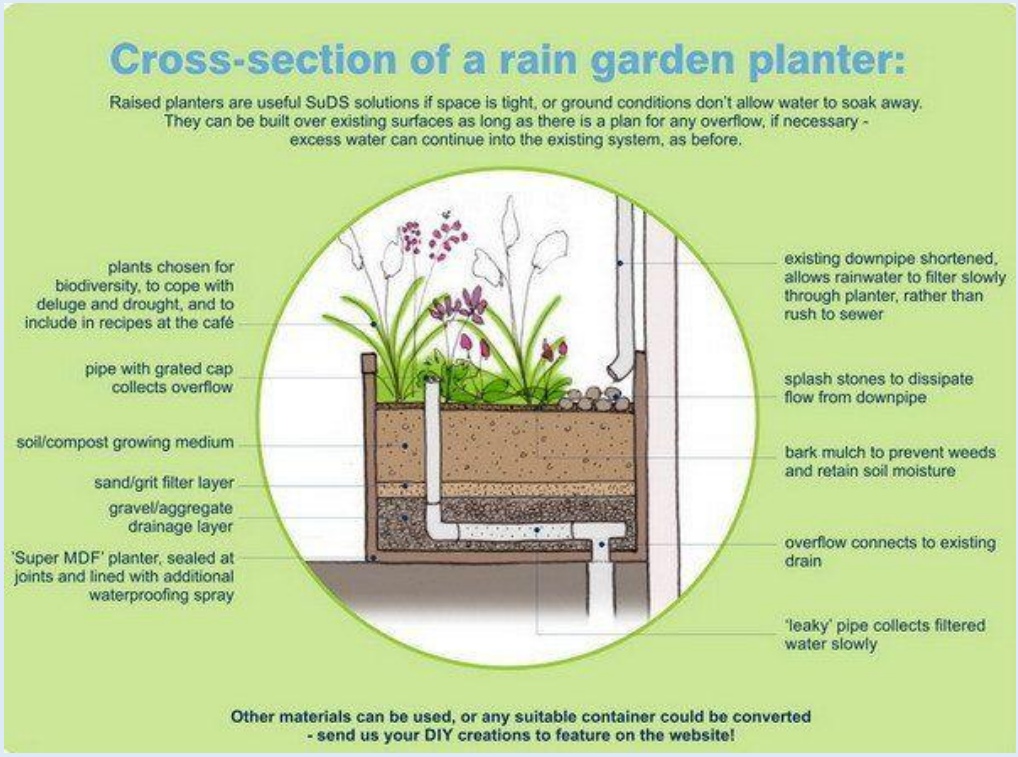
Common measures for all sites:
• Define dimensions of site
• Remove threats or obstacles - Remove and replace exotic or invasive species with native species, and establish fencing to protect re-growth from ungulates and other pressures.
• Choose the species to plant:
  • Native species mix to enhance diversity
  • Mixes of native and exotic species (if temporary shading is needed)
  • Mixes of fast and slow-growing species?
• Establish plant nursery (or support existing community nurseries)
• Planting regime of mixed native tree and understorey species
• Erosion control measures
• Monitoring and maintenance

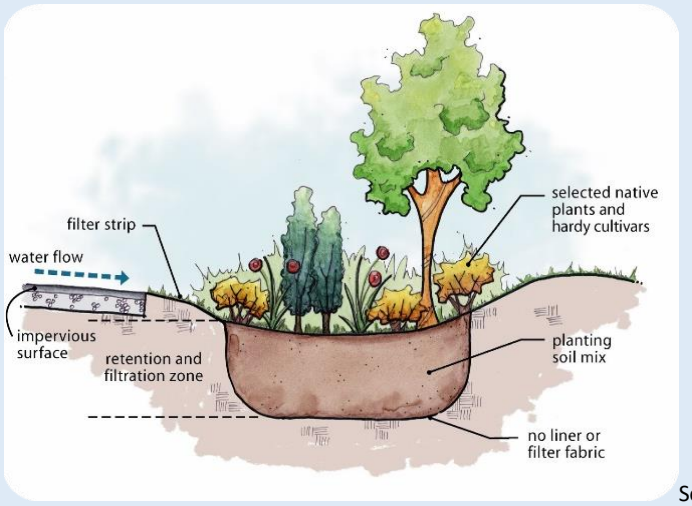
The riparian corridors may require additional location specific measures to stabilise banks – for example ICEM demonstrations in Northern Vietnam with a rip rap and live polls base and various plantings of natives (icem.com.au).</td></tr>
<tr><td>Complementary measures</td><td colspan="5">Water-sensitive forest management</td></tr>
<tr><td>Replicability</td><td colspan="5">High in other degraded areas within the park and buffer</td></tr>
<tr><td>Effects</td><td>on-site</td><td colspan="2">upstream</td><td colspan="2">downstream</td></tr>
<tr><td></td><td>Reverses forest degradation trends
Expands wildlife habitats
Stabilises soils and reduces erosion
Reduces speed and volume of water runoff – enhancing infiltration
Increases soil water storage
Develop diverse and multifunctional landscape
Improves water and air quality
Opportunity for tourism and recreation</td><td colspan="2">Enhance habitat connectivity and biodiversity
Mitigates climate changes since forest acts as a carbon sink</td><td colspan="2">Control soil erosion and sedimentation.
Improves water quality in reservoirs
Increases lifespan of reservoirs
Reduces desilting maintenance requirements
Reduces drying of waterways
Increasing the sustainability of local economies and communities</td></tr>
<tr><td>Stakeholders</td><td colspan="5">National and provincial government, protected area/park authorities, conservation groups, land owners, farmers, private sector and local communities</td></tr>
<tr><td>Structural work / Requirements</td><td colspan="5">• Nursery management for native species
• Assessing target site conditions
• Identify stressors on the areas in need of regulation and control
• Defining the kinds of biotic interventions that are needed (e.g. species and mixes)
• Identifying restrictions, for example, park zoning, drainage projects, diversions of runoff and reservoir site access</td></tr>
</table>

<table>
<tr><td>ID</td><td>6</td><td>Measure</td><td colspan="2">FOREST RESTORATION AND REHABILITATION</td></tr>
<tr><td colspan="2"></td><td colspan="3">• Labour sources and equipment needs
• Biotic resource needs and sources (e.g. community nurseries)
• The need for securing permits required by government agencies and any restrictions on restoration, for example, through zoning regulations and restrictive covenants in buffer area
• Expert advice and support on native forest species
• Identifying families and communities with an interest in participating
• Capacity building with stakeholders in sustainable forestry techniques.</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="3">Preliminary work plan</td></tr>
<tr><td colspan="3">Site demarcation
Stakeholder analysis and involvement
Selection of various plants and trees
Identify or establish potential plantation nurseries
Sizing the width of the buffer zone
Land compensation measures if land is privately-owned</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="3">Monitor forest onsite and remotely
Regularly assess to assess seedling survival and health
Track changes and receive regular problem area alerts
Detect and report illegal logging with aerial and satellite imageries
Maintenance of sites including weeding, fire control, enrichment planting, additional erosion control structures if they prove necessary</td></tr>
<tr><td colspan="3">Pros</td><td colspan="2">Cons</td></tr>
<tr><td colspan="3">Enhance reservoir life and water supply functions
Enhance biodiversity
Enhanced ecosystem services
possibilities of employment
possibilities of increasing livelihood income
Enhance ecotourism potential
Agroforest potential
Potential increase land values
Recreational opportunities
NTFPs in buffer zone</td><td colspan="2">Upfront costs
Increased effort in monitoring and management
Requires enforcement in case of illegal logging activities, which could call for additional personnel.</td></tr>
</table>

Urban rainwater retention

Measure 7: Retention and infiltration of rooftop runoff

ID	7	Measure	RETENTION AND INFILTRATION OF ROOFTOP RUNOFF
Location		Rooftops and adjacent infrastructure and features	
Illustration		Roof drainage systems into rain gardens  Source: New Horizon Horticultural Services  Source: istock.com	

<table>
<tr><td>ID</td><td>7</td><td>Measure</td><td colspan="3">RETENTION AND INFILTRATION OF ROOFTOP RUNOFF</td></tr>
<tr><td colspan="2"></td><td colspan="4"> 

Source: Curtis Hinman, 2005</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">Rooftop intervention

The measure consists of roof gutters, collection pipes and a conveyance system to bring the water to green retention and infiltration zones e.g., bioswales. The pipes must increase in diameter along the flow direction. For superficial drainage, consider trenches with grills to pass footpaths. The infiltration is limited and an overflow needs to be constructed when inflow exceeds the retention and infiltration capacity. As a rule of thumb, the infiltration area must be 10% to 20% of the connected surface area, depending on the permeability. The surface of the green infiltration areas should be vegetated and protected with rubble or stones at the edges in a surrounding with traffic and pedestrians. Ideally, the inflow should come from clean surfaces to avoid clogging and sedimentation problems, if not pre-treatment might be required. On-site infiltration is highly adaptive to various locations due to its flexible design forms, however an appropriate distance to buildings and other static structures should be maintained in order to avoid settlements.

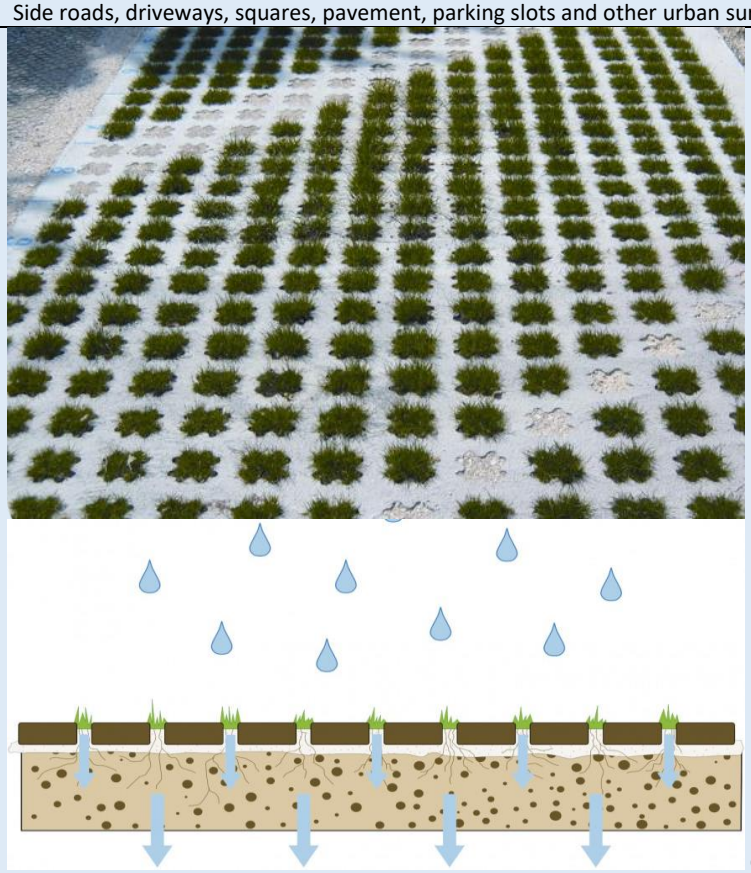
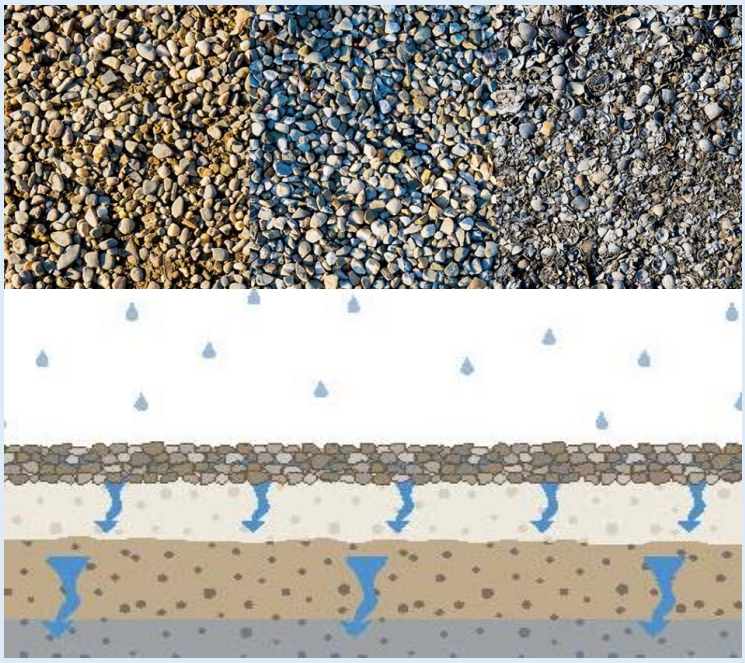
Rain gardens

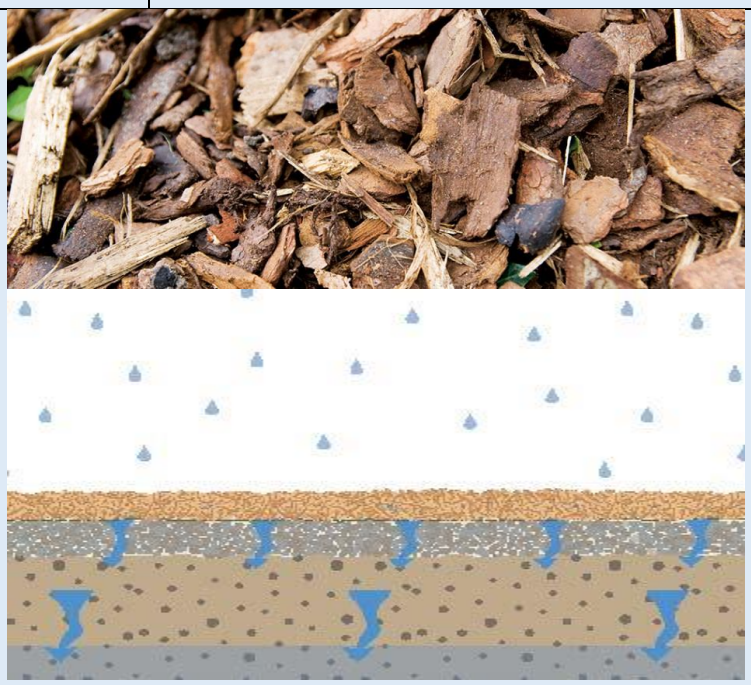
Rain gardens are shallow, densely vegetated ground depressions, with a variety of trees, shrubs, and grasses to collect, hold and soak rainwater from roofs and other features. Selected vegetation should be native, wet-tolerant species that can stand waterlogging for up to 48 hours.

Rain gardens are effective in removing up to 90% of nutrients and pollutants and up to 80% of sediments from rainwater runoff. The rain garden size is dependent on the soil type; however, it should comprise an area of approximately 20% of the size of the roof area draining into it. During heavy rainfall events, they become flooded and facilitate ground infiltration. During dry seasons, they contribute to the quality of public areas and are often located in parks, centres, and private gardens.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Lateral drainage (Measure 4), permeable surfaces (Measure 8), swales, tree pits or bioretention ponds (see Measure 9), green roofs</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High, all rooftops with surrounding free space available</td></tr>
<tr><td colspan="2">Effects</td><td>on-site</td><td colspan="2">upstream</td><td>downstream</td></tr>
<tr><td colspan="2"></td><td>Reduction of surface runoff
Groundwater recharge
Increase in green areas (biodiversity, climate change mitigation by carbon sequestration, reduce urban heat island effect)
Urban gardening</td><td colspan="2">none</td><td>Less and cleaner surface runoff</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Municipal government, private sector, engineers, land owners and local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Geodetic survey generating DEM
Development of soil maps (soil sampling, assessment of the vertical permeability)</td></tr>
</table>

ID	7	**Measure**	RETENTION AND INFILTRATION OF ROOFTOP RUNOFF
		Isolines of groundwater table Plant selection Measures against dumping waste or discharging waste water	
Work plan and cost estimate		*Preliminary work plan*	
		Planning of the conveyance system Designing of the measure based on design storm events and connected surface area Design overflow drainage ways Construction during dry season	
Maintenance		The conveyance system needs regular cleaning. The joints require regular inspection and mending.	

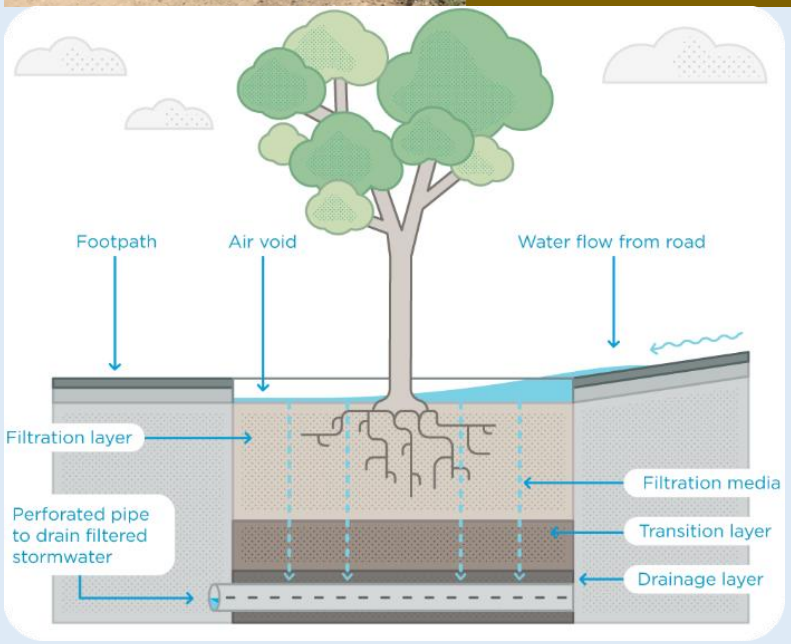
Measure 8: Permeable surfaces

ID	8	**Measure**	PERMEABLE SURFACES
Location		Side roads, driveways, squares, pavement, parking slots and other urban surface areas	
Illustration		 Grass paver © atelier GROENBLAUW  Gravel and stone © atelier GROENBLAUW	

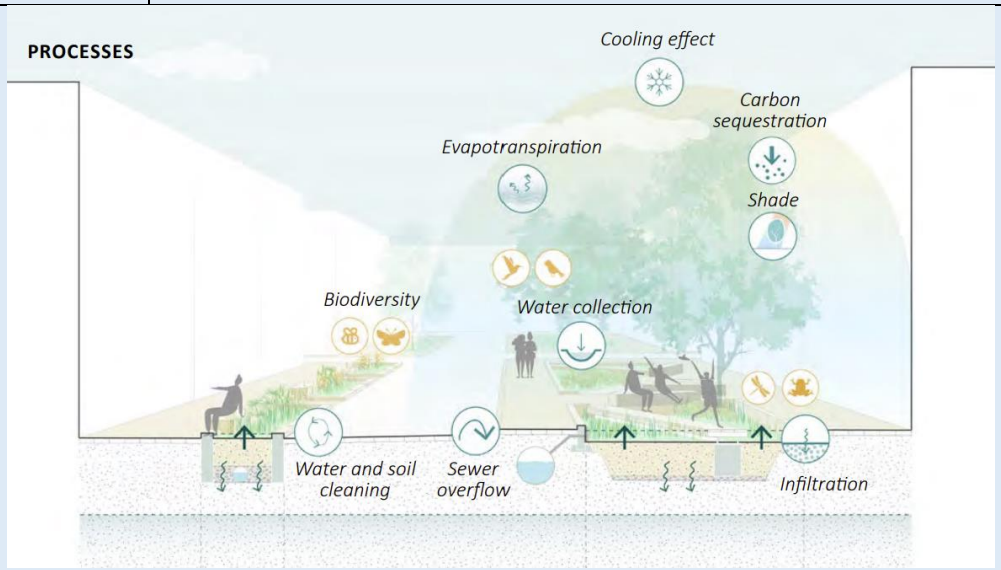
<table>
<tr><td>ID</td><td>8</td><td>Measure</td><td colspan="3">PERMEABLE SURFACES</td></tr>
<tr><td colspan="2"></td><td colspan="4"> 
Wood chips © atelier GROENBLAUW</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">Permeable paving comprises a range of sustainable materials and techniques that facilitates the movement of stormwater through the surface of paving into the soil below. It may be constructed from green and grey infrastructure, including grass (grass lawn and paver), gravel (gravel paver), pervious concrete, porous asphalt, permeable interlocking pavers, and several other materials. They function similarly to sand filters, filtering the water by forcing it to pass through different aggregate sizes and filter fabric. In addition, permeable paving surfaces trap and break down suspended solids, preventing pollutants from entering water and soil underlying the roadway, or to be carried to surface waters. They allow for water seepage to recharge groundwater while reducing peak flows and flooding.

Space, whenever possible, should be used to foster rainwater infiltration and reduce runoff. Permeability is improved through trees, gravel, stones, permeable paving and plants.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Various urban nature-based infiltration and retention measures (see Measure 7 and 9)</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">Very high, all surface areas without heavy traffic load.</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td colspan="2">upstream</td><td>downstream</td></tr>
<tr><td>Reduction of surface runoff
Groundwater recharge
Urban gardening
Improved water quality</td><td colspan="2">none</td><td>Less and cleaner surface runoff</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Municipal government, local businesses, engineers, land owners and local communities</td></tr>
<tr><td colspan="2">Structural work/ Requirements</td><td colspan="4">Identify suitable permeable surface considering future use</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Planning of the conveyance system
Designing of the measure based on design events and connected surface area</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">The conveyance system needs regular maintenance and cleaning.</td></tr>
</table>

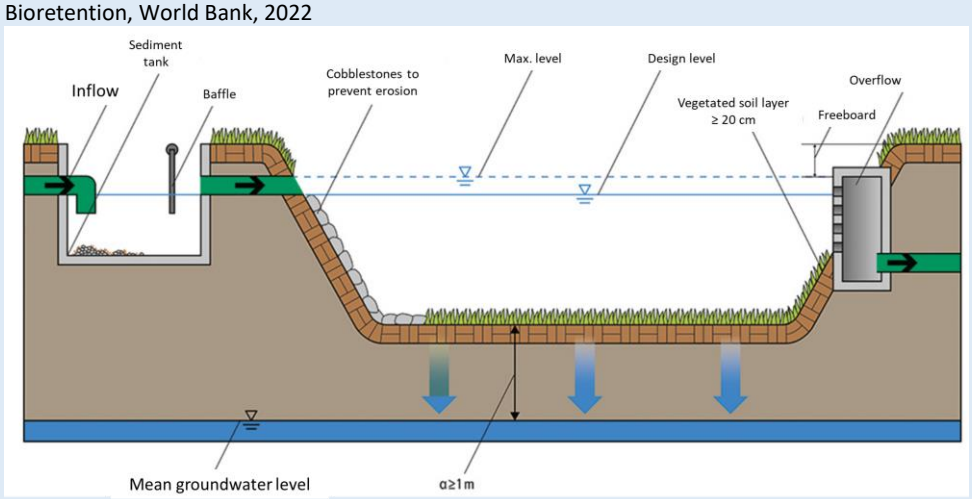
Measure 9: Retention and infiltration of surface runoff

ID	9	**Measure**	RETENTION AND INFILTRATION OF SURFACE RUNOFF
Location		Paved surfaces, along roads and other transport routes	
Illustration		  Stormwater tree pit, source: Basin Atlas	

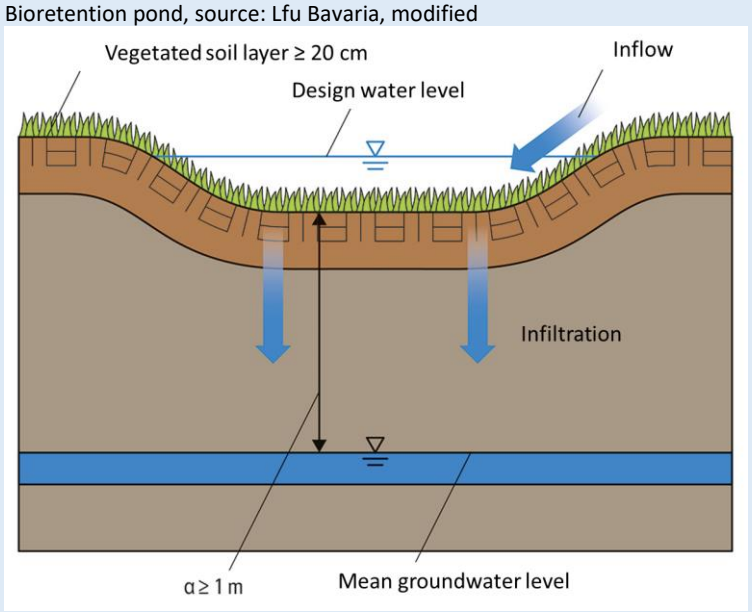
ID	9	Measure	RETENTION AND INFILTRATION OF SURFACE RUNOFF



Bioretention, World Bank, 2022



Bioretention pond, source: Lfu Bavaria, modified



Bioswale, source: Lfu Bavaria, modified

<table>
<tr><td>ID</td><td>9</td><td>Measure</td><td colspan="3">RETENTION AND INFILTRATION OF SURFACE RUNOFF</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">Bioretention

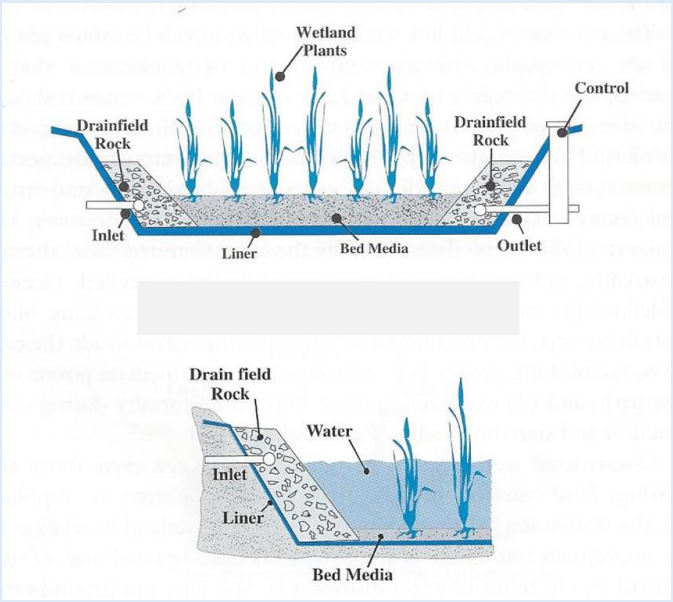
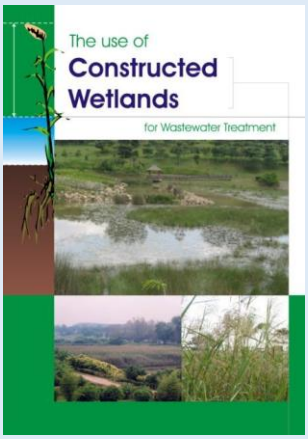
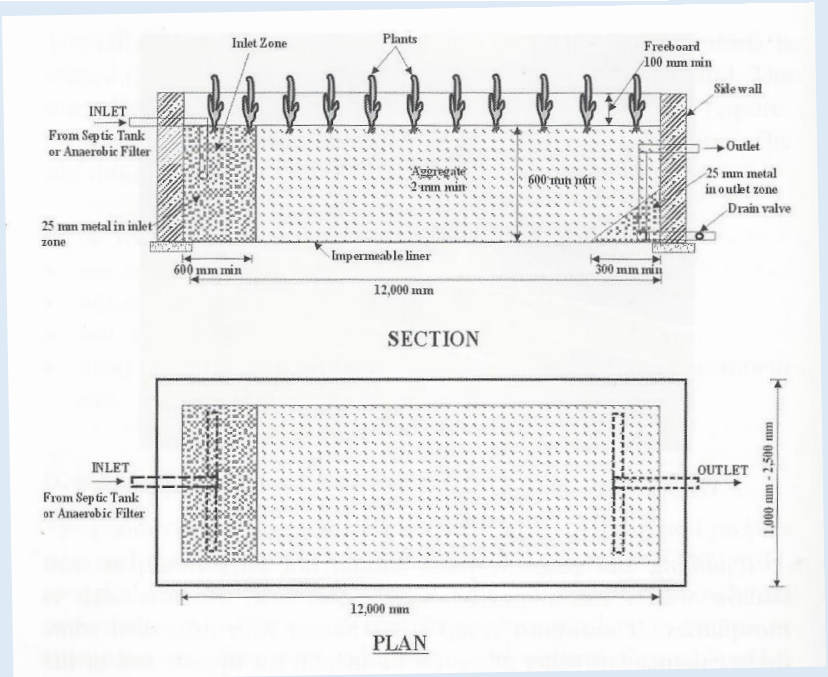
Bioretention is an NbS used to support traditional gray stormwater infrastructure and are typically designed as shallow vegetated depressions that can intercept, infiltrate, divert, slow and treat surface runoff.

Temporarily store runoff from paved surfaces is a simple way to delay runoff and foster infiltration. A superficial conveyance system to the retention/infiltration is required, considering trenches with grills to pass footpaths. The surface of the green infiltration areas should be vegetated and protected with rubble or stones at the edges in areas with traffic and pedestrians. Water quality improvements are observed through infiltration by the vegetated soil layers. If infiltration is desired, depending on the water quality, a pre-treatment (e.g. sedimentation tank) is recommended to avoid clogging and sedimentation problems. An overflow needs to be constructed when inflow exceeds the retention or infiltration capacity. On-site retention and infiltration is highly adaptive to various locations due to their flexible design, however in case of infiltration, an adequate distance to buildings and other static structures should be maintained in order to avoid settlements.

Stormwater tree pits can support infiltration of surface runoff, improving the permeability of the surrounding soil via root growth, and increasing evapotranspiration. Tree pit dimensions, species and soil type (preference for structural soils) are influenced by space availability.

Nature-based designed retention and infiltration measures fulfil more functions than water retention and infiltration. They help enhance climate conditions in an urban environment and contribute to biodiversity. Plants should be selected to suit fluctuating water levels.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Rooftop and rainwater runoff (Measure 7) and permeable surfaces (Measure 8).</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High
Bioretention areas can be adapted to a variety of urban environments</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Reduction of surface runoff
Groundwater recharge
Increase in green areas (biodiversity, climate change mitigation by carbon sequestration, reduce the urban heat island effect)</td><td>none</td><td>Less and cleaner surface runoff
Deceased flood peak</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Municipal government, private sector, land owners, engineers and local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Geodetic survey generating DEM
Development of soil maps (Soil sampling, assessment of the vertical permeability)
Isolines of groundwater table
Plant selection
Measures against dumping waste or discharging waste water.</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Planning of the conveyance system
Designing of the measure based on design storm events and connected surface area
Design overflow drainage ways
Construction during dry season</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Infiltration sites should not be compacted. The surface of the infiltration sites requires care, possibly new planting and soil improvement at the beginning of the wet season.</td></tr>
<tr><td colspan="4">Pros</td><td colspan="2">Cons</td></tr>
<tr><td colspan="4">Medium to long term solution
Intercept, infiltrate, divert, slow and treat surface runoff
Highly adaptive
Support habitat creation</td><td colspan="2">Establishment period</td></tr>
</table>

Measure 10: Constructed wetlands

ID	10	**Measure**	CONSTRUCTED WETLAND
Location		Landfill site leachates and waste water sewer outflows.	
Illustration		   Sources: Tanaka, et.al. (2011) and https://www.yumpu.com/user/rivercenter.uga.edu	
Measures		Shortcomings in sanitation systems are often related to limited financial and technical resources. Compact systems requiring substantial energy input, funds for installation and operation and technical expertise are not always practical solutions. Constructed wetlands are an alternative wastewater treatment that can reduce suspended solids, BOD, pathogens, heavy metals and nutrients[24]. Note	

[24] Tanaka, et.al., 2011: Wetlands for tropical applications. Wastewater treatment by constructed wetlands. Imperial College Press, London, UK.

<table>
<tr><td>ID</td><td>10</td><td>Measure</td><td colspan="3">CONSTRUCTED WETLAND</td></tr>
<tr><td colspan="2"></td><td colspan="4">rainwater and wastewater should be collected and treated separately, with constructed wetlands focused on wastewater. A pre-treatment lagoon is required as part of the measure.

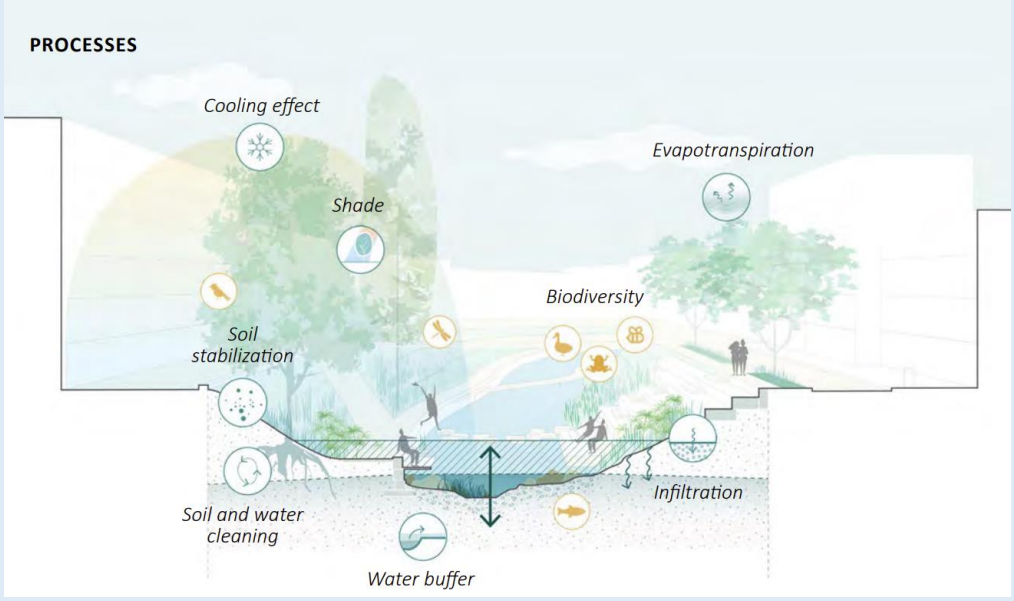
Generally, most constructed wetlands in tropical countries are soil- or gravel-based horizontal flow-systems. Design criteria are the inflow in m³/d, the quality of the wastewater in terms of concentration, the required treatment related to the outflow concentration, slope of the area, permeability of the soil and associated grain size distribution. Other parameters are the plants used.

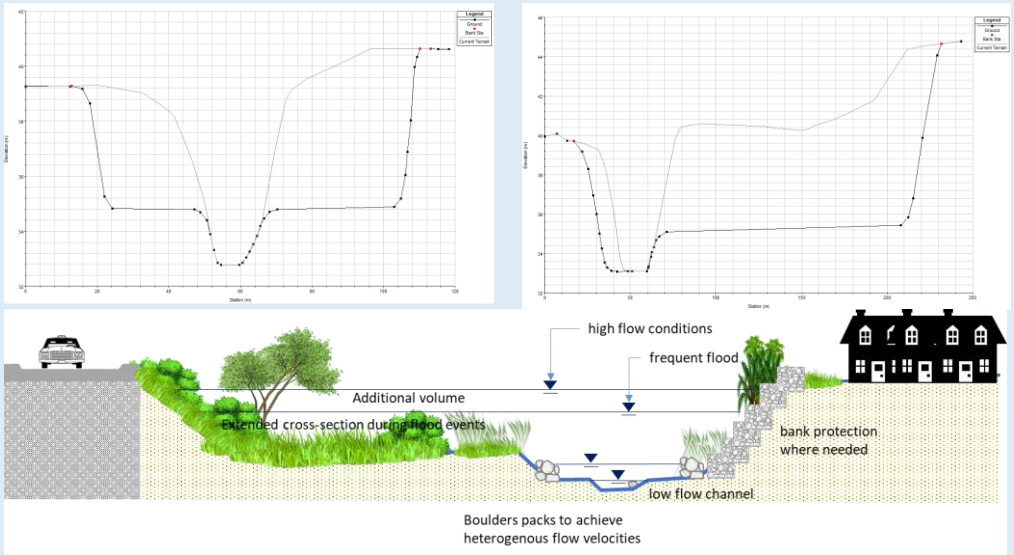
Assumptions typically made to design constructed wetland are:
• First-order kinetics are sufficient as suggested by US-EPA
• Water temperature is approximately the ambient temperature given the shallow depths

The design steps are:
• Determine the parameters and their inflow concentrations and desired treated outflow concentrations
• Calculate the process time needed to achieve the reduction in concentration
• Determine suitable plants and the required bed depth including water depth
• Set the design flow in m³/d and mean ambient temperature
• Estimate required area with equations developed for tropical environments

The constructed wetland should receive constant inflow to function effectively. As in any treatment facility, flooding can damage the wetland so it should be protected against backwater. Stormwater should be collected separately and not lead into the constructed wetland.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Measure 1, 11, 12.</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">Medium. Outlet of sewers with sufficient space.</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td>upstream</td><td colspan="2">downstream</td></tr>
<tr><td>Wastewater treatment
Biodiversity enhancement</td><td>none</td><td colspan="2">Better water quality</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and municipal government, private sector, land owners, engineers and local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Separating storm and wastewater drainage system
Preparing the wetland’s area, earthworks and levelling
Lining
Inlet and outlet structures
Soil and plant installation
Installation of monitoring and control devices</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Specification of inflow volume and concentrations
Specification of target parameters
Preliminary calculation
Site selection</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Removal of accumulated solids
Inspection of pre-treatment
Visual inspection of the flow in the wetland
Cleaning of inlet and outlet
Control of fencing around the wetland
Removal of dead plants</td></tr>
</table>

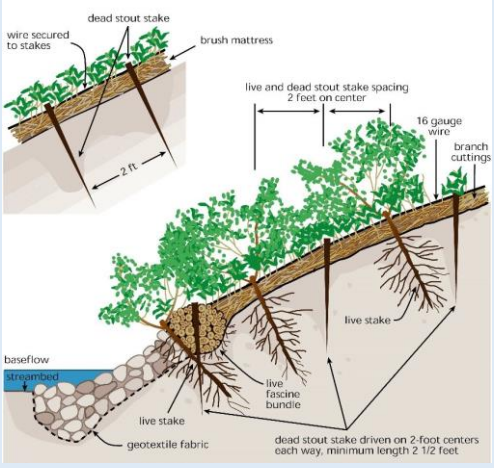
Measure 11: River channel widening and rehabilitation

<table>
<tr><td>ID</td><td>11</td><td>Measure</td><td colspan="3">RIVER CHANNEL WIDENING AND REHABILITATION</td></tr>
<tr><td colspan="2">Location</td><td colspan="4">River</td></tr>
<tr><td colspan="2">Illustration</td><td colspan="4"> 

World Bank. 2022

</td></tr>
<tr><td colspan="2">Measures</td><td colspan="4">In many urbanized areas, rivers and streams have become denaturalized, including through the construction of embankments and culverting. River rehabilitation aims at developing a river stretch towards natural conditions to achieve a sound ecosystem with all its services like water regulation, water quality and biodiversity. The measure is to design the cross-section profile to create different flow conditions, each with a specific hydrological and ecological function. The measure should prioritise river channel widening, as it is important in this context to create additional retention volumes, in order to compensate regular flood events within the flood plain. The river bed material should allow for sediment movement during annual flood events.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">River bank stabilization (Measure 12), buffer strips (Measure 1), wastewater treatment (Measure 10) and waste management</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High, all rivers</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td colspan="2">upstream</td><td>downstream</td></tr>
<tr><td>Flood mitigation and flood regulation</td><td colspan="2">Reduction of backwater effects during flood events</td><td>Reduction of flood peaks
Erosion/sediment balance</td></tr>
</table>

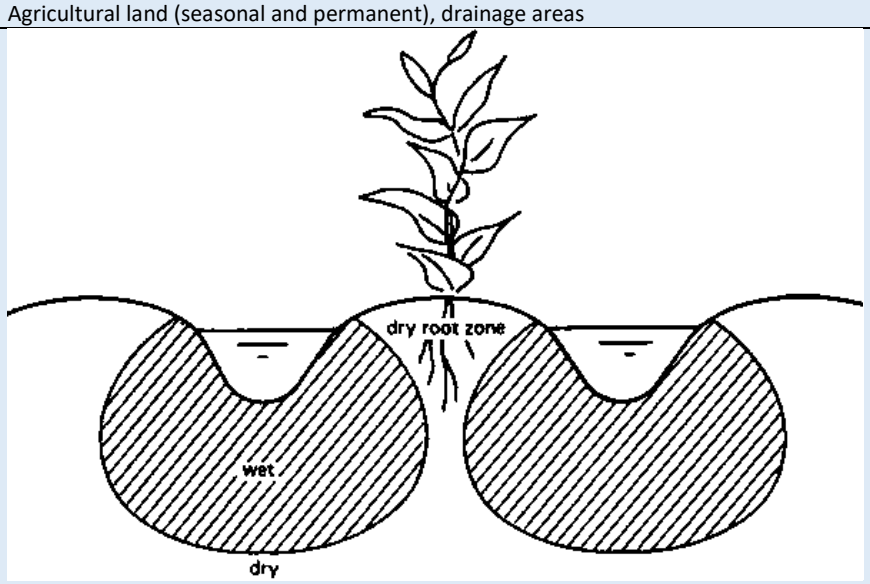
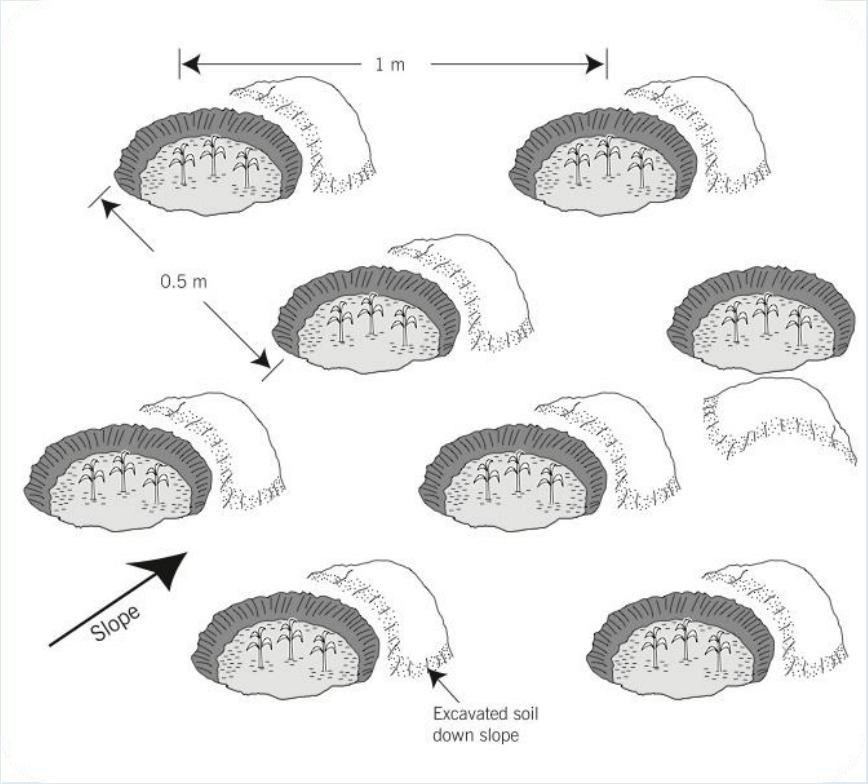
ID	11	**Measure**	RIVER CHANNEL WIDENING AND REHABILITATION	
		Erosion/sediment balance Riverbank stabilisation Solid waste removal Water quality improvement Increase in biodiversity		Water quality improvements Established bio corridor
Stakeholders		Provincial and municipal government, private sector, land owners, farmers, engineers and local groups and communities		
Structural work / Requirements		Terrestrial survey, complemented with drone/ unmanned aerial vehicle (UAV) survey River cleaning Landscaping measures Removal of polluted sediments Special attention during construction to capture polluted sediment mobilisation and to protect existing ecosystems (trees and other important habitats)		
Work plan and cost estimate		*Preliminary work plan*		
		Terrestrial and UAV surveys Development of cross-section design in collaboration with hydrologists, hydro-morphologists, urban planning and ecologists/biologists 2D modelling of measures Implementation plan Mitigation concept during construction related to avoid pollution of downstream river stretches		
Maintenance		River and stream rehabilitation projects are particularly susceptible to damage during the first one to four years after development Regular inspections should check for any signs of erosion Removal of debris		

Measure 12: River bank stabilisation and rehabilitation

ID	12	**Measure**	RIVER BANK STABILISATION AND REHABILITATION
Location		River banks	
Illustration		River channel section in Poipet   Source:https://megamanual.geosyntec.com/nps manual/brushmattresses.aspx Source: icem.com.au 	
Measures		River restoration and rehabilitation aims at developing a river stretch towards natural conditions to achieve a sound ecosystem. River bank stabilisation is important to protect river banks from erosion and avoid sedimentation downstream. Riverbank stability is achieved by considering the material that withstands the maximum design water level. It is also predominantly dependant on slope and soil material and there is a wide range of nature based and hybrid solution for river bank stabilization. Only native plants should be considered and vegetation at different zones must be selected according to the water level duration curve.	

<table>
<tr><td>ID</td><td>12</td><td>Measure</td><td colspan="3">RIVER BANK STABILISATION AND REHABILITATION</td></tr>
<tr><td colspan="2"></td><td colspan="4">Additionally, natural elements like dead wood etc. can be used at the river bed to achieve a wide flow velocity variation and to direct water off river banks, especially cut banks.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">River channel widening and restoration (Measure 11), wastewater treatment (Measure 10), buffer strips (Measure 1) and waste management</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High, all river, canal or reservoir banks</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Erosion/sediment balance
Water quality improvement
Increase in biodiversity
Riverbank stabilisation
Solid waste removal</td><td>none</td><td>Erosion/sediment balance
Water quality improvements
Established bio corridor</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and municipal government, private sector, land owners, farmers, engineers and local groups and communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Terrestrial survey, complemented with UAV survey
River cleaning
Landscaping measures
Special attention during construction to capture polluted sediment mobilisation and to take protect existing ecosystems (trees and other important habitats)</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Terrestrial and Unmanned Aerial Vehicle (UAV) surveys
Development of bank stabilisation measures in collaboration with hydrologists, hydro-morphologists, urban planning and ecologists/biologists
Implementation plan
Mitigation concept during construction related to avoid pollution of downstream river stretches</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Once vegetation is successfully established, maintenance can be reduced, although it is important to ensure the regular control of invasive species and monitoring for pests and diseases
Sapling maintenance and nurturing activities in place until establishment
Vegetation cut, removal of debris</td></tr>
</table>

Measure 13: Sustainable irrigation measures

ID	13	**Measure**	**SUSTAINABLE IRRIGATION MEASURES**
Location		Agricultural land (seasonal and permanent), drainage areas	
Illustration		 Source: FAO  Source: Malesu et al., 2007	
Measures		*Water saving practices* Practices to support sustainable water saving agricultural practices include field trenches and planting pits. Field trenches involve extensive ploughing to the right angle of a field's slope. By breaking the slope of the ground, they increase precipitation harvesting and reduce the velocity of water runoff. Field trenches filter runoff water and hence reduce soil degradation and enhance infiltration of surface run-off and soil moisture. Crops are planted on the elevated land between the trenches. Planting pits are a form of micro-catchment for precipitation harvesting to prevent water runoff and thereby preserve soil and soil moisture, increase infiltration and reduce erosion. Holes are typically dug	

<table>
<tr><td>ID</td><td>13</td><td>Measure</td><td colspan="3">SUSTAINABLE IRRIGATION MEASURES</td></tr>
<tr><td colspan="2"></td><td colspan="4">50-100 cm apart from each other with a depth of 5-15 cm in order to prevent water runoff. They are suitable to semi-arid and tropical areas for annual and perennial crops.

Small-scale bioretention ponds

A bioretention pond is a shallow planted depression designed to retain or detain stormwater before it is infiltrated or discharged downstream. During storms, surface runoff is directed into shallow, landscaped depressions.

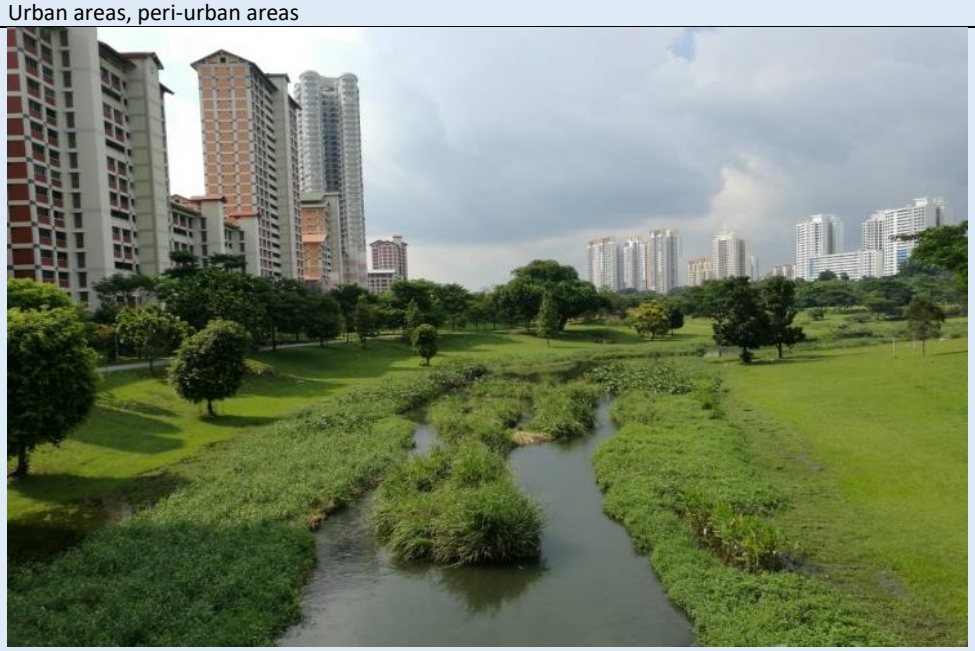
They create an environment for runoff reduction, filtration, biological uptake, and microbial activity, and provide high pollutant removal. Depending on the design, they can provide retention or detention of runoff water, and will trap and remove suspended solids and filter or absorb pollutants to soil and plant material.

Permeable soil ponds, designed with a permeable soil layer, aims to support water retention and ensure infiltration into the subsoil. This may be particularly beneficial for irrigated areas that experience flood and drought.

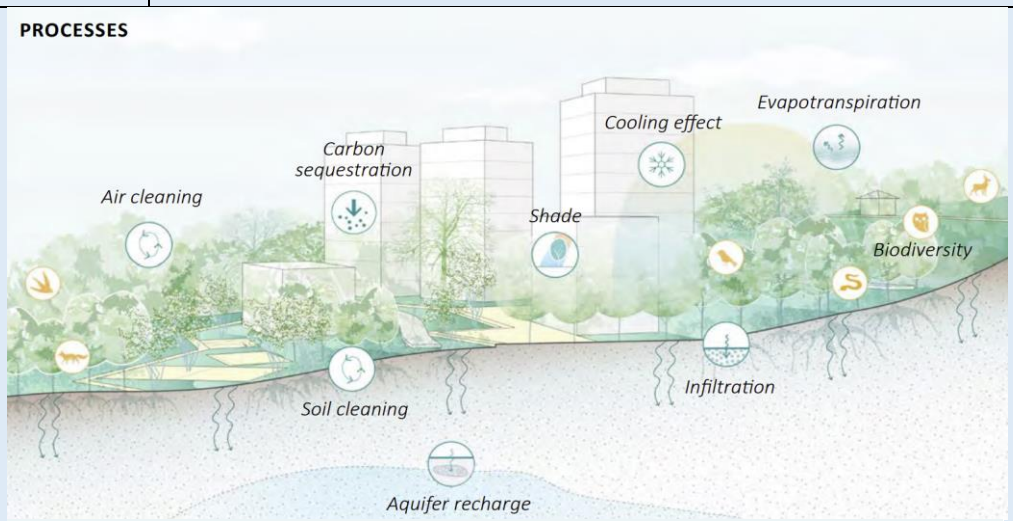
Planning and designing such ponds via a network approach can enhance water retention benefits, resulting in a viable irrigation solution for water scarcity expected in the dry season.

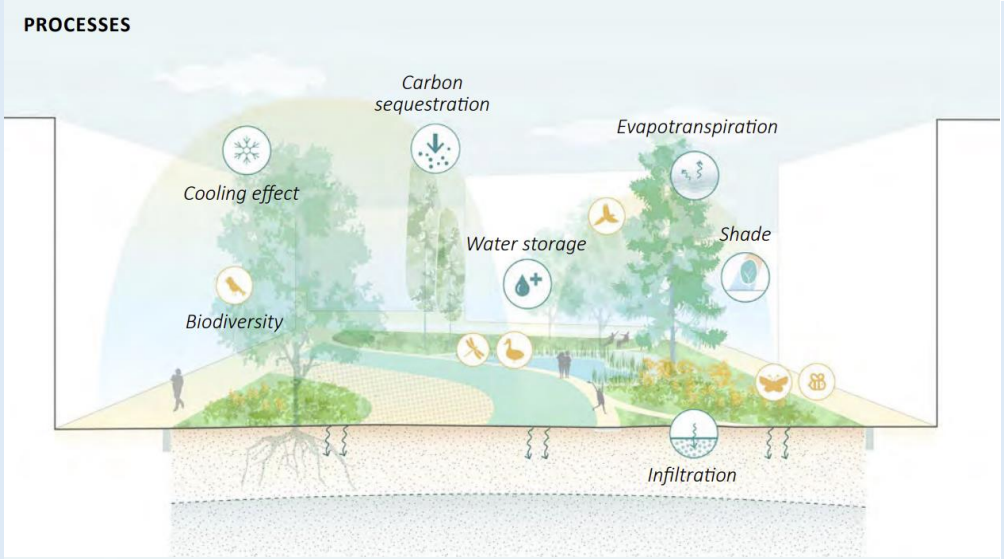
Sustainable ponds include
- Natural bank protection (Measure 12) to avoid sedimentation,
- Natural buffer (Measure 1 and Measure 15) to create shade and reduce sediment entry</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Measure 1: Riparian buffer, measure 3: water management, measure 12 natural bank protection, measure 15: agricultural field buffer</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High – can be applied in almost any soils or topography.
Planting pits are most suitable on soil with low permeability, such as silt and clay.
Bioretention areas should only be used on small sites (i.e., five acres or less) as larger ponds tend to clog</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td>on-site</td><td colspan="2">upstream</td><td>downstream</td></tr>
<tr><td>Stormwater control
Retention or detention of runoff water and enhanced infiltration
Reduced erosion
Trapping and removal of suspended solids
Filter or absorb pollutants to soil and plant material</td><td colspan="2">None</td><td>Stormwater control
Reduction in sedimentation
Water quality improvements</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and municipal government, private sector, land owners, farmers, local unions/groups, engineers and local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Land survey
Installation of irrigation ponds
Landscaping and planting
Surveying, sediment grain size distribution, design floods, design water levels, soil reconnaissance</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Design of measures in collaboration with hydrologists, engineers, agricultural specialists and ecologists/biologists
Digging of ditch or depression
Placing of the structures
Compact immediate surrounding</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">Regular inspection (cyclically and after significant rainfall/flood events)
Bathymetric study to calculate the volume of water within pond
Regular sediment removal
Replanting
Pest removal</td></tr>
</table>

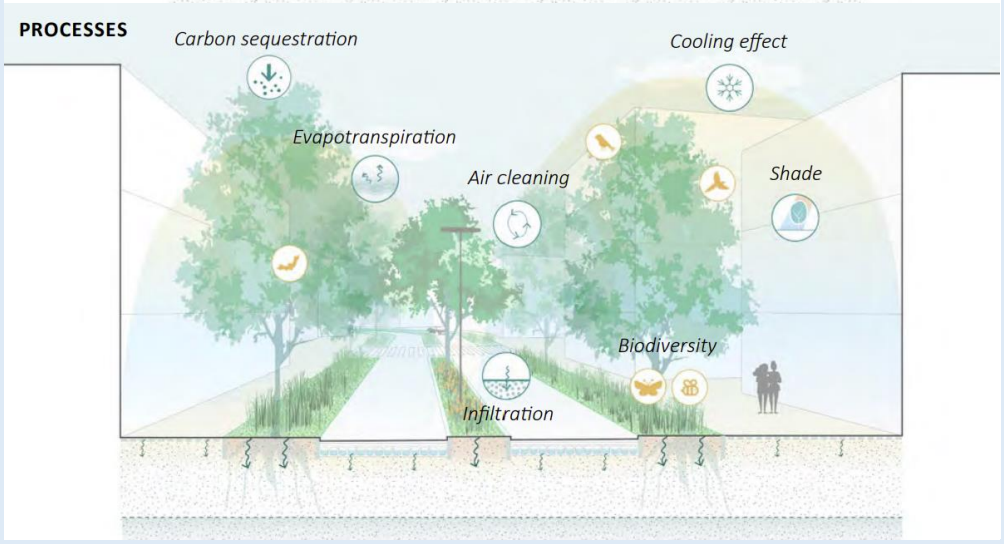
Measure 14: Urban Greening

ID	14	**Measure**	URBAN GREENING
Location		Urban areas, peri-urban areas	
Illustration		 Source: Jian Vun/World Bank  Source: Natural walking cities	

ID	14	Measure	URBAN GREENING







World Bank, 2022

Measures	*Green spaces*

<table>
<tr><td>ID</td><td>14</td><td>Measure</td><td colspan="3">URBAN GREENING</td></tr>
<tr><td colspan="2"></td><td colspan="4">Urban green spaces can be protected, restored, constructed and maintained in strategic locations, through a range of interventions implemented at different scales in both public and private spaces. Examples include parks, gardens, play areas, landscaped areas and trees.

Open spaces such as parks and greenways can be intentionally constructed or protected in strategic locations to capture and store runoff from upstream basins and adjacent areas, offer recreational, wildlife and cultural spaces for urban communities and provide areas for cooling.

They must be designed with clear objectives and encourage collective ownership and stewardship. The cost of open spaces is highly variable and largely dependent on land prices.

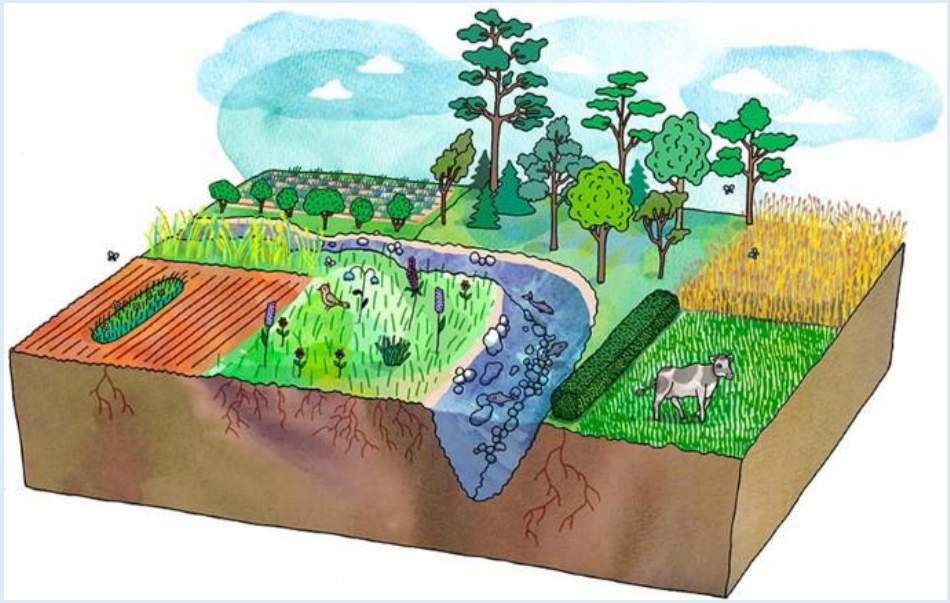
The surface of the green infiltration areas should be vegetated and protected with rubble or stones at the edges in a surrounding with traffic and pedestrians. Ideally, the inflow should come from clean surfaces to avoid clogging and sedimentation problems.

Green corridors

Highly fragmented urban landscapes, with large distances between green spaces and insufficient or absent corridors, reduce the potential to mitigate flood risk, via enhanced interception and infiltration.

Green corridors, also known as linear natural infrastructure, can include riparian corridors, green streets and gardens. These strips and buffers of trees, plants, shrubs or grass areas can be found at a range of scales, and typically connect green spaces in an urban landscape, creating an urban green infrastructure network. Green corridors complement green spaces and protect natural habitat.</td></tr>
<tr><td colspan="2">Complementary measures</td><td colspan="4">Measure 7: Retention and infiltration of rooftop and rainwater runoff, Measure 8: Permeable surfaces and Measure 9: Retention and infiltration of surface runoff</td></tr>
<tr><td colspan="2">Replicability</td><td colspan="4">High – can be applied in almost any soils or topography.
New green spaces may require changes in land use and impact on land price and rent levels.</td></tr>
<tr><td colspan="2" rowspan="2">Effects</td><td colspan="2">on-site</td><td>upstream</td><td>downstream</td></tr>
<tr><td colspan="2">Rainwater infiltration and reduce runoff
Habitats, ecological networks, supporting biodiversity
Aesthetic appeal
Physical and mental health benefits in urban populations
Canopy cover and number/size of green spaces can support in mitigating the urban heat island effect</td><td>None</td><td>Less and cleaner surface runoff
Deceased flood peak</td></tr>
<tr><td colspan="2">Stakeholders</td><td colspan="4">Provincial and municipal government, architects, private sector, land owners, local communities</td></tr>
<tr><td colspan="2">Structural work / Requirements</td><td colspan="4">Survey generating DEM
Development of soil maps (soil sampling, assessment of the vertical permeability)
Isolines of groundwater table
Plant selection and nursery management for native species
Identify restrictions (car park, zoning, drainage projects, diversions)
Land compensation measures if land is privately-owned</td></tr>
<tr><td colspan="2" rowspan="2">Work plan and cost estimate</td><td colspan="4">Preliminary work plan</td></tr>
<tr><td colspan="4">Design of measures in collaboration with landscape architects, hydrologists, engineers, urban planners and ecologists/biologists
Site selection and demarcation
Landscape design and planning (including plant selection)
Designing of the measure based on design storm events and connected surface area
Construction during dry season</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="4">The cost of maintenance can vary widely depending on the location, type, condition and composition of urban greening. For up to five years after establishment, seedlings may require watering or irrigation and need protection from weeds competing for nutrients, light and moisture, and from grazing wild and domestic animals
Pruning and cutting may also be required.</td></tr>
</table>

Measure 15: Agriculture field buffer

ID	15	**Measure**	AGRICULTURAL FIELD BUFFER
Location		Field margins, arable land, pastures, transport infrastructure and water courses (linked to riparian buffers)	
Illustration		 ©2023 Farm Wildlife  ©Gunilla Hagström/Form Nation	
Measures		Buffer strips are areas of natural vegetation cover, including trees, shrubs and grass (or a combination of these), at field boundaries or within fields and arable land. The type, structure and success of buffer strips is characterised by site-specific conditions such as the buffer zone width, slope, vegetation density and soil characteristics. Buffer strips, such as hedgerows and wild flower strips, can provide ecosystem services such as erosion control (particularly across steep slopes), pollination, pest control and natural water retention, through water infiltration and slowing surface flow. They can also significantly reduce agricultural runoff, catching pollutants originating in crop fields. Buffer zones are important for ecological connectivity within the wider landscape, connecting and separating landscape features and linking habitats. Note riparian buffer strips along watercourses in wetlands and headwaters are considered a separate NbS solution with different applications, design, implementation and management criteria (see measure 1).	

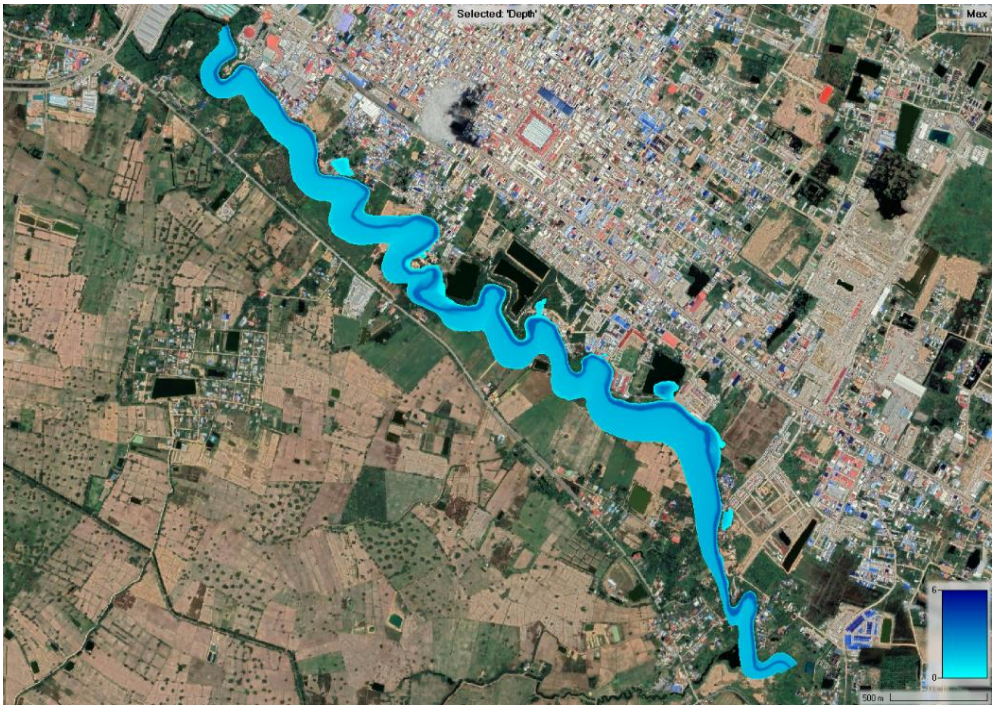
ID	15	**Measure**	AGRICULTURAL FIELD BUFFER	
Complementary measures	Measure 1 (riparian buffer), Measure 13 (sustainable irrigation)			
Replicability	High. Can be replicated on all agricultural lands			
Effects	*on-site*		*upstream*	*downstream*
	Trap and filter surface sediment, reducing erosion and sediment delivery and filtering pollutants Reduction in flood risk Provision of habitats and ecological networks connecting habitats		-	-
Stakeholders	Provincial and municipal government, architects, private sector, land owners, local communities			
Structural work / Requirements	Planting Landscaping measures (depending on topography) Selection of various native plants and trees Sizing in terms of width of the buffer zone Involvement of land owners Land compensation measures if land is in private hands			
Work plan and cost estimate	*Preliminary work plan*			
	Design of measures in collaboration with landscape architects, hydrologists, engineers, urban planners and ecologists/biologists Site selection and demarcation (and involvement of land owners) Landscape design and planning (including plant selection) Designing of the measure based on design storm events and connected surface area Construction during dry season			
Maintenance	Control and restoration of structures and plants			

ANNEX 2: RIVER CHANNEL MODELING OF PROJECT 4

Poipet and Aranyaprathet simulations

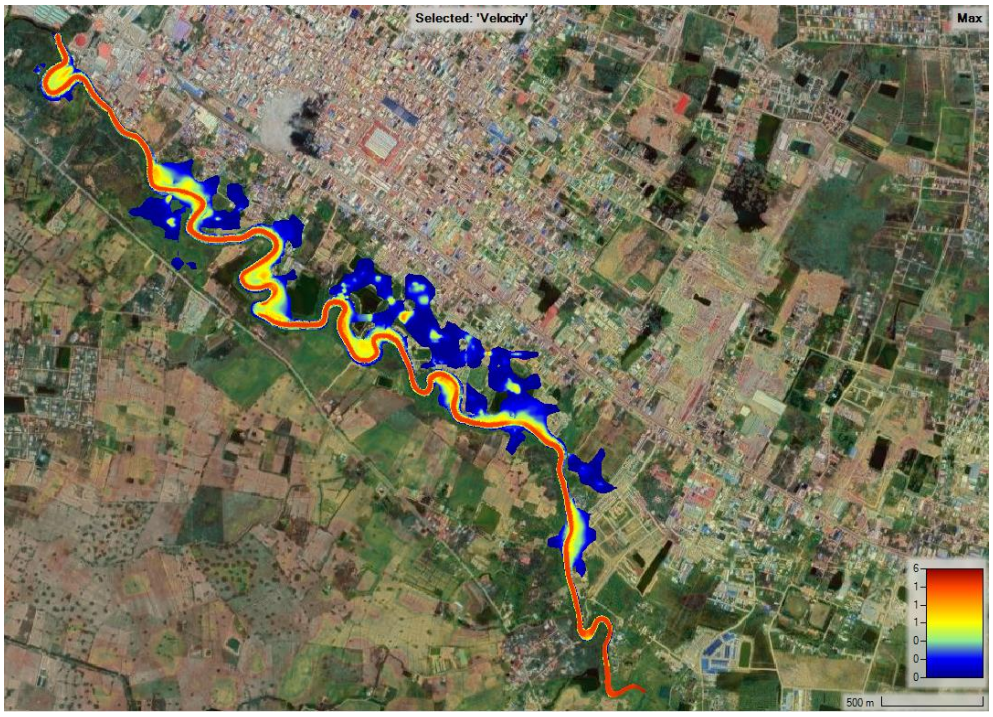
Figure 41. Model results based on the very coarse cross-section data

Inundation without measure

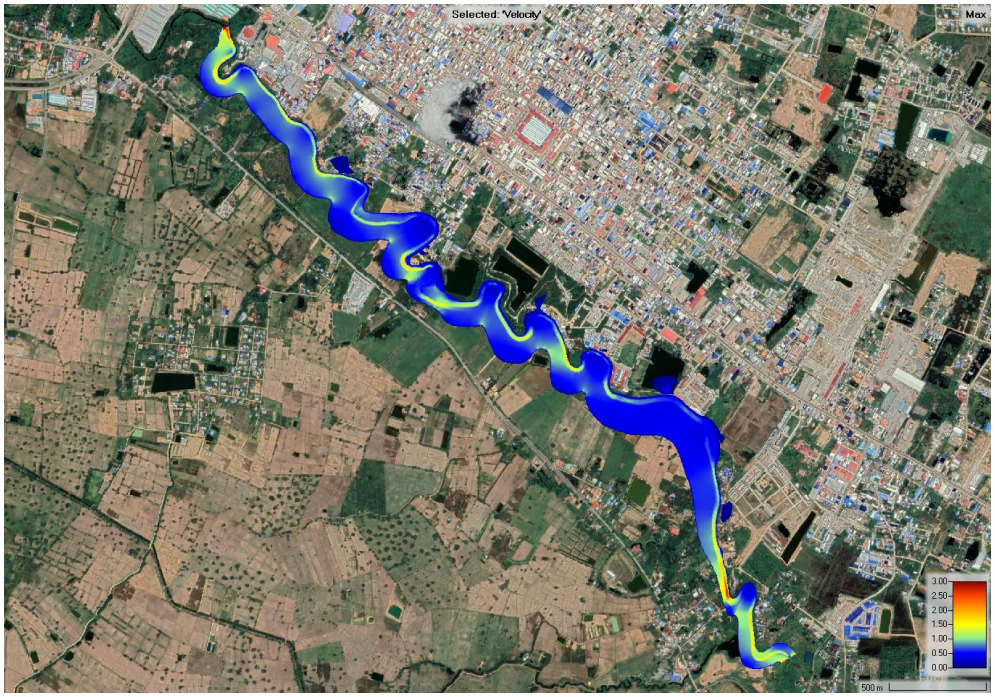


Inundation with measure

Figure 42: Location of cross-sections used in the model



Flow velocity without measure



Flow velocity with measure

Figure 43: Example of profile plots

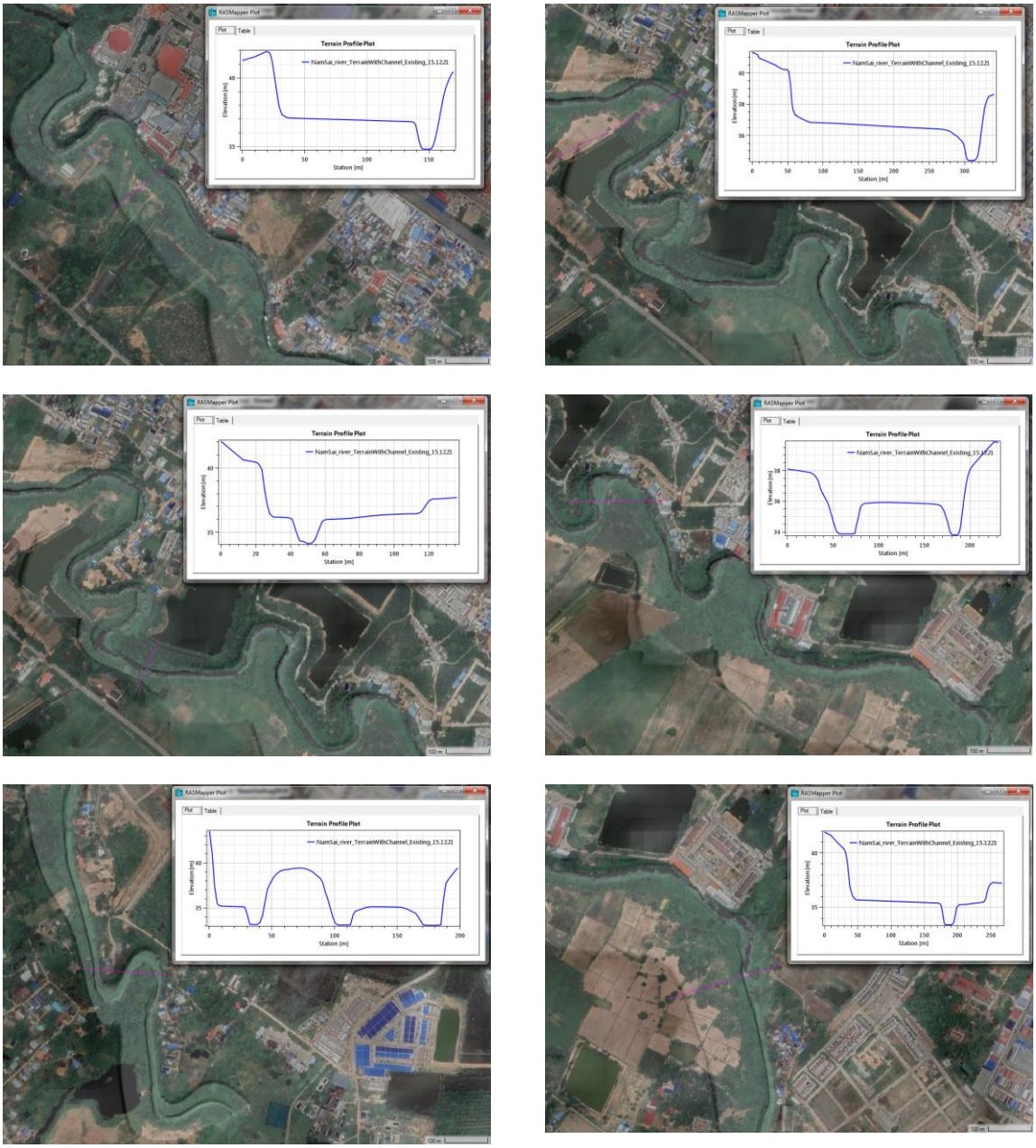


Figure 44: Model representation of different river stretches

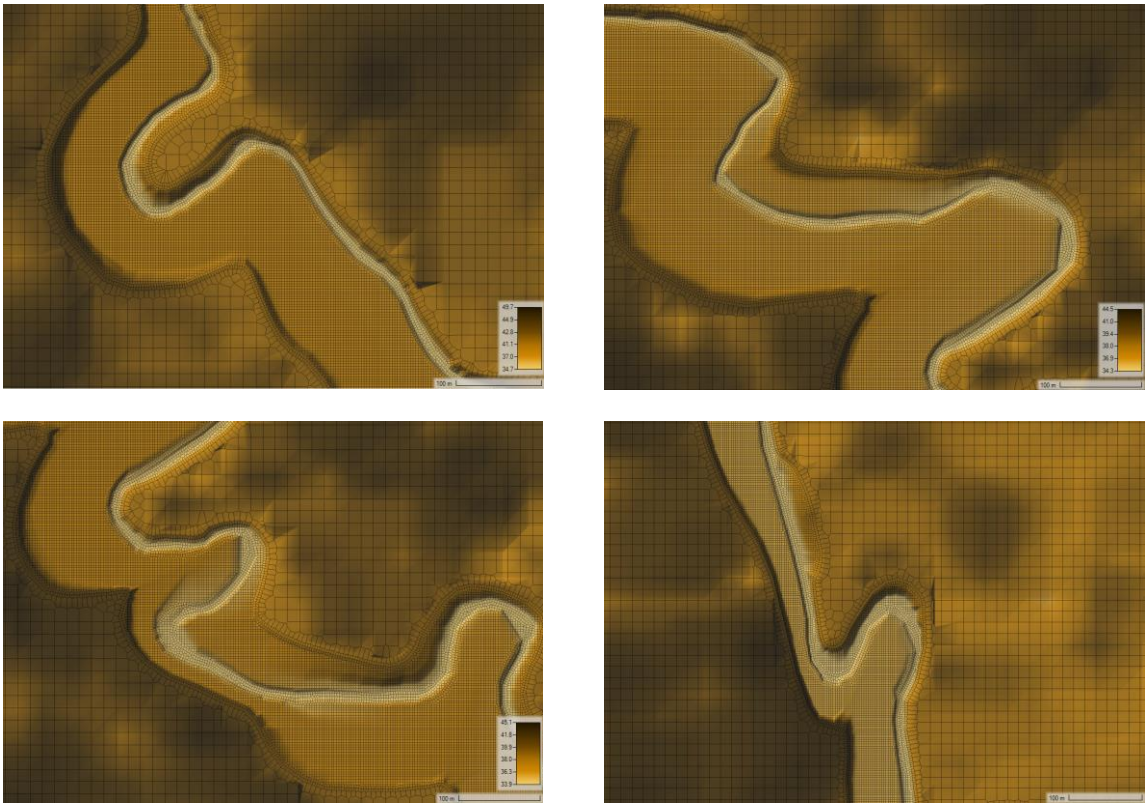
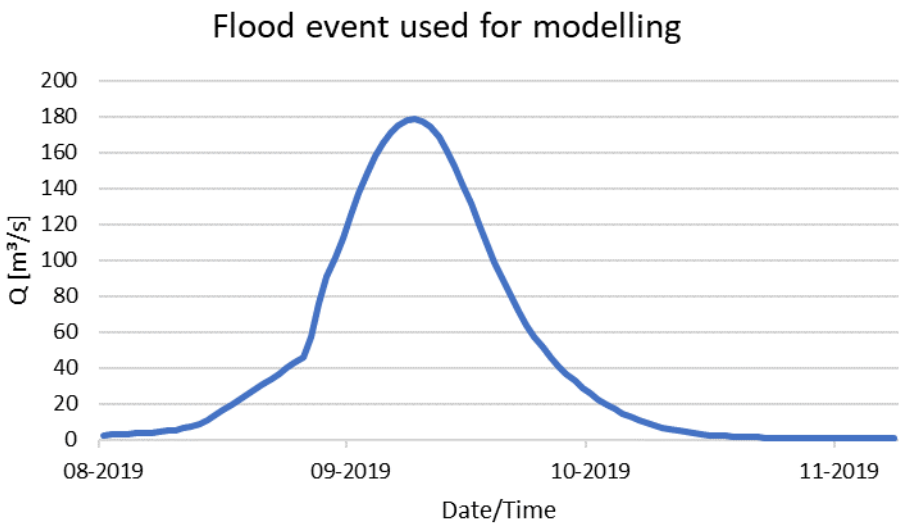


Figure 45: Input into the model



ANNEX 3: FIELD MISSION REPORTS

Correspondence:
P.O.Box 6101
184 Fa Ngoum Road Unit 18
Ban Sithane Neua
Sikhottabong District
Vientiane 01000
Lao PDR

Tel: +856 21 263 263
Fax: +856 21 263 264
www.mrcmekong.org