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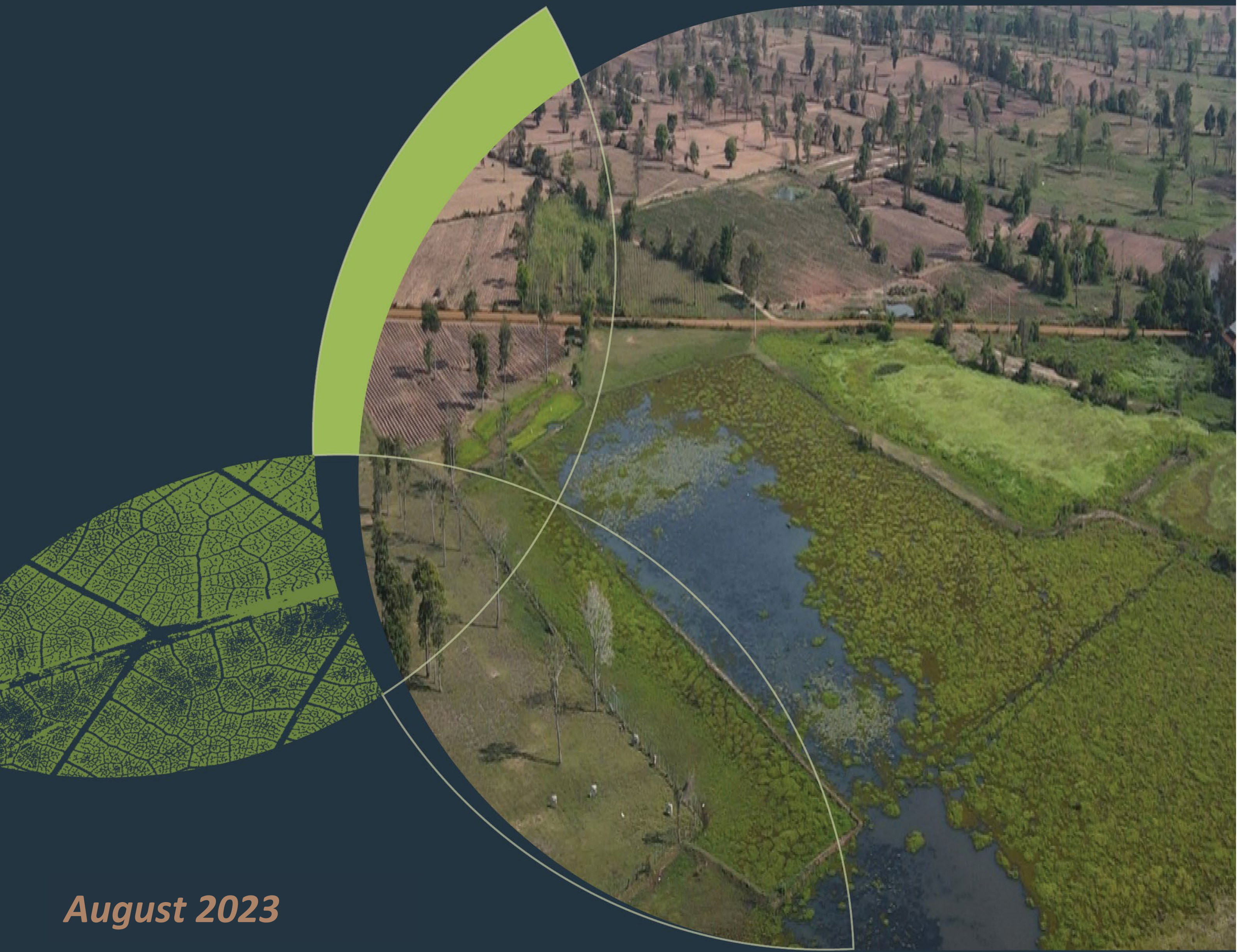
# Final Report

## Economic Analyses on Nature-based Solutions (NbS) for Flood and Drought Resilience of the 9C-9T Sub-basin

**MEKONG RIVER COMMISSION - JOINT PROJECT ON FLOOD AND DROUGHT MANAGEMENT**



***August 2023***

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| Front page photo | ICEM |

# ABBREVIATIONS

| | |
|---|---|
| ATT | Ang Trapeang Thmor |
| BAU | Business-as-usual |
| BC | Benefit cost |
| BMZ | German Ministry for Economic Cooperation and Development |
| CAPEX | Capital expenditures |
| CBA | Cost-benefit analysis |
| CNMC | Cambodia National Mekong Commission |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH |
| ELD | Economics of Land Degradation (ELD) Initiative |
| GCM | Global Circulation Model |
| GIS | Geographic Information System |
| Ha | Hectares |
| IBA | Important Bird and Biodiversity Area |
| ICF | International Crane Foundation |
| IFI | International Finance Institution |
| MCA | Multi-criteria analysis |
| MOWRAM | Ministry of Water Resources and Meteorology (Cambodia) |
| MRC | Mekong River Commission |
| MUSLE | Modified Universal Soil Loss Equation |
| NbS | Nature-based solutions |
| NGO | Non-governmental Organisation |
| NPV | Net present value |
| NTFP | Non-timber forest product |
| NWG | National Working Group |
| O&M | Operation and Maintenance |
| OPEX | Operating expenditures |
| ONWR | Office of National Water Resources (Thailand) |
| PMU | Project Management Unit |
| RCP | Representative Concentration Pathway |
| ROM | Rough Order of Magnitude |
| RSC | Regional Steering Committee |
| SEZ | Special Economic Zone |
| UN | United Nations |
| VCM | Voluntary Carbon Market |

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# 1 INTRODUCTION

## 1.1 The 9C-9T Joint Project on Flood and Drought Management

The 9C-9T is a shared sub-basin of the Mekong River basin – it is bisected by the international border between Thailand and Cambodia and encompasses what is called the Tonle Sap River basin in Thailand and the Mongkol Borey river basin in Cambodia. The river headwaters rise in the Dangrek Mountains in the north, the Sankamphaeng Mountains to the west and the north-western edge of the Cardamom Mountains to the south, the headwaters join to form the Mongkol Borey river in the flood plain near Sisophon and goes on into the great lake - Tonle Sap.

The 9C-9T river basin is highly degraded. Over the past two decades the basin has seen significant socio-economic change with increased urbanisation, agricultural expansion and intensification, and unsustainable use of forest resources. Because of these changes a significant amount of forest cover has been lost through logging and conversion to agricultural land. Large areas of agricultural land have also been converted to urban uses without adequate spatial planning or infrastructure provision. Currently, the basin faces increasing issues with watershed degradation, land degradation, erosion (and corollary sedimentation), flooding, water shortages and drought. These problems have been compounded by uncoordinated and inappropriate infrastructure development. Increasingly variable rainfall and higher temperatures due to climate change is expected to pose further challenges to water management in the basin.

In this context, in 2018, Cambodia and Thailand established a partnership for the management of the 9C-9T sub-basin of the Mekong River within the collaborative framework of the Mekong River Commission (MRC). The cooperation is facilitated by the MRC with support from Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) funded by the German Ministry for Economic Cooperation and Development (BMZ). The goal of this agreement is to improve joint planning and implementation in the sub-basin, aimed at enhancing resilience to floods and droughts. A 9C-9T Flood and Drought Master Plan has been developed and endorsed in December 2021 under this programme of cooperation, implementation of the plan started in 2022.

Nature-based Solutions (NbS) [1] for addressing the challenges posed by floods and droughts in the basin have been developed as part of the planning process. Initial conceptual designs for NbS projects in preselected demonstration sites have been designed to be implemented under the Master Plan Component 2.[2] The NbS project concepts, for which six priority demonstration landscapes within the 9C-9T have been identified, will be further developed with lead implementing agencies during Master Plan implementation from 2023. These NbS approaches will illustrate how NbS can be implemented within the national and regional context, to build skills and understanding around NbS and to demonstrate their efficacy in addressing the challenges of floods and droughts in the river basin.

In addition to the development of a network of NbS demonstration projects, an assessment of the economic performance of these NbS and hybrid measures has been commissioned to demonstrate the economic case for investment in NbS approaches. The economic analyses will be developed in cooperation with the Economics of Land Degradation (ELD) Initiative[3], which Secretariat is hosted by GIZ.

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[1] Nature-based solutions use nature and the power of healthy ecosystems to protect people, optimise infrastructure and safeguard resources and biodiversity. 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.

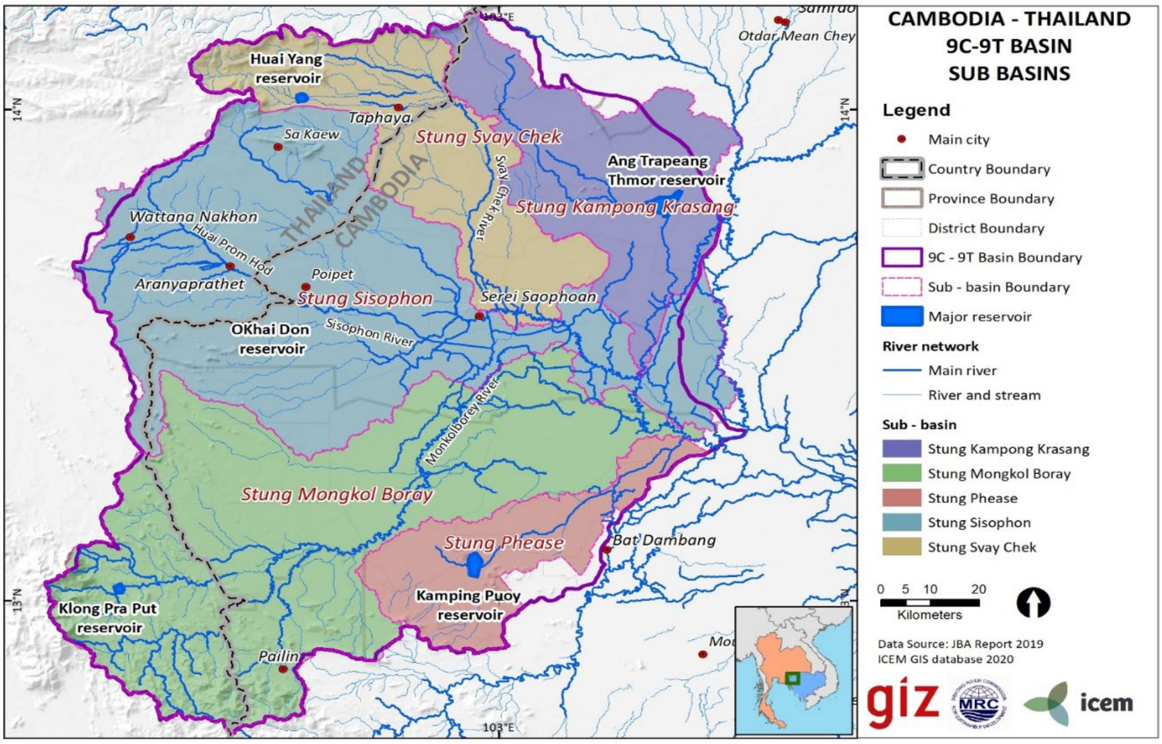
[2] See MRC. 2023. *Initial Project Concepts: A Network of Nature based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan*. Mekong River Commission – 9C-9T Joint Project on Flood and Drought Management. Vientiane, Lao PDR

[3] A global initiative established in 2011 by the United Nations Convention to Combat Desertification (UNCCD), the German Federal Ministry for Economic Cooperation and Development (BMZ), and the European Commission.

## 1.2 9C-9T sub-basin – location, context and main geographical characteristics

The 9C-9T sub-basin river network flows through Cambodia and Thailand, covering an area of 14,952 km$^2$. Most of the basin lies in Cambodia, where it is known as the Stung Mongkol Borey basin, covering 10,866 km$^2$, or 72.7% of the total area. The remaining 27.3% of the sub-basin lies in Thailand, where it is referred to as the Tonle Sap basin (Figure 1), and includes the headwaters of the basin, which is also the location of several National Parks and other protected areas.[4]

**Figure 1. 9C-9T boundary and sub-basin**




The 9C-9T sub-basin is of significant ecological importance to the Lower Mekong Basin, with its forests, wetlands, and rivers supporting important ecosystem services and aquatic biodiversity, particularly in the Tonle Sap Lake. Protected areas at higher elevations in the Cambodian area include the Samlaut Multiple Use Area, and the Ang Trapeng Thmor and Banteay Chhmar protected landscapes. Ang Trapeng Thmor in particular is an important site for the endangered Eastern Sarus Crane, being designated as a Sarus Crane Conservation Area and an Important Bird and Biodiversity Area (IBA).[5]

Despite its ecological importance, the 9C-9T sub-basin has experienced significant land use alteration and degradation in the past 30 years, resulting in the loss of forests and wetlands. Agricultural crops, particularly rice, dominate land use throughout the sub-basin, with the largest rice-growing region surrounding Battambang in Cambodia. Agriculture is also a major consumer of water in the basin and is vulnerable to drought. Flooding is also an increasing problem particularly in the larger urban areas.

Water quality in the 9C-9T sub-basin is variable, due to uncontrolled development and pollution in urban areas, the use of agricultural chemicals, loss of vegetative cover, and inadequate infrastructure for wastewater and waste management. Floods can act to spread contaminated waters into agricultural areas, during droughts, pollution becomes concentrated in creeks, rivers, and reservoirs. Despite these challenges, the 9C-9T sub-basin remains a critical part of the ecological and socioeconomic fabric of the region, requiring careful management to ensure its continued health and sustainability.

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[4] MRC. 2023. *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 – 9C-9T Joint Project on Flood and Drought Management. Vientiane, Lao PDR

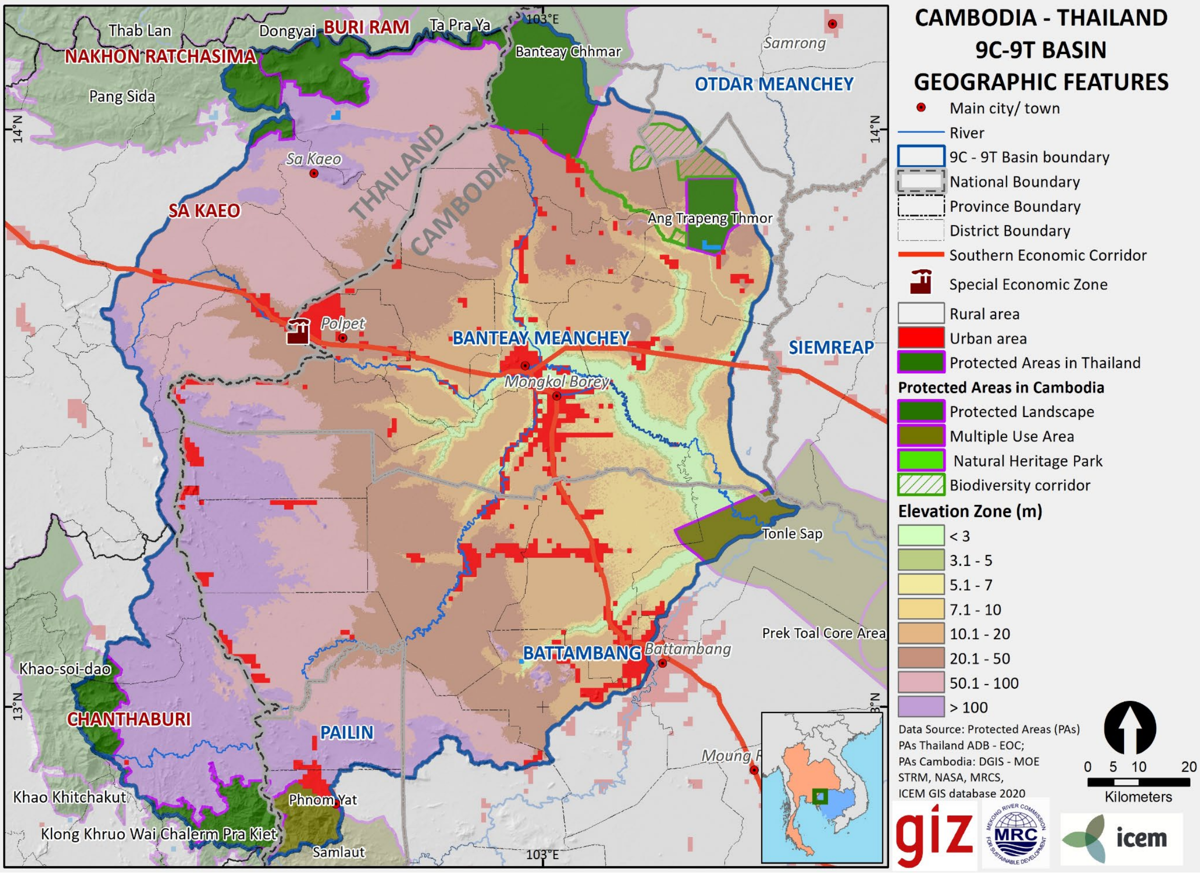
[5] Ibid.

## 1.3 Socio-economic context of the 9C-9T

The 9C-9T river basin is a transboundary basin most of the basin is within Cambodian territory, but roughly a quarter of the upper reaches of the basin is in eastern Thailand. The basin covers areas in Oddar Meanchey, Banteay Meanchey, Battambang and Pailin provinces in Cambodia, and Buriran, Sa Kaew and Chanthaburi provinces in Thailand. This includes several large population centres, notably the large and rapidly growing border towns of Aranyaprathet in Thailand and across the border in Cambodia, Poipet.[6]

Rapid socio-economic change in the basin in Thailand, but particularly the Cambodian administered portion of the sub-basin, has seen an increase in urbanisation, off-farm employment and increased population density in and around urban areas in the basin. This has been particularly marked in the two Special Economic Zones (SEZs) located at the Cambodia-Thai border (adjacent to Cambodia's Poipet and Thailand's Aranyaprathet) (Figure 2). The border between these two zones is the busiest crossing between Cambodia and Thailand, connecting the cities of Siem Reap and Battambang with Bangkok. The highway from Siem Reap is part of the Greater Mekong Subregion Southern Economic Corridor which meets the major highway from Battambang at the urban centre of Sisophon. Poipet and Aranyaprathet SEZs are fast-expanding areas for development and major hubs within their provinces. Population densification over the last decade is particularly marked in a corridor around highway 5, which links the town of Poipet on the border with the city of Battambang, with considerable ribbon development along the road.[7]

**Figure 2. Geographic and socio-economic features in the 9C-9T[8]**




6 Ibid.
7 NIS, 2022, General Population Census of Cambodia 2019 Series. Thematic Report on Population Distribution and Urbanization. Phnom Penh.
8 Ibid.

In rural areas agricultural employment remains the predominant source of household income, with most residents within the 9C-9T sub-basin engaged in livelihoods linked to agricultural production. In Cambodia, Battambang and Banteay Meanchey provinces are among the top agricultural producers of rice, and Battambang is the leading province for maize and cassava production. Tourism including the attraction of natural areas, natural parks and cultural heritage sites is another important foundation of the economy in both countries.

Despite rapid economic development, poverty rates within the 9C-9T sub-basin are still relatively high. Mapping of commune poverty rates[9] in the Cambodia section of the basin from 2015 shows relatively high poverty rates in excess of 15% for all communes with the exceptions of Battambang and Serei Sisophon. Thailand had a national reported poverty rate of approximately 9% in 2017 but provincial-level mapping indicates that Sa Kaeo and Chanthaburi provinces have higher poverty rates than surrounding provinces, at 15-20% of households.

## 1.4 Key environmental challenges in the 9C-9T basin

Development in the basin has been pursued without coordinated and integrated approach to spatial planning, and without important investment safeguards such as transboundary impact assessment. Infrastructure development, urbanization, and agriculture expansion have taken place without adequate consideration of the broader impacts on ecological sustainability and ecosystem services. As a result, many of these services have been compromised or lost, exasperating issues of flood and drought, poor water quality, erosion and soil loss and loss of biodiversity.

Hard infrastructure development throughout the basin has occurred in a largely uncoordinated manner, with projects moving forward on an ad hoc basis promoted by single agencies and without transboundary and catchment wide cumulative assessment and planning. This siloed approach to development has fragmented the hydrological connectivity of the watershed leading to unexpected and unplanned impacts – and the steady degradation of the basin creating and exacerbating flood and droughts. There is limited investment in watershed restoration, with most going to reservoirs, dams, irrigation, and transport infrastructure, which are in turn increasingly impacted by the effects of environmental degradation, through increased erosion, sedimentation, and more frequent flooding.

Land use alteration and degradation of ecosystems has occurred throughout the 9C-9T with significant loss of forests and wetlands in the past 30 years. Degradation of land and waterways has reduced natural infiltration and storage capabilities of the watershed, increased runoff and hastened erosion and sedimentation. This process degrades water quality, reduces upstream water security, and increases downstream flood risk. In many areas, water abstraction for irrigation has resulted in natural catchments being greatly reduced, with streams disappearing.

In the 9C-9T basin, climate change is projected to change precipitation and temperature patterns and to increase the intensity of flood and drought events, hastening deterioration of land and natural resources under current management practices.

## 1.5 Nature-based solutions for flood and drought management

The 9C-9T basin needs to be rehabilitated. 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 conventional infrastructure solutions such as reservoirs, irrigation systems, dams and transport infrastructure, which in turn suffer from increasing catchment erosion, sedimentation and flood damage.

NbS use a set of structural and non-structural interventions that protect, manage, restore, or create natural features, so by providing equivalent services to those offered by conventional measures. In addition, NbS typically supply a range of additional services that are difficult or impossible to supply

[9] Based upon local poverty rates obtained from provincial authorities.

though conventional means (such as carbon sequestration, erosion control, biodiversity improvement etc.). To provide these services, NbS based measures to build on, restore and extend the fragments or corridors and networks of natural systems that remain in a landscape.

Approaches for building resilience against floods and droughts that are based on services nature can provide have not yet been systematically applied in Cambodia or Thailand. The 9C-9T NbS approach is to concentrate on piloting and testing networks of small to medium scale NbS measures in degraded landscapes with at risk infrastructure, rather than implementing large scale schemes. NbS interventions seek to enhance and reinforce existing ecosystem services and hybrid infrastructure in the catchments. NbS interventions are cumulative and long-term, promoting the development of an expanding catchment-wide system of measures.

## 1.6 Study rationale and objectives

One of the key barriers to scaling investment in NbS for climate resilience is the limited understanding of their benefits at project level. A better understanding of the costs and benefits of NbS may enable further uptake by articulating their value to beneficiaries across multiple sectors and, thereby, help to mobilize additional funding and financing opportunities. The economic analysis conducted in this study aims to evaluate the performance of proposed NbS for the 9C-9T sub-basin in Cambodia and Thailand. In particular, the study aims to achieve to following objectives:

- Provide an initial understanding of the expected economic value of the benefits provided by NbS to address floods and droughts in general;
- Provide a rough order of magnitude (ROM) estimate of the economic value of the proposed NbS measures in the three landscapes; and
- Introduce tools and methodologies for the economic evaluation of NbS.

The analysis also partially fulfils the 9C-9T Masterplan's output 1.3.1 "*to conduct economic valuation of ecosystem services to assess benefits of climate-sensitive, gender-sensitive, ecosystem-based adaptation for flood and drought resilience measures*".

As noted above, six landscapes have already been identified in the 9C-9T masterplan for the priority development of NbS measures. Of these, three landscapes were selected for economic evaluation, two rural landscapes – Ang Trapeang Thmor (ATT), Cambodia and Sompoi Reservoir, Thailand – and a transboundary urban landscape – comprising Poipet, Cambodia and Aranyaprathet, Thailand.

## 1.7 Report structure

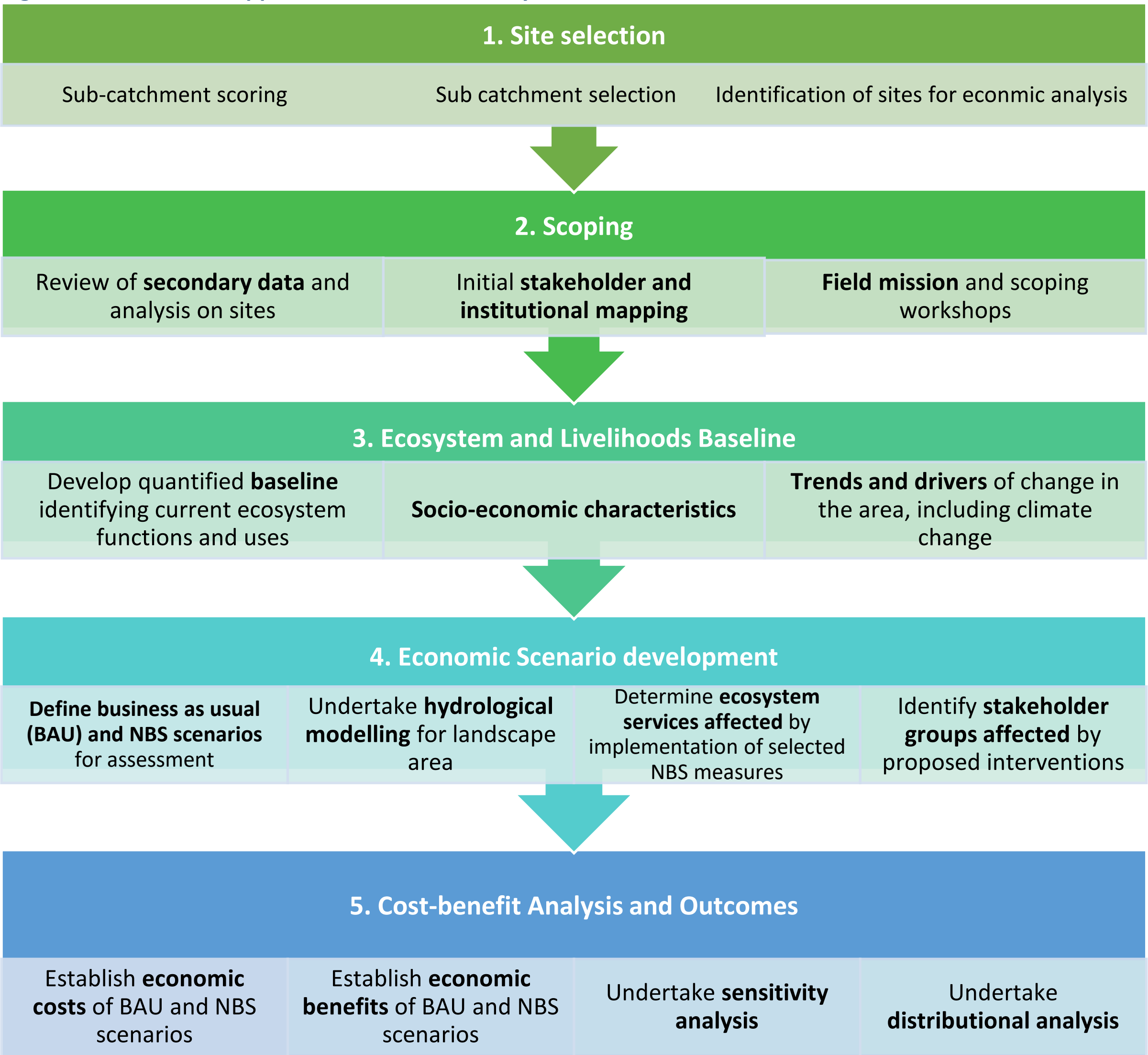
Section 2 of this report gives a brief description of the methodology used in the economic valuation of NbS measures in the four landscapes. Section 3 considered the NbS interventions in the two rural landscapes of ATT and Sompoi and their economic performance. Section 4 looks at the Poipet and Aranyaprathet and the economic evaluation of NbS measures designed for these landscapes, and section 5 of this report offers some conclusions and recommendations.

# 2 APPROACH AND METHODOLOGY

## 2.1 Introduction

The basic steps in the approach to the economic evaluation are given in Figure 3.[10] The activities conducted at each of these steps and methodology used is explained below.

**Figure 3. Overview of approach to economic analysis**[11]

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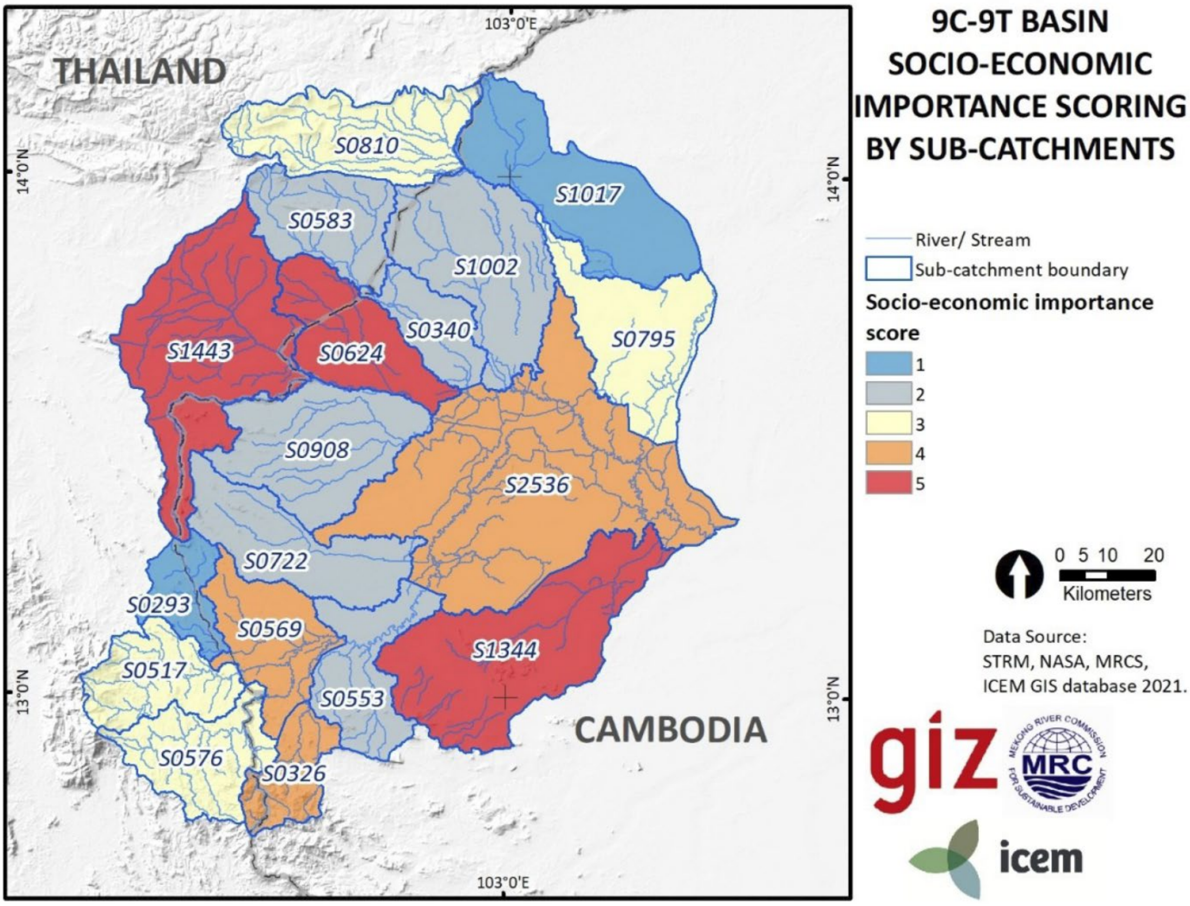
[10] It should be noted that the context for the study differed from a typical ELD study in that 1. All three landscapes in question are already highly degraded and the focus was on the restoration of ecosystem function, and associated services, through NBS measures, rather than preserving existing ecosystem services; 2. The focus is on the evaluation of NBS measures rather than land degradation per se. Land degradation is an important part of the story in the rural catchments, but the focus has been on measures to address droughts and flooding in the landscapes; 3. The proposed NBS represent a more interventionist approach than are usually considered in ELD assessments, proposed interventions tend to rely less on management approaches and be more cost intensive particularly in the urban areas; 4. One of the areas considered is urban which implies more cost-intensive interventions on a much smaller spatial scale.

[11] This approach has been broadly based upon the ELD initiative's 6+1 approach to evaluating the economics of land degradation. This includes the following steps, 1. Inception (establishing scope, location, scale and strategic focus of the study); 2. Geographical Characteristics (establishment of the geographical and ecological boundaries of the area and established ecosystems/land uses); 3. Types of ecosystem services (for land cover types identified in step 2, identification and analysis of stocks and flows of ecosystem services); 4. Economic value of ecosystem services (identification of the roles of ecosystem services and their valuation); 5. Patterns and drivers of change (identification of drivers of change in the area, pressures on sustainable management of natural resources etc.); and, 6. Cost -benefit analysis and decision making (comparing the costs and benefits of a BAU scenario with an alternative scenario in which appropriate action is undertaken). A final step of the approach is the design and implementation of actions resulting from the analysis.

## 2.2 Identifying priority landscapes for a network of NbS demonstration projects

A watershed assessment was conducted as the starting point for identifying priority landscapes for watershed rehabilitation. The 9C-9T sub-basin was divided into 18 sub-catchments that were subject to assessment and ranking using remote sensing and hydrological data, supplemented by exploratory visits to the catchment locations.[12] Multi-criteria analysis (MCA) comprising five key indexes, including socio-economic importance[13], was undertaken for the 18 sub-catchments. The results of the socio-economic scoring are presented in Figure 4. Sub-catchments S1443 (Sa Kaeo province – incorporates Aranyaprathet), S0624 (Banteay Meanchey province – incorporates Poipet) and S1344 (Battambang province) were identified as areas with the highest levels of socio-economic importance.

**Figure 4. Socio-economic scoring performance by sub-catchment**




Watersheds were also ranked according to the following criteria:

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

Within the 18 sub-catchments, a network of 13 key landscapes were identified for the development of NbS (or hybrid) interventions (Figure 5).

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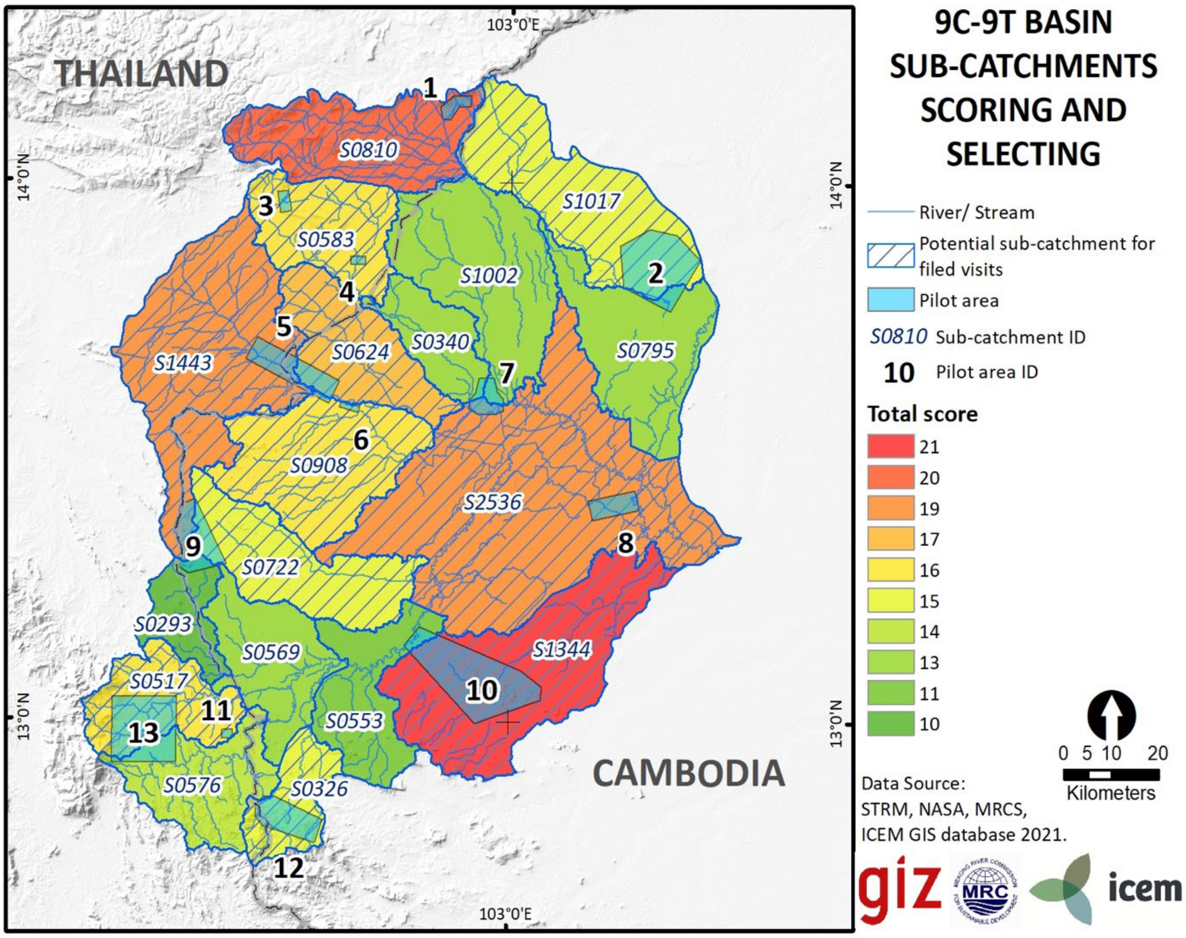
[12] Annex 2 of the 9C-9T Flood and Drought Master Plan provides details of this watershed assessment.

[13] Sub-catchments scorings for the following indexes were mapped from least (1) to most at risk (5): 1 *Drought risk*: A composite score based on sub-catchment soil and water characteristic (Total Available Water, Interception, Exfiltration, Evapotranspiration), evidence of historical drought events and trends, and projected dry season precipitation; 2 *Flood risk*: A composite score based on average flood depth, flood area, and evidence of historical flash floods; 3 *Soil erosion risk*: A composite score based on historical soil loss and local knowledge on soil erosion; 4 *Biodiversity and forest loss risk*: A composite score based on forest coverage, recent forest loss, and biodiversity importance; 5. *Socio-economic importance*: A composite score based on population density and economic importance of the area.

**Figure 5. Sub-catchments scoring and selection per sub-catchment and the 13 demonstration landscapes**




Subsequently, six of these landscapes were selected for the development of more detailed conceptual design and planning. These were selected to ensure representation of a diversity of ecosystems, infrastructure and management challenges, and a geographical balance of target areas between Cambodia and Thailand. In these six locations, fifteen different conceptual designs for NbS and hybrid interventions were developed; these are covered in detail in the report on Initial Project Concepts.[14] Preparation of the NbS project concepts has been conducted with the cross sectoral National Working Groups (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).

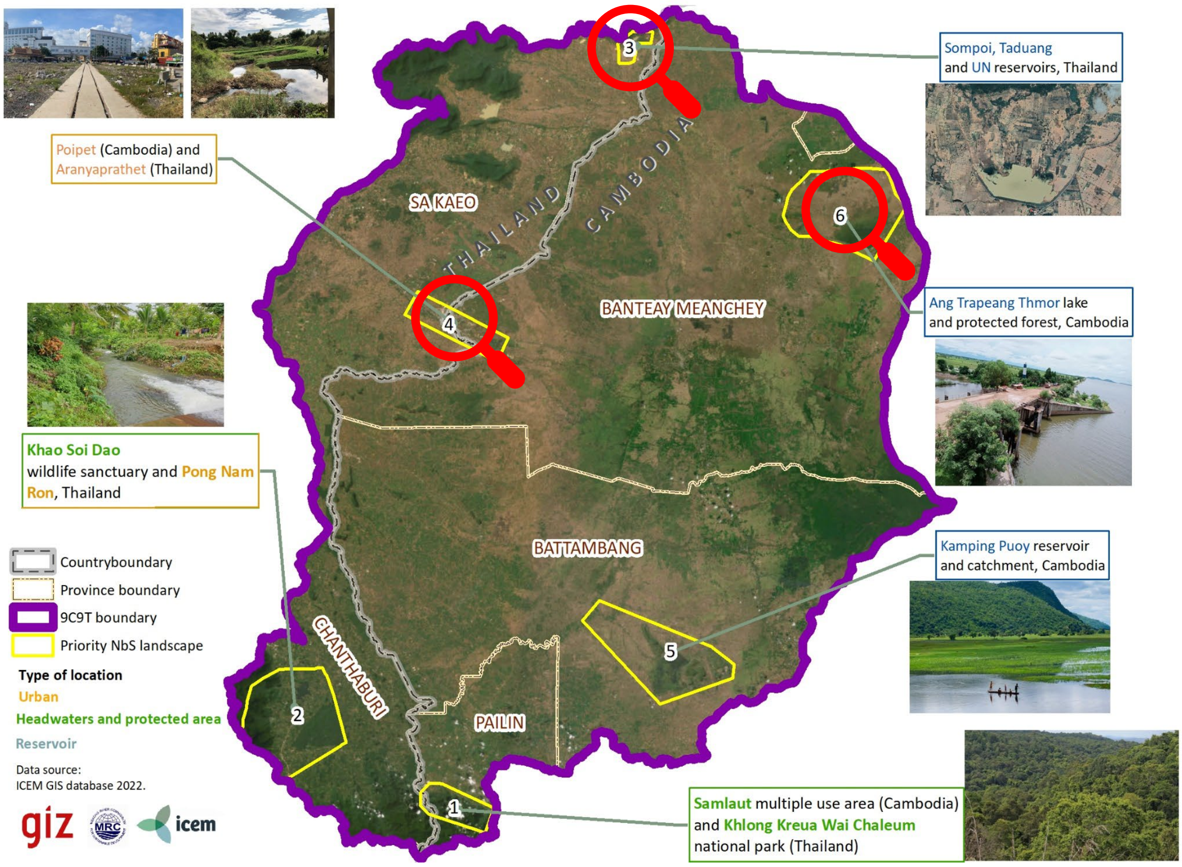
## 2.3 Selection of landscape areas for the economic analysis

Of the six demonstration landscapes, three were chosen for economic analysis (Figure 6). These were selected to provide initial high-level demonstration examples for identified NbS conceptual interventions, focusing on both (i) rural and (ii) urban landscape settings in Cambodia and Thailand. Future economic assessments under the 9C-9T Master Plan implementation will consider broader 9C-9T landscapes, including as part of detailed design of NbS interventions.

The three sites represent a broad range of challenges typical of the 9C-9T river basin. The two rural sites around the Sompoi, reservoir in Thailand and the ATT reservoir in Cambodia are typical of issues facing rural catchments in the basin including water availability, and erosion and sedimentation. The cross border urban corridor including Aranyaprathet and Poipet face issues with flooding and waste management. Section 3 describes the characteristics of these areas in greater detail.

[14] See MRC. 2023. *Initial Project Concepts: A Network of Nature based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan 2022-2026*. Mekong River Commission – 9C-9T Joint Project on Flood and Drought Management. Vientiane, Lao PDR.

**Figure 6. (i) Six priority landscapes for NbS conceptualisation and (ii) the three landscapes selected for the economic analyses**




## 2.4 Scoping

The first step of the evaluation was a scoping stage. This phase was designed to allow a better understanding of the NbS landscapes though data collection and initial field visits, and to set the scope of the evaluation. During this stage of the project, a review of secondary data on the landscapes was conducted and additional data collected from the local authorities, including consultations on key costs and benefits of the proposed NbS measures. This was facilitated by team visits to the landscapes, meetings with key stakeholders and scoping workshops held in both Poipet and Aranyaprathet.

As an outcome of this consultation exercise the spatial and functional scope of the project was defined and the inception report was drafted at the end of this step describing the proposed approach to the project in detail. Site visits were also conducted for the two rural landscapes in the initial evaluation stage of the project.

## 2.5 Ecosystems and livelihoods baseline

The next step involved the consolidation and analysis of baseline data for the catchments to better characterise ecosystems and socio-economic conditions in the three landscapes. The identification of ecosystem services, including their links to livelihoods, are presented in later sections for each landscape. Ecosystem services include provisioning, regulating, supporting and cultural services (Figure 7). Some ecosystem services involve the direct provision of material and non-material goods to people and depend on the occurrence of specific species of flora and fauna. Other ecosystem services arise directly or indirectly from the functioning of ecosystem processes. Valuing the benefits of an NbS intervention is typically linked to an ecological or physical production function. A benefit flow links the production function to risk reduction benefits and other benefits for people (Figure 8).

Key ecosystem and livelihood trends and their drivers are also identified. This understanding of the context fed into the development of the economic assessment scenarios in the next step.

**Figure 7. Services provided by ecosystems. Source: Based upon WWF 2018** [15]

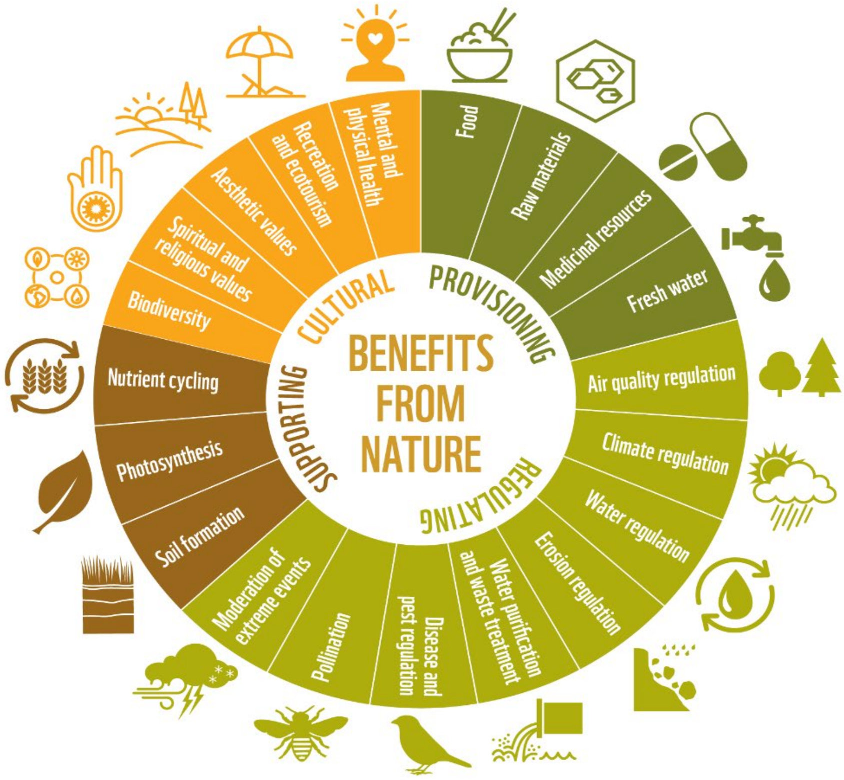
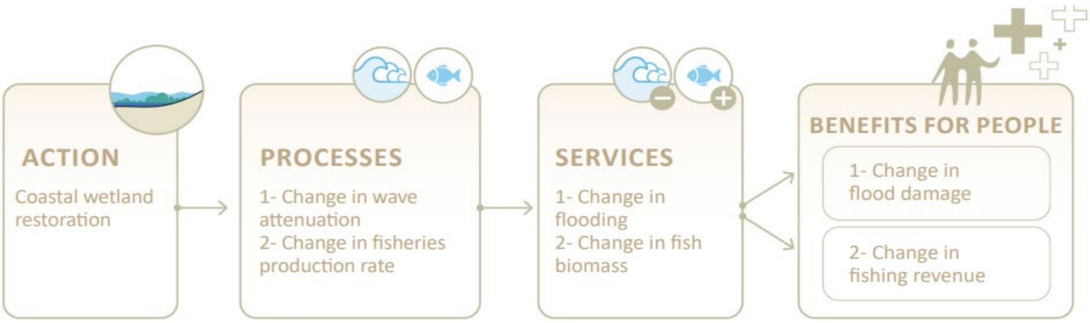



**Figure 8: Example NbS and ecosystem service benefit flow for coastal wetland restoration. Van Zanten et al. (2023)**[16]




## 2.6 Cost-benefit analysis

Cost-benefit analysis (CBA) involves calculating the costs and benefits of a project in monetary terms. Attribution of impacts to the project to be valued is typically assessed by comparing cost and benefits in scenarios with and without the project. The total economic benefit of an NbS includes both the core benefits the project is designed to address and other co-benefits, in many cases with NbS measures the combination of co-benefits are often larger than the core benefit of the project (Table 1). Table 1 also indicates is benefits are best regarded as private (with associated direct financial implications for

[15] WWF. 2018. Living Planet Report - 2018: Aiming Higher. Grooten, M. and Almond, R.E.A.(Eds). WWF, Gland, Switzerland.
[16] Van Zanten, B.T., Gutierrez Goizueta, G., Brander, L.M., Gonzalez Reguero, B., Griffin, R., Macleod, K.K., Alves Beloqui, A.I., Midgley, A., Herrera Garcia, L.D. and Jongman, B., 2023. Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers. World Bank, Washington, DC

beneficiaries) or public (with indirect and often non-financial implications or beneficiaries, or a combination of both.[17]

**Table 1. Private and public, core and co-benefits considered**

| Core benefits | Co-benefits |
|---|---|
| • Flood mitigation (fluvial) (public and private)<br>• Flood mitigation (pluvial) (public and private)<br>• Water supply/drought mitigation (private) | • Carbon sequestration (public)<br>• Fisheries production (private)<br>• Provisioning of Non-timber forest products (NTFPs) (private)<br>• Ambient air temperature reduction (public)<br>• Air purification (public) |

Costs of proposed interventions were gathered through local consultations, and the review of similar projects in the region. It should be noted that as NbS measures are often novel approaches, established costs norms were not always available leading to a higher degree of uncertainty than would typically be the case for the assessment of investments offering similar benefits.

### *2.6.1 Cost and benefit valuation methodology*

Across the life cycle and time horizon of an NbS intervention, various costs need to be considered (Figure 9). Under this study, costs of proposed interventions will focus on investment costs (CAPEX), O&M costs (OPEX) and opportunity costs.

NbS benefits were established based upon both quantified impacts modelled in the previous step, through estimates of impacts on system productivity and through transfer pricing from evaluation of similar benefit streams. Approaches to the evaluation of benefits for NbS measures depended upon the data available for the benefit in question and data available for each of the landscapes (see Figure 9). As noted above for each of the landscapes some modelling was conducted to allow the quantification of core benefit streams. As such, a slightly different approach was taken to the benefits in the different landscapes, the detailed methodology for the valuation of benefit streams is given in the sections on NbS benefits for each of the project locations.

The cost-benefit analysis was conducted over a 30-year time horizon reflecting the long-term nature of investments in NbS. A base-case discount rate of 9% was adopted in line with typical investment projects in the region.

[17] See for example Le Coent, P., Graveline, N., Altamirano, M. A., Arfaoui, N., Benitez-Avila, C., Biffin, T., ... & Piton, G. (2021). Is-it worth investing in NBS aiming at reducing water risks? Insights from the economic assessment of three European case studies. *Nature-Based Solutions*, *1*, 100002.

**Figure 9. Typical cost components used in the economic evaluation of NbS. Source: Van Zanten et al. (2023) [18]**

| CAPEX | OPEX | Transaction costs | Opportunity costs [a] | Disservices |
|---|---|---|---|---|
| - Design and planning<br>- Securing permits<br>- Land acquisition<br>- Community resettlement<br>- Site preparation<br>- Construction<br>- Tree planting | - Monitoring labor and technology<br>- Tree and vegetation maintenance<br>- Invasive species removal<br>- Land use (for example, rent or other payments to landowners)<br>- Land protection, including managing and controlling access | - Scoping studies and other technical assistance<br>- Community engagement / stakeholder outreach<br>- Goal setting and prioritization | - Value of using land for other purposes such as agriculture or residential/ commercial development<br>- Opportunity cost of local labor and materials used for implementing the NBS project | - Negative impacts from NBS (for example, mosquitoes, pests) |

Note: CAPEX = capital expenditures, OPEX = operating expenditures. [a] The opportunity cost approach avoids double counting between opportunity cost and CAPEX/OPEX cost components

### *2.6.2 Economic scenario development*

The next step included the definition of both scenarios with and without NbS interventions to inform the economic scenarios. Hence, two scenarios are presented in later sections for each landscape:

- **Business as usual (BAU) scenario** – for this study, this is represented by the baseline scenario (i.e., without the project/NbS interventions);[19] and
- **NbS scenario** – as the project is still at the conceptual stage, this has largely been based on landscape scale spatial mapping of proposed NbS interventions and discrete hydrological modelling.

The scenario development involved the identification of likely positive and negative impacts of NbS interventions, identification of the most significant impacts and identifying a means of quantifying impacts. For the four different evaluation sites considered (over three landscapes) these were as follows:

- **Ang Trapeang Thmor** – hydrological and sediment modelling using the Talsim-NG model[20] and modified universal soil loss equation and GIS analysis with and without NbS interventions;
- **Sompoi** – hydrological and sediment modelling using the Talsim-NG model and modified universal soil loss equation and GIS analysis with and without NbS interventions;
- **Poipet** – hydrological modelling using Hec-Ras model for flooding and GIS analysis with and without NbS interventions; and,

[18] Van Zanten, B.T., Gutierrez Goizueta, G., Brander, L.M., Gonzalez Reguero, B., Griffin, R., Macleod, K.K., Alves Beloqui, A.I., Midgley, A., Herrera Garcia, L.D. and Jongman, B., 2023. Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers. World Bank, Washington, DC

[19] The assessment of conventional/ grey infrastructure measures was considered as an alternative to a static BAU baseline. However, in the context of the current study it was not feasible for a number of reasons: i) In the urban landscapes, there was not the capacity to design feasible alternative grey infrastructure measures. Similarly, hard infrastructure interventions for the rural landscapes were considered (e.g. raising the height of dykes/impoundment walls) likely not to be feasible and without further technical assessment it was not possible to estimate at this stage; ii) Even if feasible conceptual designs were available, the assessment of alternative conventional infrastructure measures would have required additional modelling to assess their effectiveness which was not possible; iii) In the rural landscapes conventional alternatives were effectively considered, in that the cost of dredging was used to assess the value of the reduction of sedimentation; and , iv) Many, if not most, of the benefits of the NBS measures considered are not feasibly replicable using conventional measures.

[20] The 9C-9T Joint Project facilitated the establishment of a high-resolution hydrological model for the sub-basin – applying the Talsim-NG model, which is hosted on the MRCS server. Further information on the model and its outputs is presented in Annex 3.

- **Aranyaprathet** – run-off modelling using Talsim-NG model based upon GIS analysis with and without NbS interventions.

## 2.7 Addressing uncertainty

Investments often face significant uncertainties regarding future costs and benefits. Sensitivity analysis involves testing the robustness of the analytical results by varying the input parameters, values, and assumptions. The sensitivity analysis was applied as a stress test to verify the robustness of results that may affect NbS outcomes, assuming different scenarios of future economic development, climate change, natural hazards, or assumed discount rate.

The sensitivity analysis was conducted around key assessment parameters including investment costs, O&M costs and the value of benefit streams. This illustrates the sensitivity of the results to changes in the assessment assumptions and ensures the overall results are robust given a degree of uncertainty.

## 2.8 Distributional considerations

As costs and benefits of NbS measures are unlikely to be distributed evenly, and NbS measure are unlikely to be distributionally neutral, a qualitative distributional analysis was undertaken[21] highlighting which groups are likely to benefit from NbS measures and which groups are likely to bear most of the costs. This is particularly important in the rural contexts were NbS measures may imply significant changes to land use patterns.

## 2.9 Climate change considerations

Climate change is highly likely to pose a challenge for water management issues in the 9C-9T sub-basin, however it has not been possible to effectively model the impact of climate change on the proposed measures due to data, resource and time constraints. Climate change impacts in terms of longer periods of drought, higher temperatures and more intense rainfall are all likely to affect the catchments in question.[22] However, it is deemed that this will not alter the economic case for NbS measures, in most cases it will enhance the value of benefit streams coming from NbS and strengthen the case for NbS investments.

Up to date downscaling of Global Circulation Models (GCMs) may currently be available for the areas in question, however, understanding what this means for floods, droughts, for ambient temperatures in urban areas and production on agriculture cannot be clearly understood without more detailed catchment and sub-catchment level modelling.

In future assessments, considerations of climate change in the catchments could be more fully addressed through the provision of:

- Catchment level downscaling of GCMs for selected Representative Concentration Pathways (RCPs) for key climate parameters, such as seasonal maximum temperatures, maximum average daily precipitation etc. for selected time slices (e.g., 2050, 2100 etc.);
- Landscape/sub-catchment level hydrological modelling of flooding events of different return periods for different climate scenarios;
- Landscape/sub-catchment level hydrological modelling of water availability for different return periods for different climate scenarios; and
- Modelling of crop production under different climate scenarios (taking particular account of water availability and ambient temperatures in growing seasons).

## 2.10 Data availability and study limitations

[21] A quantified analysis was considered in the inception report but adequate information on affected groups and the likely distribution of benefits was not available to enable this analysis.

[22] See for example, MRC, 2017, Summary of the basin-wide assessments of climate change impacts on water and water related resources in the Lower Mekong Basin. Mekong River Commission Climate Change and Adaptation Initiative.

An important initial caveat to the CBA concerns the availability of data. The veracity and accuracy of a CBA relies upon the availability of adequate quantifiable data relating to the costs and benefits of the intervention in question. This poses an important limitation to this study since data availability has been constrained.

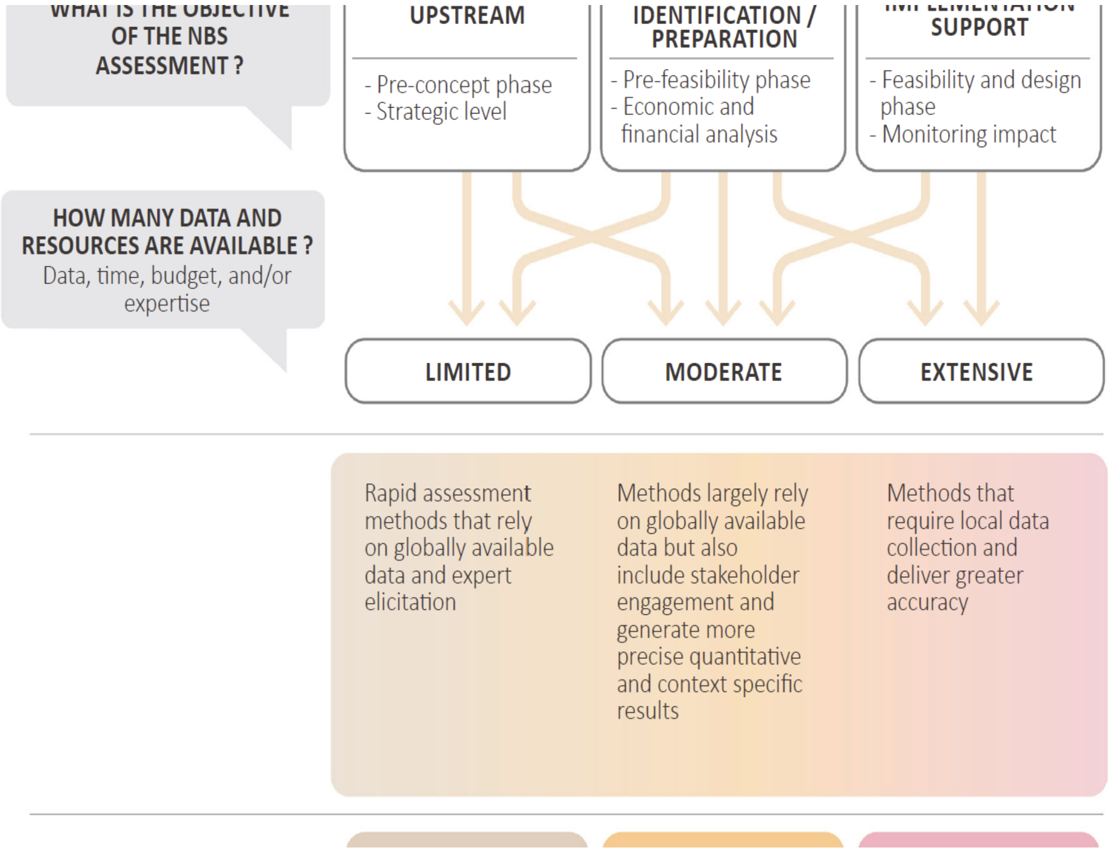
As part of this study, field missions to all three landscapes have enabled high-level primary and secondary data collection on site characteristics, capacities, trends, stakeholders and proposed interventions. However, time and resources do not allow for the collection of extensive primary data, such as through the conduct of detailed surveys and consultations. Ideally, this would be collected on the basis of a survey of a representative sample of households in each landscape. Future data collection should consider the following issues:

- The value of provisioning from natural ecosystems (capture fisheries, forest products etc.), time spent and other costs associated with fisheries and obtaining forest products;
- The economics of agricultural production in the catchments, including cropping patterns, input costs, output values;
- Household and business flood damage costs (both pluvial and fluvial), including physical damages to assets, crop losses, losses in income/disruption of daily activities, loss of life and other risks to physical health;
- Household and business damage costs relating to drought/lack of water availability in rural areas; and
- Household health costs associated with sanitary environment and ambient temperatures.

Furthermore, the NbS project concepts identified for the economic evaluation are at the conceptual design stage. Site specific locations, dimensions, and architectural and engineering designs for the proposed NbS measures are therefore not available for the economic analyses. Detailed design will be developed at a later stage under future project phases.

As such the CBA assessment, and cost and benefit estimates included in this report are best regarded as rough order of magnitude (ROM) estimates that offer an economic proof of concept, and establish the case for further more detailed investigation and design activities. Figure 10 illustrates the relationship between the decision context, level of data and resources available and the type of analysis conducted. This study lies between Tier 1 and Tier 2 on the diagram, at the conceptual design stage, but prior to pre-feasibility.

**Figure 10. The decision context, resource availability, and tiers of analysis. Source: Van Zanten et al. (2023)[23]**




[23] Van Zanten, B.T., Gutierrez Goizueta, G., Brander, L.M., Gonzalez Reguero, B., Griffin, R., Macleod, K.K., Alves Beloqui, A.I., Midgley, A., Herrera Garcia, L.D. and Jongman, B., 2023. Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers. World Bank, Washington, DC

# 3 ANG TRAPEANG THMOR LAKE AND PROTECTED LANDSCAPE, CAMBODIA

## 3.1 Overview of Ang Trapeang Thmor (ATT) landscape

ATT is a lake and protected area complex located in Cambodia's Banteay Meanchey province, approximately 60 km north of the provincial capital of Sisophon. ATT comprises 12,650 hectares, is designated as a protected landscape, as well as an important bird and Biodiversity Area, including the ATT Sarus Crane Conservation Area.[24]

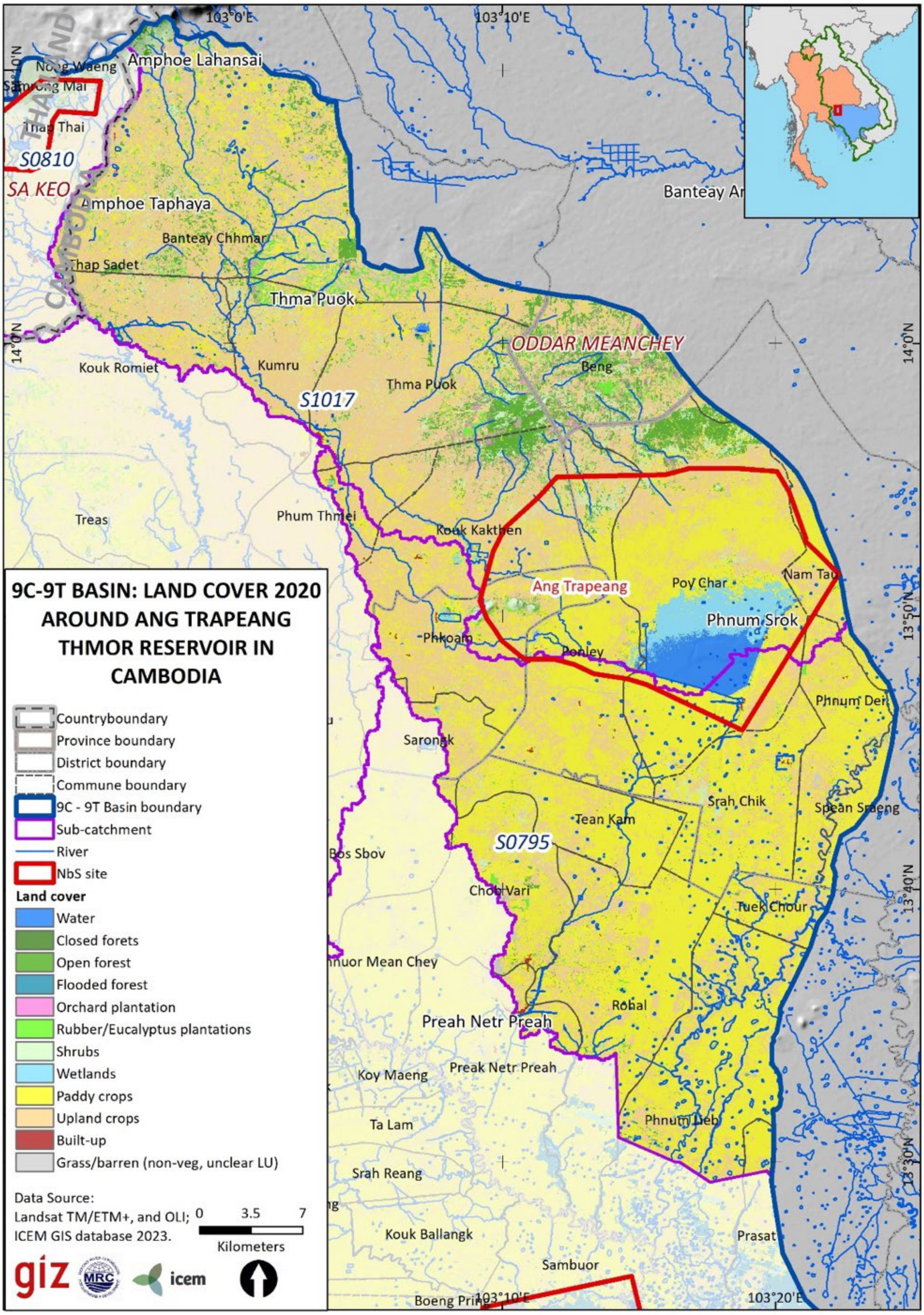
The landscape contains a large artificial reservoir, deciduous forests, natural flooded grasslands, inundated forests and rice fields (Figure 11). During the Angkorian period, from the 10th to the 13th century AD, a major causeway was constructed through the area, which led to increased water accumulation to the north, mainly of surface runoff. In 1977, an 11 km stretch of this causeway was converted into a dam and a 9 km dyke constructed perpendicular to it.

The reservoir was reconstructed in the late 1990s as part of a larger development project aimed at improving agricultural productivity in the region.[25] The reservoir has since become an important source of livelihoods for local communities, fishing, farming and some tourism activities in and around the reservoir. The reservoir reportedly supports 12,000 hectares of rice fields and provides water for over 20,000 families.[26] The coverage irrigation areas are within 5 communes (Ponley, Poy Cha, Sras Cheak, Phnom Srok district and Tean Kam and Rohal at Preah Net Preah District), according to PDoWRAM. The lake provides opportunities for a range of ecosystem services, includes non-timber forest products (NTFP), fishing grounds and wetland activities.

The area is marked by significant seasonal variations in inundated area. During the dry season, only the south-eastern corner of the reservoir remains inundated. By 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. According to the Ministry of Environment and Banteay Meanchey Provincial Department of Water Resources and Meteorology, the maximum water storage capacity is 180 million $m^3$. The minimum water depth is 0.2m in January through April, 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.

[24] The site is the single most important non-breeding season feeding area for Sarus Crane globally and supports several other globally threatened species.
[25] Cambodia Daily. 2016, February 4. Irrigation project to help more than 20,000 families. Retrieved from https://www.cambodiadaily.com/news/irrigation-project-to-help-more-than-20000-families-105013/
[26] Ibid.

**Figure 11. Ang Trapeang Thmor reservoir location and 2020 land cover**

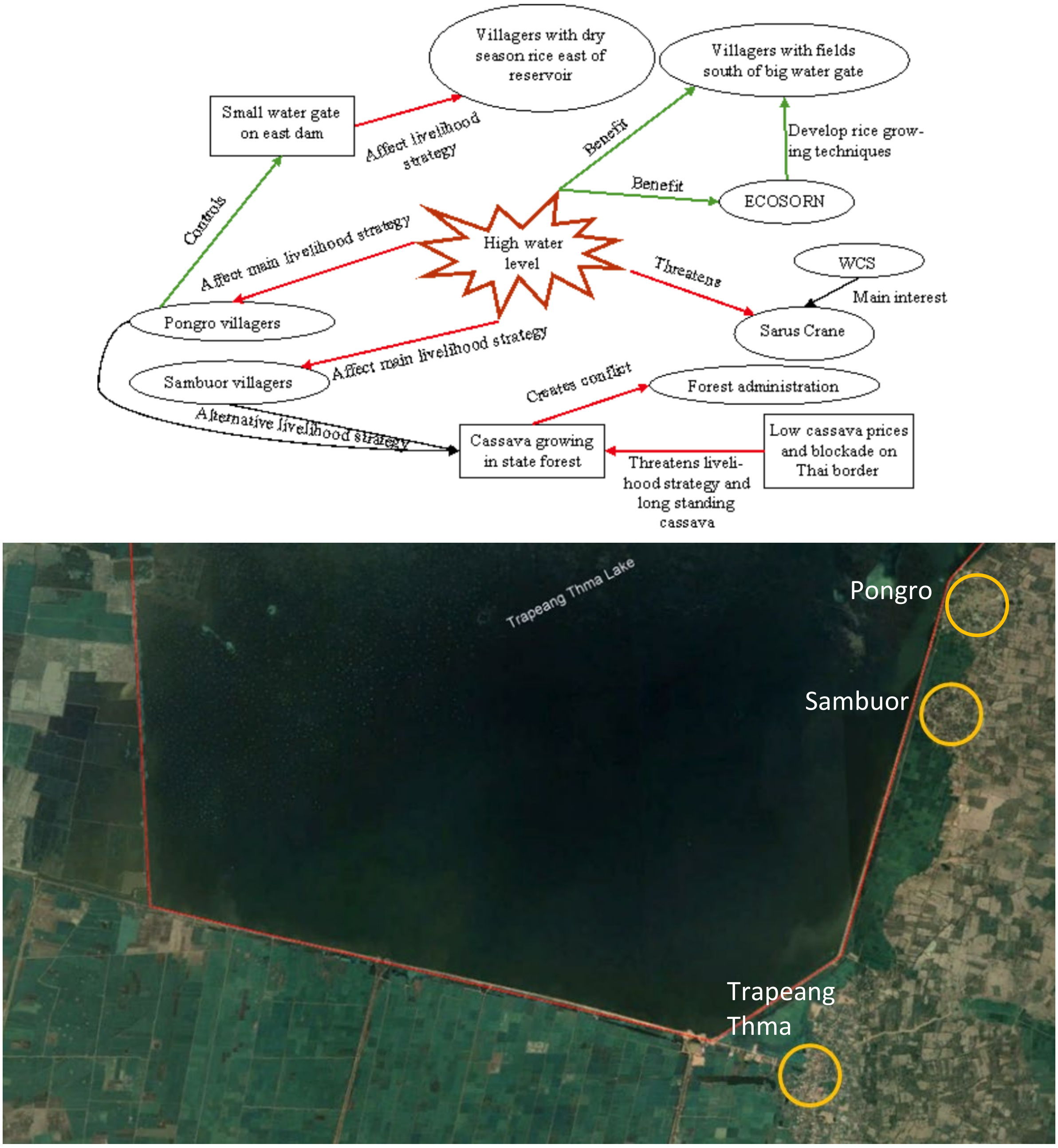


### *3.1.1 Socio economic conditions and trends*

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.

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 rely on water from the reservoir, over the control of water resources, including for irrigation purposes.

**Figure 12. (Top) historic water-related conflict at ATT; (Bottom) location of villages in ATT area**



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 protected area, leading to historic renegotiation of agricultural vs. biodiversity zones, such as between the International Crane Foundation (ICF) and Pongro and Sambuor villages in 2003.[27] 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.

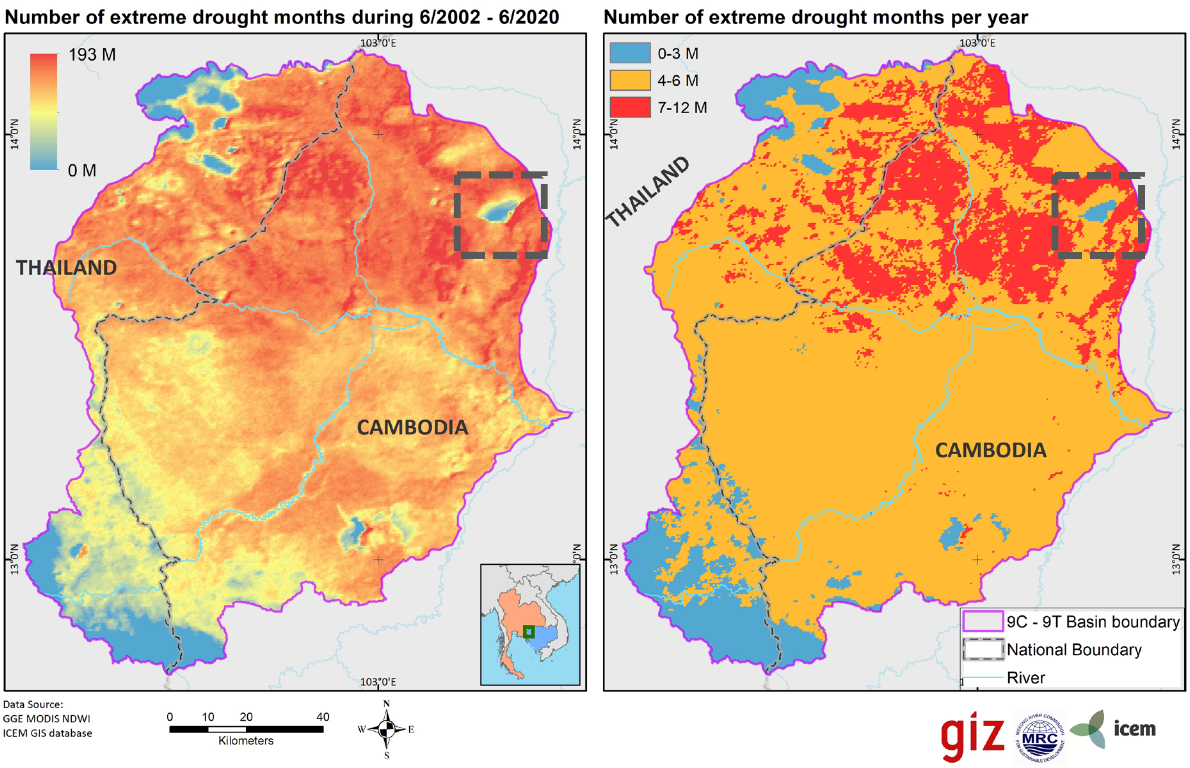
The population in Poy Char commune (that occupies the whole of the ATT landscape), increased from 11,671 people in 2016 to 12,862 people in 2021. Most of this change was accounted for through natural population growth, although 121 people moved into the commune, and a further 850 people migrated from the area, general to find work in urban centres.[28]

The main occupation in the ATT landscape is agriculture, with rice farming being the main livelihood activity. Most farmers cultivate rice twice per year, between October to January and between April to August. With the intensification of the rice system, farmers can obtain yields of up-to 5 to 6 tons per hectare. Communities in Poy Char also conduct fishing activities as the main secondary livelihood activity. At least 2,000kg of fish per household were caught and sold to the market each year, excluding home consumption. Besides agriculture and fisheries, local people also provided services such as food provision and act as tour guides for tourists.

### *3.1.2 Natural hazards*

The main natural hazard for ATT is reducing 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 13), to worsen significantly with climate change and a projected reduction in annual precipitation. The area to the east of the reservoir, covered extensively by agriculture, is one of the highest drought risk locations in the 9C-9T. This risk is exacerbated by the land use changes of recent years and the increasing sedimentation of the reservoir.

**Figure 13. 9C-9T MODIS Normalized Difference Water Index (NDWI) drought frequency months**




27 Wan, A. et al. 2009. Dammed protected areas impact on nature and local livelihoods, Ang Trapeang Thmor, Cambodia
28 Commune level data.

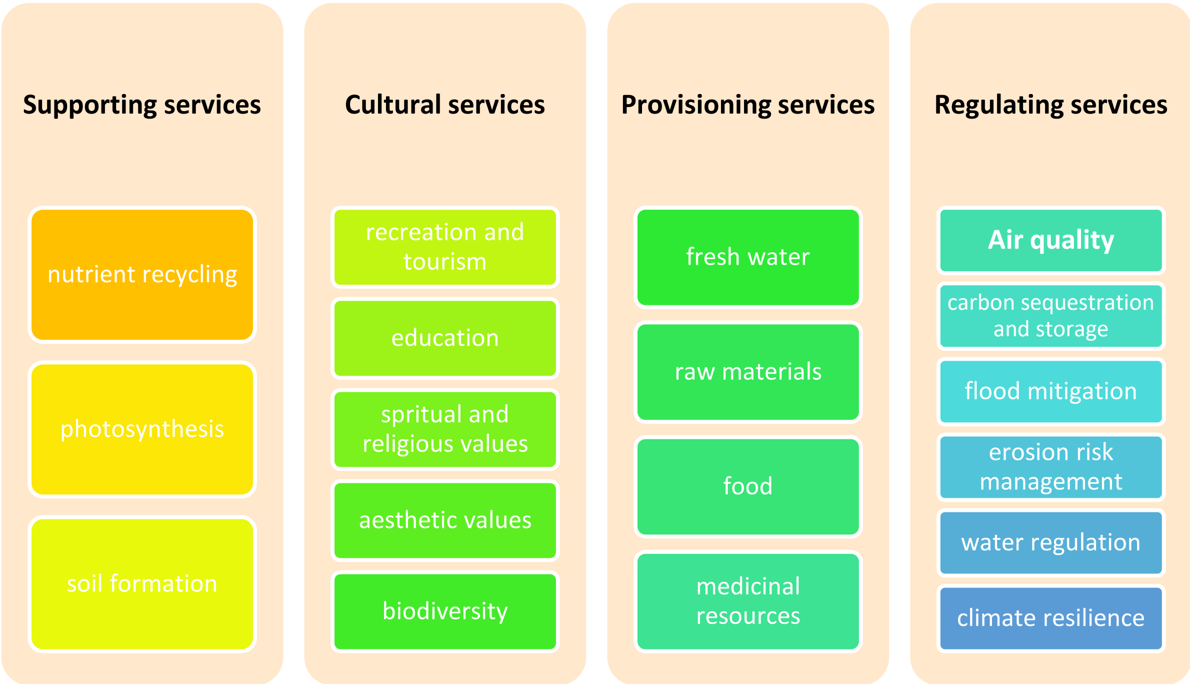
Forest fire can also be triggered during and after periods of drought or by human actions. There are now only two community forests remaining within ATT; the Konkleng Community Forest, and the Prey Daurm Rang. The Konkleng forest comprises a sparse, dry dipterocarp forest. Historic logging of high value species and forest fires has degraded around 300-500 Ha of the forest.

### 3.1.3 Ecosystem services and livelihoods

The ATT protected landscape and lake provides opportunities for a range of ecosystem services for flood and drought management, includes provisioning services such as 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. ATT also attracts domestic tourists with can amount to 15,000 to 30,000 per day during the national holidays. International tourists are still, however, limited with only around 80 international tourists per year visiting ATT mostly to see the Sarus Crane.

The ATT landscape also provides regulation services that help mitigate natural disasters and ensure the continued productivity of the landscape. For example, the Konkleng community protected areas, flooded forest and Plong grass in the reservoir that play an important role for carbon storage. These ecosystems also provide important hydrological functions such as run-off reduction, nutrient recycling and erosion control.  The core ecosystem services, their status and value are presented in Figure 14.

**Figure 14. ATT ecosystem services for flood and drought management**

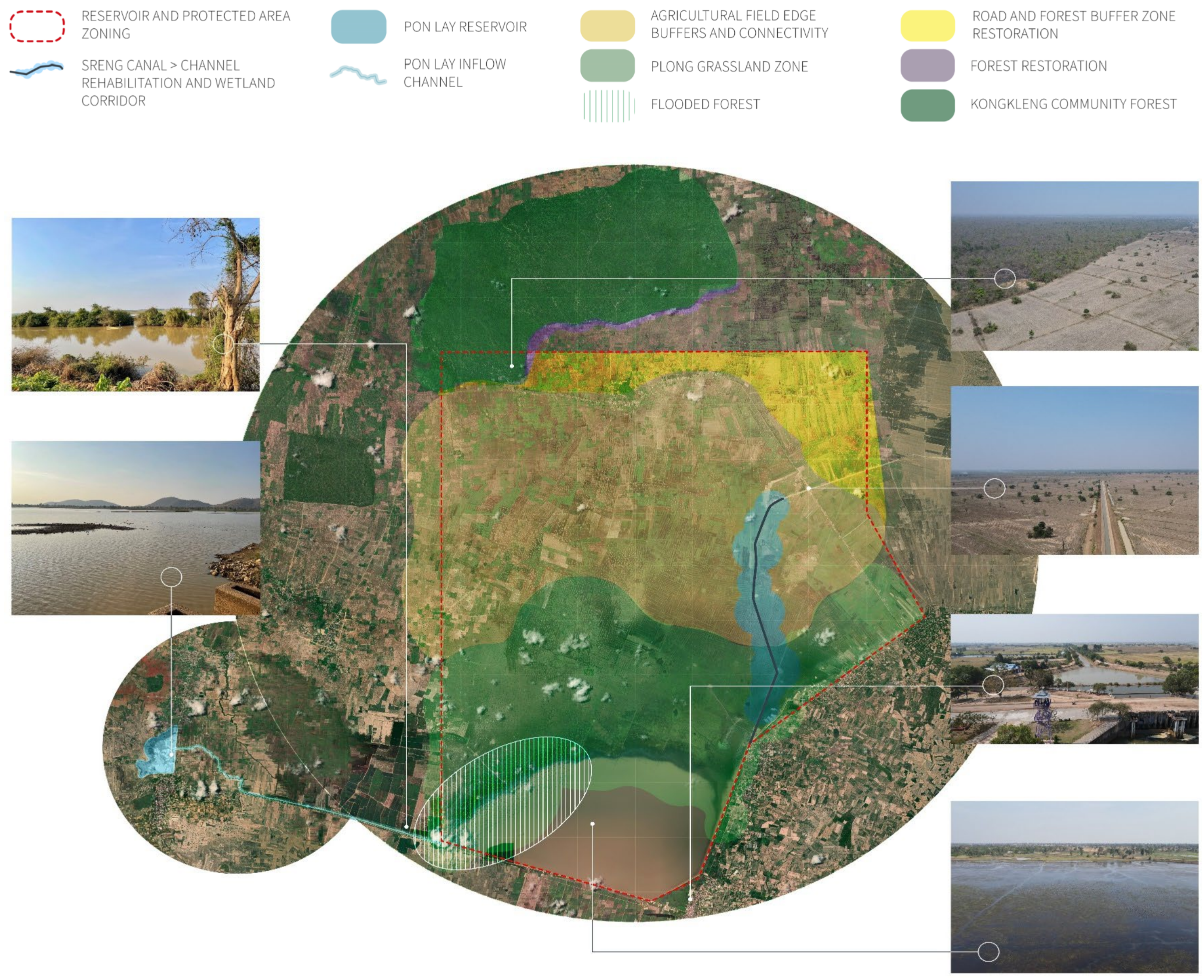



## 3.2 Proposed NbS project concepts

The ATT NbS project concepts are concerned with protected area encroachment, drought and erosion risk. The project objectives for this landscape are:

- Sediment management and watershed rehabilitation;
- Protected area restoration and management, forest restoration, development of riparian buffers and biodiversity safeguards;
- Wetland restoration, reservoir zoning and water management; and
- Development of an integrated approach to watershed, drought and flood management with local and provincial stakeholders, aligning with the 9C-9T Master Plan and Action Plan.

### Figure 15. Proposed NbS interventions for ATT landscape




1. Riparian buffer | 2. Reservoir zoning (and wetland restoration) | 3. Catchment water management | 4. Sediment trapping | 5. Forest restoration and rehabilitation | 6. Sustainable irrigation measures | 7. Agricultural field edge buffers and connectivity

Table 2 summarizes the challenges in the landscape and the proposed NbS conceptual designs to address these issues. More details on the NbS project concept and NbS measures are available in the Project concepts report.[29]

### Table 2. Summary of Ang Trapeang Thmor – drivers of environmental degradation, impacts, NbS measures and expected range of benefits

| Drivers |
| --- |
| • Lack of integrated water management principles<br>• Soil erosion and sedimentation problem<br>• Encroachment on the reservoir. Upstream deforestation and land degradation<br>• Reduced rainfall and drought |

[29] MRC. 2022. *A Network of Nature based Solutions for Flood and Drought Resilience of the 9C-9T Sub-basin. Project Concepts.* Mekong River Commission - Joint Project on Flood and Drought Management. Vientiane, Lao PDR

| **Impacts** |
|---|
| • Contribution of sediment from upstream areas including the canal<br>• Loss of water storage in the reservoir<br>• Overexploitation of river resources in the catchment Forest and grassland loss and biodiversity risk |
| **NbS measures** |
| • Riparian buffer strips along inflow and outflow channels, with wetland corridors where appropriate<br>• Check dams, leaky weirs and other sediment management measures<br>• Reservoir and wetland zoning<br>• Catchment water management plan<br>• Decentralised irrigation/fish ponds in upper catchment<br>• Forest restoration upstream of the reservoir, including linked to the community forest area<br>• Agricultural field buffers along field margins and along roads<br>• Wetland restoration, including of the Plong grassland area and the flooded forest |
| **Expected benefits** |
| • Improved water supply and irrigation for the command area of 12,000 ha<br>• Multi-functioning sediment trapping interventions to prevent sedimentation and decreased water storage capacity of the reservoir<br>• 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<br>• Reforestation for over 200 Ha of community forest to support habitats, NTFPs and other ecosystem services<br>• Natural buffer development for 7 km of existing degraded natural channels, including wetland corridors, to provide erosion control, retain surface runoff, reduce evaporation losses and reduce the load of sediment, organic matter and nutrients<br>• Construction of over 200 new decentralised irrigation/fish ponds, to provide improved seasonal water and food security<br>• Restored forest nodes and corridors within approximately 6700 Ha of agricultural land within the protected areas, including field buffers and road buffers<br>• Sustainable agricultural measures to reduce encroachment, support and more effective cultivation and water management in the ATT catchment<br>• Zoning, regulation and guidelines about sustainable water use and management associated with ATT and its catchment<br>• Establishment of reservoir zones to ensure effective reservoir management, habitat conservation, water security and support for ecologically sustainable activities |

## 3.3 NbS evaluation

### *3.3.1 NbS scenario and costs*

Two basic modelling scenarios were developed to allow the attribution of benefits to NbS interventions. The baseline scenario assumed conditions in the catchment remained approximately the same as is currently the case, with no change in key parameters. The NbS scenario assumed a range of nature-based interventions took place to address the environmental risks in the basin and restore ecosystem functionality.

Table 3 gives details of the proposed NbS measures for ATT along with estimated investment, operations and maintenance (O&M) and opportunity costs. Total estimated investment costs are approximately US$ 3.8 million, the largest components of which are construction costs for 200 decentralised fish/irrigation ponds (US$ 1.2 million) and various afforestation measures (US$ 2.6 million) including re-establishing forested areas and buffer strips around key water features and infrastructure in the catchment. The main components of O&M costs are those for caring for newly established forested areas (such as weeding, replacing dead tress etc).

The opportunity cost of land[30] has also been considered and is an important component of the economic costs of afforestation measures. The full rental cost of land for rice production of 150 US$/ha was used as an estimate, although this may overestimate opportunity costs in areas of the catchment where land is more marginal and unsuited for rice production. More details on the sources of costs estimates are given at the foot of the table.

**Table 3. ATT measures and estimated costs**

| Measure | Details | Investment costs [a] (US$) | O&M costs (US$) | Opportunity costs (US$) |
|---|---|---|---|---|
| 1. Sreng natural channel buffer and wetland corridor | Using native species, cost of US$ 944/ha [b] Area is 50 m either side of channel for 6.95 Km total area 69.42 Ha. Maintenance costs US$ 100/ha for first 10 years | 65,532 | 6,942 | 10,413[c] |
| 2. Decentralised irrigation/fishponds | 200 fishponds constructed in upper catchment of capacity 4,000 m3 (100 m x 20 m x 2 m). Including bank stabilisation measures and 5 m buffer equivalent to 0.12 ha per pond or 24 ha over 200 ponds. Maintenance costs as in 1 | 1,222,656[d] | 2,400 | - |
| 3. Restoration of former drainage channels | 30 m restoration either side of channels for 40 Km equivalent to 240 ha with costs as in 1.[e] Plus 5-10 leaky weirs in each channel, or 60 in total | 256,560 | 24,000 | -[f] |
| 4. Agricultural field edge buffers and connectivity | 20 m field buffers for approximately 336.4 km of field edges equivalent to 673 ha. Planting and maintenance costs as in 1 | 635,123 | 67,280 | 100,860 |
| 5. Reforestation of flooded forest | Planting and maintenance of restored area of 734 ha costs as in 1 | 692,896 | 73,400 | 110,100 |
| 6. Forest rehabilitation and reforestation areas | Planting and maintenance of restored area of 1,017.8 ha on southern edge of community forest and road buffer strip. Costs as in 1 | 960,803 | 101,780 | 122,670 |
| **Total** | | **3,833,571** | **275,802** | **344,043** |

Notes: [a] Unless otherwise indicated, investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] 944 US$ planting costs per Ha (0.6 US$ per seedling, 0.25US$ planting costs, for 1,110 seedlings per ha);[c] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 150 US$/ha; [d] Construction costs for ponds estimated based upon earth removal costs of 1.5 US$/m$^3$; [e] all afforestation costs, for reestablishment of upper catchment forests, flooded forest and buffer strips are assumed to have the same unit investment and maintenance costs; [f] restoration of relic drainage channels was assumed to require no additional land take.

### *3.3.2 NbS benefits*

The proposed NbS measures for the ATT catchment will provide a range of benefits summarised in Table 4. These include water availability, reduction in soil erosion and sedimentation, sustainable provisioning of food, fuelwood and other resources from forested areas, increased fisheries production from expansion of flooded forest areas and provision of fish/irrigation ponds, and additional carbon sequestration in additional biomass in the catchment (Table 5). The details of these benefit streams and the approach taken to their estimation is given below.

[30] That is the economic value forgone under an alternative use.

**Table 4. NbS benefit streams assessed**

| Benefit | Assessed | Notes |
|---|---|---|
| **Carbon sequestration** | Yes | Assessed based upon increased forested area and established sequestration coefficients |
| **Biodiversity** | No | Not assessed. Would require contingent valuation for which data is unavailable |
| **Ecotourism** | No | Not assessed. At the moment relatively minor |
| **Provisioning from forested areas** | Yes | Assessed based upon transfer pricing from similar locations in Cambodia |
| **Air purification** | No | Not assessed. Robust transfer prices not available |
| **Nutrient retention** | No | Not assessed, issues with double counting and reliable transfer prices |
| **Water quality improvement** | No | Not assessed as robust transfer pricing methodology not available |
| **Reduced erosion** | No | No, issues with double counting (reduced sedimentation) and with assessing costs of erosion in the catchment |
| **Fisheries** | Yes | Assessed using established production and price figures |
| **Water supply** | No | Not assessed. Double counting with reduced sedimentation and lack of data on catchment yields |
| **Sedimentation** | Yes | Assessed using hydrological modelling |

**Table 5. ATT assessed benefits in NbS scenario**

| Benefits | Sources | Average Annual gross value (US$/year) |
|---|---|---|
| ***Core benefits for flood and drought management*** | | |
| **Additional water supply for irrigation** | Decentralised fish/irrigation ponds | 65,032 |
| **Sediment reduction** | Afforestation, buffer strips | 12,638 |
| ***Co-benefits*** | | |
| **Provisioning from forested area** | Afforestation | 47,851 |
| **Fisheries** | Fishponds, flooded forest | 684,260 |
| **Carbon sequestration in additional biomass** | Afforestation, buffer strips | 1,074,596 |

### *Core benefits for flood and drought management*

**Water availability** – stakeholder consultations in the catchment demonstrated that water supply for irrigation was an important constraint on crop production in the catchment. Water users downstream of the ATT reservoir are less constrained as water is provided both from the reservoir itself and through the Sreng canal which transfers water from a different catchment to the northeast. Water levels in the reservoir are maintained using the canal to ensure the preservation of the Plong grassland habitat and to provide water for irrigation lower in the catchment. However, details of water demand and reservoir management have not been available.

Therefore, the valuation focused on the benefits of increased water availability through the provision of the 200 decentralised fish/irrigation ponds in the upper catchment. Although water may be repeatedly utilised and replenished in the ponds over the course of a growing season, details were not available. It was conservatively assumed that the total storage of each pond would be available for irrigation each year, i.e., 4,000 $m^3$. The water stored in these ponds was valued based upon estimates of the marginal productivity of water for rice cultivation in Cambodia of 0.09 US$/$m^3$.[31] The ponds are assumed to be established over a five-year period and irrigation water benefits are estimated to be worth 360 US$/year per pond and 72,000 US$/year for all 200 ponds after establishment.

[31] See Hussain I., H. Turral and D. Molden. 2007. Measuring and enhancing the value of agricultural water in irrigated river basins. Irrigation Science, 25(3):263-282; Mainuddin and Kirby, 2009, Spatial and temporal trends of water productivity in the lower Mekong River Basin, Agricultural Water Management, Vol.96, No. 11, pp. 1567- 1578; World Bank, 2020, Valuing the Ecosystem Services provided by Forests in Pursat Basin, Cambodia.' World Bank: Washington D.C.

**Sediment reduction –** Sediment reduction attributable to NbS measures was estimated based upon the results of hydrological modeling, utilizing a modified universal soil loss equation (MUSLE) conducted for the catchment. The modeling showed that annual sediment load was 804,913 t/year in the baseline scenario, and 797,737 t/year with the NbS measures; a reduction of 9,582 t/year or 1.19%. Of this, approximately 75% of the reduction is attributable to afforestation in the upper catchment, and the remainder is attributable to buffer strips in the catchment. Sediment mass was converted to achieve a wet sediment volume,[32] sediment reduction was valued at the price of removal from water bodies of 1.5 US$/m$^3$.[33] The annual value of sediment reduction was estimated to be approximately US$ 19,000. Benefits were calculated based on the assumption that afforested areas yield 10% of sediment reduction benefits, increasing to 100% of sediment reduction benefits by 10 years after planting.

*Co-benefits*

**Provisioning from forested area** – Provisioning values from the forest area have been calculated based upon transfer pricing from a similar study conducted in Cambodia. Kibria et al.[34] estimated the value of goods provisioned from forested areas in Veun Sai-Siem Pang National Park in Cambodia based upon a household survey. Resources communities sourced from the forests included timber, mushrooms, rattan shoots, bamboo shoots, fish, resin, jungle fowl, lizards, frogs, snakes, malva nuts and firewood. These had an estimated value of 38.3 US$/ha/year. Only forested areas additional in the NbS scenario were considered to offer provisioning benefits – although buffer strips may offer some fraction of this value these were excluded from the valuation. Additional forested area in the NbS scenario is approximately 1,752 ha, and provisioning from this area is estimated to be worth over US$ 67,000 annually. As with the benefits of reduced sedimentation, provisioning benefits were calculated based upon the assumption that on planting afforested areas yield 10% of provisioning benefits, increasing to 100% of benefits by 10 years after planting.

**Fisheries** – Fisheries are important to rural livelihoods in most parts of Cambodia and in the ATT catchment specifically. Fisheries production is expected to increase in the NbS scenario as a result of the provision of decentralized fish/irrigation ponds (40 ha) and the expansion of the flooded forest area (734 ha). Fish productivity from similar household ponds in Cambodia is estimated to be 5,000 t/ha/year.[35] Given the need to draw down water levels in the ponds periodically for irrigation purposes, fish yields were assumed to be 60% of those estimated by Joffre at al. or 3,000 t/ha/year, equivalent to 600 t/pond/year and 120,000 t/year for all 200 ponds. The fisheries productivity of flooded forest is estimated to be 66 t/ha/year,[36] additional fisheries production in the NbS scenario is estimated to be 48,444 t/year. Fish price is estimated to be 4.5 US$/Kg[37], this suggests an annual additional gross value of approximately US$ 760,000.

**Carbon sequestration** – the value of additional carbon sequestration for the NbS scenario was estimated based upon annual carbon stored in additional biomass from afforestation of 2,758 ha of land including afforestation in the upper catchment and of flooded forest, and plantation of field edge,

[32] The ratio of sediment wet volume (m$^3$) to sediment dry weight (t) is approximately 1:1.3, estimated for unknown sediment types based upon Parsmo, undated, presentation, Conversion Factors in Reporting. IVL. retrieved from https://portal.helcom.fi/meetings/EN%20DREDS%2011-2021-847/Related%20Information/Presentation1_Conversion%20factors.pdf

[33] Based upon local consultations.

[34] Kibria, A. S., Behie, A., Costanza, R., Groves, C., & Farrell, T. (2017). The value of ecosystem services obtained from the protected forest of Cambodia: The case of Veun Sai-Siem Pang National Park. *Ecosystem Services*, *26*, 27-36.

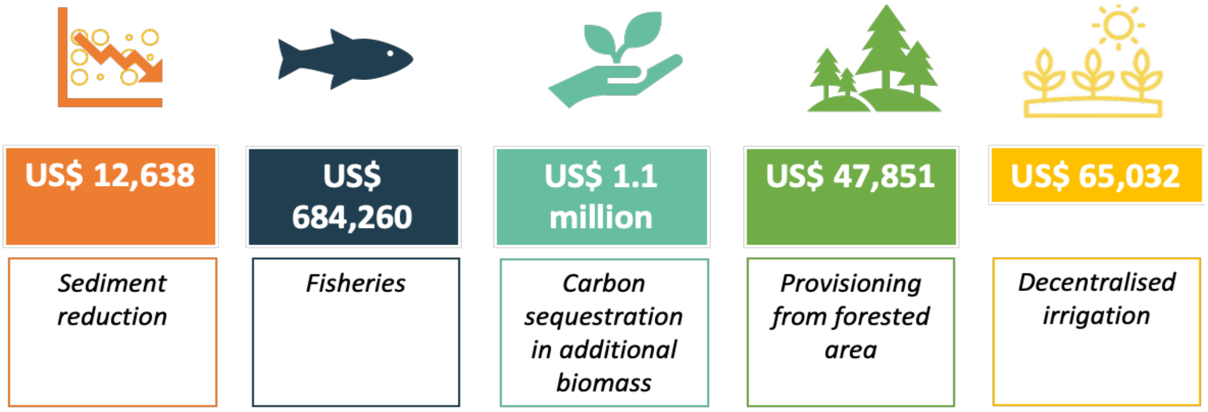
[35] Joffre,O., Kura,Y., Pant,J., Nam, S. 2010, Aquaculture for the Poor in Cambodia – Lessons Learned. World Fish Centre Cambodia.

[36] Chheng P., Un S., Tress J., Simpson V., Sieu C. 2016. Fish productivity by aquatic habitat and estimated fish production in Cambodia. Inland Fisheries Research and Development Institute, (Fisheries Administration) and WorldFish. Phnom Penh, Cambodia.

[37] Price estimated to be US$ 3.60 per Kg in 2015 inflated to reflect changes in price level, obtained from So, N., Phommakone, S., Ly, V., Samphawamana, T., Nguyen, H. S., Khumsri, M., Ngor, P. B., Kong, S., Degen, P., & Starr, P. (2015). Lower Mekong fisheries estimated to be worth around $17 billion a year. Catch and Culture, 21(3), 4–7. http://www.mrcmekong.org/assets/Publications/Catch-and-Culture/CatchCultureVol-21.3.pdf

water body and infrastructure buffer strips throughout the catchment. Annual sequestration for newly grown tropical forest assumed to be 3.5 tC/ha/year based upon FAO figures,[38] equivalent to 12.8 $tCO_2$/ha/year.[39] It was conservatively assumed that buffer strips would offer 10% of these sequestration benefits, or sequester approximately 1.3 t $CO_2$/ha/year. Emissions were valued using IMF's suggested carbon price floor for middle income countries of 50 US$/$tCO_2$,[40] which it should be noted is well below recent estimates of the social cost of carbon, recent estimates of which suggest a mean price of 185 US$/$tCO_2$.[41] Total annual $CO_2$ sequestration was estimated to be 23,795 t/year, with an annual value of US$ 1.2 million.

**Figure 16. Approximate average annual benefits over lifetime of the project at Sompoi**




## 3.4 Cost-benefit analysis

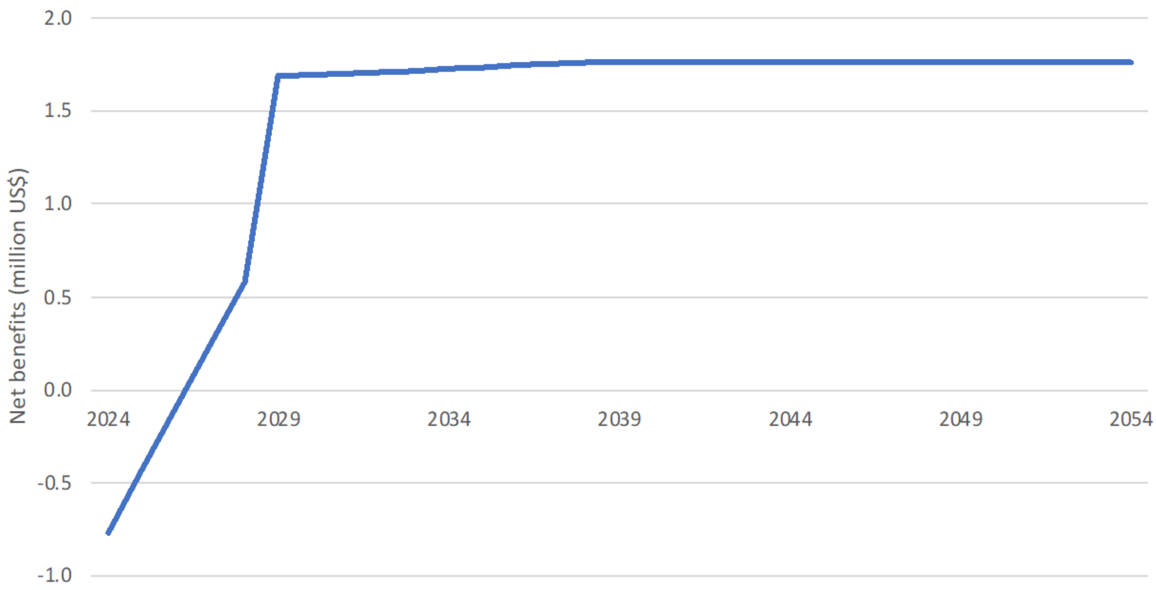
In all cases the benefits of proposed NbS interventions substantially outweighed the costs over the 30-year period of the evaluation (Table 6). In the base case the net present value (NPV)[42] was estimated to be US$ 10.6 million for a discount rate of 9%, and the ratio of benefits to costs was estimated to be 2.6. Sensitivity analysis was conducted around these results to test the robustness of the analysis, and reflect substantial uncertainties surrounding estimates of both costs and benefits, as well as highlighting the effect of differing discount rate assumptions. In all cases considered NPV were substantial and benefit costs (BC) ratios exceeded 1. Even with a 50% decrease in benefits the proposed interventions pass common investment thresholds.[43] While a 9% discount rate has been assumed for the base case, reflecting common practice of governments and development partners in the region, for environmental goods and services, strong arguments have been made for the adoption of lower discount rates, which in effect favour longer-term investments.[44] Figure 16 illustrates the development of net benefits over time. It should also be noted that many of the assumptions for this evaluation are conservative, for example no provisioning from buffer strips was assumed, a low value for carbon sequestration was adopted. A number of important values for which data was not available were excluded, including biodiversity, recreation and any additional benefits associated with adaptation to climate change.

[38] FAO, 2020, Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca9825en/CA9825EN.pdf
[39] Using a conversion factor of 3.67.
[40] IMF, 2022, website retrieved from https://www.imf.org/en/Blogs/Articles/2022/05/19/blog-why-countries-must-cooperate-on-carbon-prices
[41] Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., ... & Anthoff, D. (2022). Comprehensive evidence implies a higher social cost of CO2. *Nature*, *610*(7933), 687-692.
[42] The sum of discounted benefit streams minus the sum of discounted costs.
[43] Investment thresholds differ depending on context. Broadly speaking, a BC ratio exceeding 1, i.e., where expected benefits exceed costs is a threshold often applied. In OECD countries public investment projects with BC ratios below 1 are often considered viable.
[44] See, for example, a recent discussion by Brumby and Cloutier, 2022, Using a zero-discount rate could help choose better projects and help get to net zero carbon. Retrieved from https://blogs.worldbank.org/governance/using-zero-discount-rate-could-help-choose-better-projects-and-help-get-net-zero-carbon

**Table 6. ATT cost benefit analysis and sensitivity analysis results**

| | NPV for different discount rates (million US$) | | | BC ratio |
|---|---|---|---|---|
| **Case** | 6% | 9% | 12% | |
| **Base case** | 16.3 | 10.6 | 7.1 | 2.59 |
| **20% increase in investment costs** | 15.7 | 10.0 | 6.6 | 2.59 |
| **20% increase in O&M costs** | 15.5 | 10.1 | 6.7 | 2.61 |
| **20% increase in all costs** | 14.9 | 9.5 | 6.2 | 2.38 |
| **50% decrease in project benefits** | 4.6 | 2.5 | 1.2 | 1.43 |

**Figure 17. Net benefits over time**




### *3.4.1 Distributional considerations*

Proposed NbS interventions in the ATT landscape are unlikely to be distributionally neutral. The costs and benefits are likely to fall on different groups in the area. These distributional implications are briefly summarized in Table 7. Investment costs likely to be borne by the central government and O&M costs borne by provincial governments, other substantial costs are likely to be those associated with changes in land use.

Restrictions on the exploitation of forest areas may mean that sustainable use of NTFPs can continue in the long term, but at the same time communities involved in land clearance in the upper reaches of the watershed, may be deprived valuable income from conversion of forest to cropland, harvesting of fuelwood and grazing livestock in scrub areas. Whereas the benefits of forest restoration and protection will largely be enjoyed in the middle and lower watershed from improved reservoir storage and water availability, and improved conditions for management of the Plong ecosystem.

Communities in the middle of the catchment will likely see significant benefits from the development of fish/irrigation ponds. Increased fish production will likely allow the sale of some fish to generate cash incomes for some households. Households will also have better access to water for irrigation of crops and see improved crop production as a result. At the same time, communities will be affected by the loss of some agricultural land to buffer strips. Much of this is likely to be marginal, although inevitably some landholders will be affected more than others. Smaller subsistence landholders with land holdings close to the road or canal are likely to be most affected as the buffer strips have the potential to cover a significant portion of their land. In all cases it will be important to ensure that landholders are fully compensated for any losses, but in cases where a significant portion of household land is required, additional livelihood restoration support will also need to be considered.

Reduced carbon emissions represent a significant benefit. Despite the high value of carbon emissions reductions, at present there is no means of returning some portion of that value to affected communities in the area. The longer-term sustainability of afforestation measures in the area is likely to depend upon the establishment of incentive mechanisms to encourage communities to better preserve forest areas. Development of institutional arrangements that can distribute funds for carbon sequestration and storage (though REDD+, Voluntary Carbon Market (VCM) or similar mechanisms), and more generally for watershed protection is likely to be an important complement to the proposed NbS measures in the future.

Substantial gendered impacts are not expected to be associated with the proposed interventions, although further specific analysis of the potential for gender differentiated outcomes is warranted.

**Table 7. Distributional considerations for NbS interventions in the ATT landscape**

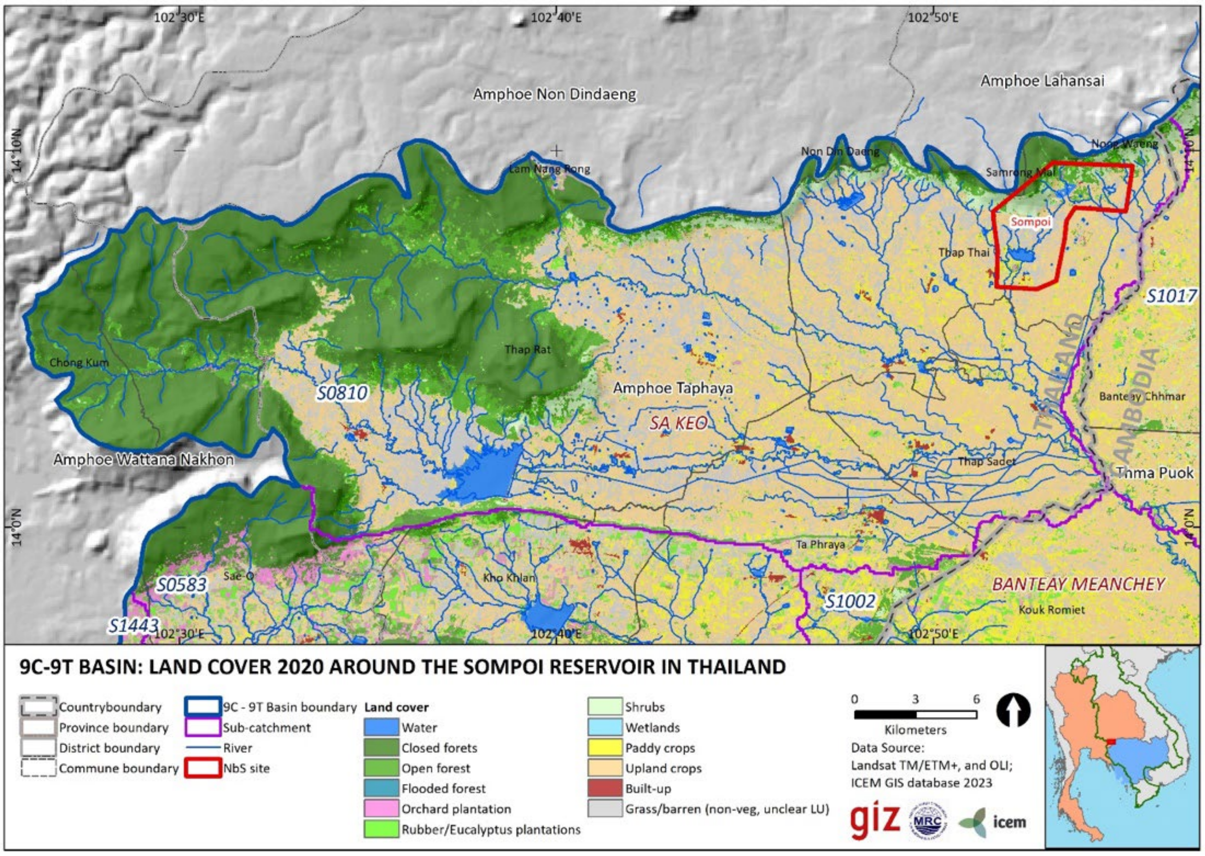
| NbS intervention | Benefits | Costs |
|---|---|---|
| **Forest restoration** | • Employment in forest restoration and protection<br>• Provision of NTFPs at a sustainable level to communities<br>• Reduction in sedimentation benefiting PDOWRAM and irrigation users<br>• Increased carbon storage and biodiversity giving national and international benefits | • Restriction on use of forests and scrub land (timber and some NTFP extraction, animal grazing in scrubland) affecting communities in upper watershed<br>• Costs of afforestation and maintenance borne by central government and provincial authorities |
| **Riparian, field edge and infrastructure buffers** | • Employment in forest restoration and protection<br>• Reduction in sedimentation benefiting PDOWRAM | • Some loss of agricultural land in upper and middle catchment<br>• Costs of maintaining buffers borne by provincial authorities |
| **Restoration of former drainage channels** | • Reduction in sedimentation benefiting PDOWRAM | • Costs of investment and O&M borne by government |
| **Fish/irrigation ponds** | • Irrigation users in the middle catchment<br>• Fish raising households in middle catchment | • Central government will bear costs of construction |

# 4 SOMPOI RESERVOIR, THAILAND

## 4.1 Overview of Sompoi landscape

The Sompoi reservoir is located in Sa Kaeo Province, Amphoe Taphaya district in the most northern part of the 9C-9T basin. The headwaters are in the hilly and forested Tapraya national park which is located close to Pang Sida national park, and part of the Phnom Dong Rak mountain range and the Dong Phayayen-Khao Yai Forest Complex World Heritage Site, a site of global conservation importance. The hills fade out to the south where agricultural land prevails. The location is home to many reservoirs, which provide domestic water and irrigation (Figure 18). The Sompoi reservoir provides a range of benefits to the surrounding rural area, including irrigation for agriculture and domestic water supply.

**Figure 18. Sompoi reservoir location and 2020 land cover**




However, the landscape inside and outside the national parks is becoming increasingly degraded. The sandy and dispersive soils in the area are suspectable to severe erosion. This leads to high sediment loads in the ephemeral drainage channels and gullies in the area. Erosion is particularly a problem where vegetation cover is sparse. Data analysis conducted between 1990 and 2000 shows significant progressive forest loss in the upstream catchment.[45] The long-term functioning of the reservoirs is determined by the condition of the upstream catchment, with water quality, erosion and sedimentation, and water availability being identified as key challenges in the area.

[45] See MRC. 2023. *Initial Project Concepts: A Network of Nature based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan 2022-2026*. Mekong River Commission – 9C-9T Joint Project on Flood and Drought Management. Vientiane, Lao PDR.

### *4.1.1 Socio economic conditions and trends*

The area has undergone rapid changes over recent decades. The area 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 area around Sompoi comprises a network of reservoirs, agricultural land and small villages. Thap Thai village is situated to the south of Sompoi – the Thap Thai SAO have jurisdiction for the landscape, within which land tenure arrangements are complex. The National Park to the north is managed by the National Park Authority. The UN Road is managed by the Highways Authority. The waterways that dissect the agricultural land to the north of Sompoi are situated on public land – managed by Thap Thai SAO, separated from adjacent private land through its buffer zone.

### *4.1.2 Natural hazards*

Drought is an increasing concern for Sompoi, with reducing water availability in the dry season, combined with degrading, water intensive and erosive land uses.

On the other hand, flooding and erosion is a concern in the wet season. During the rainy season, water rapidly flows from the mountains and forests upstream of the reservoirs downstream towards agricultural land, resulting in incision, gulley erosion and surface water runoff via small ephemeral channels into the Sompoi reservoir. Significant sediment build-up and localised erosion occurs dispersing through a system of ephemeral streams from north near the UN road to Sompoi reservoir, resulting in the transfer of sediment during periods of high discharge into the reservoir. Flash floods associated with steep slopes compound this problem, and result in highly turbid waters in the reservoir. Significant volumes of runoff are generated during periods of intense rainfall.

### *4.1.3 Ecosystem services and livelihoods*

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. The national park and forested areas form a natural wildlife corridor of international importance and an essential upper catchment for Sa Kaeo Province downstream to Cambodia.

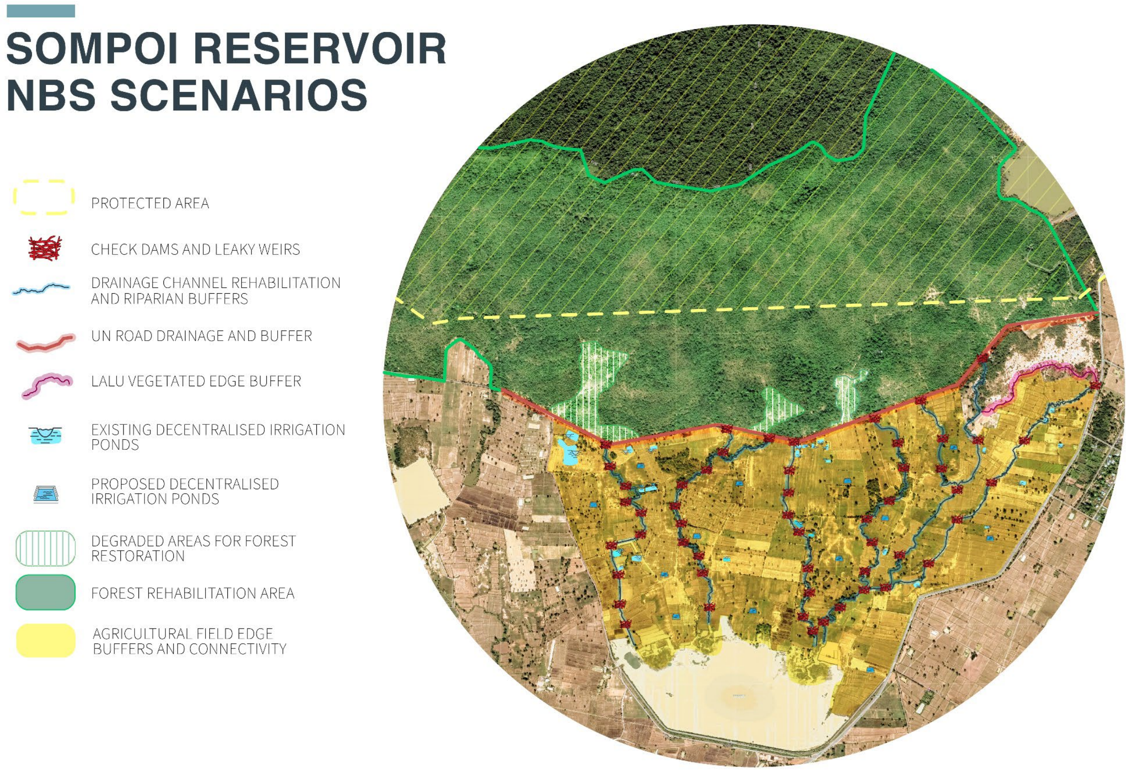
The farming around Sompoi is undertaken on private land, mostly of rice and cassava plantations – lowland for rice crops and highland for cassava crops. The land is cultivated based on local practices and experience, cropping patterns for rice in the rainy season, from July until December (four months per crop, finishing the harvesting in December). The dry season commences in February and lasts until May. The village has no water user groups or committees.

## 4.2 Proposed NbS project concepts

The landscape is suffering from encroachment in the protected areas of the headwater, drought, erosion and sedimentation and reduced water quality. The project objectives for Sompoi address these concerns (see Figure 19) by focusing on:

- Measures for reservoir and watershed rehabilitation and management, including introducing riparian buffers, sediment trapping, reforestation, agricultural buffers, a network of irrigation ponds and channels 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 water resources, protected area, drought and erosion management, aligning with the 9C-9T Master Plan and Action Plan.

**Figure 19. Proposed Sompoi project concept and NbS measures**




1. Riparian buffer | 2. Catchment water management | 3. Drainage in combination with nature-based retention | 4. Sediment trapping and check dam | 5. Forest restoration and rehabilitation | 6. Sustainable irrigation measures | 7. Agricultural buffer

Table 8 summarises the challenges in the landscape and the proposed NbS conceptual designs to address these issues. More details on the project concept and NbS measures is available in the Project concepts report.[46]

**Table 8. Summary of Sompoi reservoir – drivers of environmental degradation, impacts, NbS measures and expected range of benefits**

| Drivers |
|---|
| • Erodible soil and vegetation with less pronounced canopies<br>• Inadequate drainage structures and vegetated buffers for roads and paths<br>• Missing drainage buffer strips<br>• Missing sediment management upstream of reservoirs<br>• Logging |
| **Impacts** |
| • Loss of water storage in the reservoirs and ponds<br>• High turbidity in reservoirs and ponds<br>• High evaporation losses from the reservoir and pond water surfaces<br>• Reduction of flow capacity in rivers due to sediment |

[46] MRC. 2023. *Initial Project Concepts: A Network of Nature based Solutions to Implement Component 2 of the 9C-9T Flood and Drought Master Plan 2022-2026*. Mekong River Commission – 9C-9T Joint Project on Flood and Drought Management. Vientiane, Lao PDR.

| **NbS measures** |
|---|
| • Natural drainage corridor riparian buffers<br>• Drainage in combination with nature-based retention for the UN road<br>• Leaky weirs and check dams for sediment management<br>• Forest restoration and rehabilitation<br>• Sustainable irrigation and infiltration measures and agricultural field buffers |
| **Expected benefits** |
| • Restoration of degraded reservoir and catchment, improving water supply functionality<br>• Water conservation irrigation measures to support improved irrigation and more sustainable agricultural practices<br>• Rehabilitation and riparian buffers for 12 km of drainage channels, to provide erosion control, retain surface runoff, reduce evaporation losses and reduce the load of sediment, organic matter and nutrients<br>• Construction of over 50 new small-scale irrigation ponds, to support decentralised seasonal water security<br>• Restored vegetation nodes and corridors within approximately 330 Ha of agricultural land north of Sompoi reservoir, including field buffers, for increasing ecological connectivity and biodiversity, sediment control and water retention<br>• 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<br>• Restoration and reforestation of over 25 Ha of selected degraded forest sites within Taphraya national park buffer zone |

## 4.3 NbS evaluation

### 4.3.1 NbS scenario and costs

Table 9 gives details of the proposed NbS measures for Sompoi reservoir as well as estimated investment, O&M and opportunity costs. Total estimated investment costs are approximately US$ 786,000. The largest single cost is the construction of 50 decentralised irrigation ponds at a cost of US$ 419,000, followed by the various afforestation and forest restoration measures at US$ 332,000. As with ATT, the main components of O&M costs are those for caring for newly established forested areas (such as weeding, replacing dead tress etc.). The opportunity cost of land has also been considered and is an important component of the economic costs of afforestation measures where land can be expected to be taken out of agricultural usage. The full rental cost of land for agricultural production of 200 US$/ha was used as an estimate. Further details on the sources of costs estimates are given at the foot of the table.

**Table 9: Sompoi NbS measures and estimated costs**

| Measure | Details | Investment costs (US$) [a] | O&M costs (US$) | Opportunity costs (US$) |
|---|---|---|---|---|
| **1. Drainage channel rehabilitation and riparian buffers** | 34.95 ha of existing and relic drainage corridors and their buffers at 787 US$/ha [b], with 15 m riparian buffer width either side of channel. With bank stabilisation and mixed native species. No agricultural encroachment | 27,491 | 7,235[c] | - |
| **2.Check dams and leaky weirs** | 70 leaky weirs on drainage channels | 35,000[d] | 700 | - |
| **3. Decentralised irrigation ponds** | 50 decentralised irrigation ponds of 4,000 m$^3$, 100 m x 20 m x 2 m [e] Including bank stabilisation measures and 5 m buffer equivalent to 0.12 ha per pond or 6 ha over 50 ponds. Investment and maintenance costs for buffers as in 1 | 418,722 | 1,242 | - |

| Measure | Details | Investment costs (US$) [a] | O&M costs (US$) | Opportunity costs (US$) |
|---|---|---|---|---|
| **4. Agricultural field edge buffers and connectivity** | 20 m field buffers for an area of approximately 33.1 ha. Planting and maintenance costs as in 1 | 26,050 | 6,852 | 6,620[f] |
| **5. Forest rehabilitation and reforestation areas** | 636.5 ha for protection and rehabilitation of National Park foothills and buffer zone. Planting and maintenance costs assumed to be 50% of 1 | 250,463 | 65,878 | - |
| **6. Reforestation of selected degraded sites** | Reforestation of 26.1 ha of degraded forest pocket sites within National Park for reforestation. Planting and maintenance costs as in 1 | 20,541 | 5,403 | - |
| **7. Lalu vegetated edge buffer** | 5.4 ha of vegetated buffer to southern boundary of Lalu site. Planting and maintenance costs as in 1 | 4,250 | 1,118 | 1,080 |
| **8. UN Road drainage and buffer** | 3.75 ha of road buffer (also extending north to protected area boundary). Planting and maintenance costs as in 1 | 2,951 | 776 | 750 |
| **Total** | | **785,467** | **89,203** | **8,450** |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for afforestation and creation of buffer strips assumed to be THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices - based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector; [c] Forest and buffer strip maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in 2023 prices respectively; [d] Leaky weirs estimated to cost US$ 500 each plus an average annual 2% maintenance cost; [e] earth moving and dredging costs range from between THB 45 – 97 /$m^3$ costs assumed to be in middle of this range equivalent to 2.07 US$/$m^2$; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha.*

### 4.3.2 NbS benefits

The proposed NbS measures for the Sompoi reservoir area provide a number of benefits including greater water availability, reduction in soil erosion and sedimentation, sustainable provisioning of food, fuelwood and other resources from forested areas, and carbon sequestration in additional forest biomass in the catchment. Details of NbS benefit streams and those which were included in the economic analysis is given in Table 10. The details of these benefit streams and the approach taken to their estimation is given below.

**Table 10. NbS benefit streams assessed**

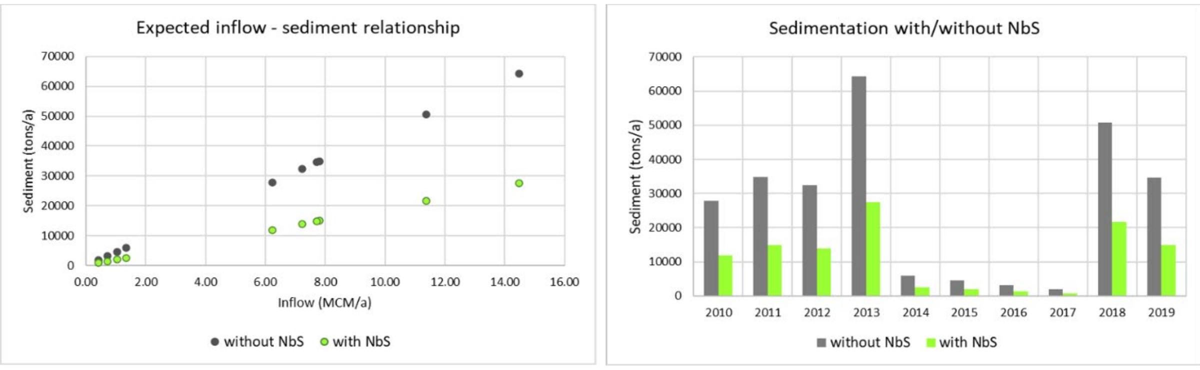
| Benefit | Assessed | Notes |
|---|---|---|
| **Carbon sequestration** | Yes | Assessed based upon increased forested area and established sequestration coefficients |
| **Biodiversity** | No | Not assessed. Would require contingent valuation for which data is unavailable |
| **Provisioning from forested areas** | Yes | Assessed based upon transfer pricing from similar locations in Cambodia |
| **Air purification** | No | Not assessed. Robust transfer prices not available |
| **Nutrient retention** | No | Not assessed, issues with double counting and reliable transfer prices |
| **Water quality improvement** | No | Not assessed as robust transfer pricing methodology not available |
| **Reduced erosion** | No | No, issues with double counting (reduced sedimentation) and with assessing costs of erosion in the catchment |

| | | |
|---|---|---|
| **Water supply** | No | Not assessed. Double counting with reduced sedimentation and lack of data on catchment yields |
| **Sedimentation** | Yes | Assessed using hydrological modelling |

**Water availability** – Details of water demand and reservoir management have not been available. Therefore, the valuation focused on the benefits of increased water availability through the provision of the 50 decentralised irrigation ponds in the upper catchment. As with ATT water may be utilised and replenished in the ponds a number of times over the course of a growing season, details were not available so it was conservatively assumed that the total storage of each pond would be available to use for irrigation each year, i.e., 4,000 $m^3$.[47] The water stored in these ponds was valued based upon estimates of the marginal productivity of water for rice cultivation in Thailand of 0.22 US$/$m^3$.[48] The ponds are assumed to be established over a five-year period, with 20% of the ponds completed each year, and irrigation water benefits are estimated to be worth 880 US$/year and 44,164 US$/year for all 50 ponds.

**Sediment reduction –** Sediment reduction attributable to NbS measures was estimated based upon the results of hydrological modeling utilizing the modified universal soil loss equation conducted for the catchment. The Sompoi reservoir is already heavily impacted by sedimentation, with the delta of sediment almost reaching the outlet. Simulation runs have shown that water management is barely possible, with the reservoir filling quickly and spills. In its current state, the reservoir dries up even after a prolonged wet season. Figure 20 illustrates the impact of NbS on expected sediment generation in the catchment and a significant reduction in sediment load.

**Figure 20. Relationships based on the Modified Universal Soil Loss Equation (MUSLE). Source: Modelling conducted for catchment**



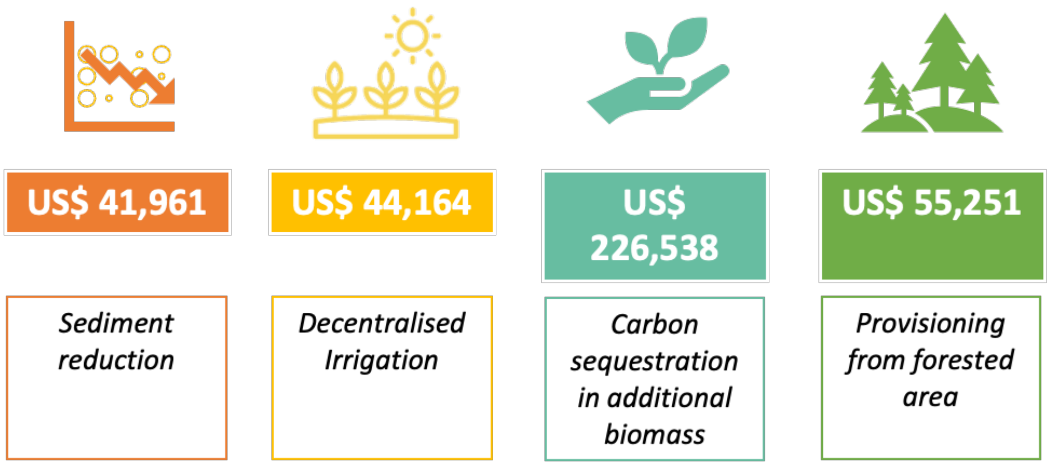

Assuming the reservoir has a trapping efficiency of 100%, simulation modelling over a 10-year period NbS measures are shown to reduce sedimentation by an average of 15,227 t/year. Sediment mass was converted to achieve a wet sediment volume,[49] sediment reduction was valued at the price of removal from water bodies of 2.07 US$/$m^3$.[50] The annual value of sediment reduction was estimated to be approximately US$ 42,000. As with ATT, benefits were calculated based upon the assumption that on planting afforested areas yield 10% of sediment reduction benefits, increasing to 100% of sediment reduction benefits by 10 years after planting.

[47] Based upon the storage area of the proposed ponds.
[48] Value for dry season water and unsubsidised crop prices of 0.19 US$/m3, from Saringkarn, P. (2012). Alternative models to finance irrigation services and their impacts along the rice chain value: a case study in central Thailand (Doctoral dissertation, AIT).
[49] The ratio of sediment wet volume ($m^3$) to sediment dry weight (t) is approximately 1:1.3, estimated for unknown sediment types based upon Parsmo, undated, presentation, Conversion Factors in Reporting. IVL. retrieved from https://portal.helcom.fi/meetings/EN%20DREDS%2011-2021-847/Related%20Information/Presentation1_Conversion%20factors.pdf
[50] Based upon local consultations.

**Provisioning from forested area** – Provisioning values from the forest area been estimated based upon a transfer pricing approach, using the Kibira et al.[51] study conducted in Cambodia in 2017 (and used to estimate provisioning values in the ATT landscape). Provisioning included a range of goods obtained from forested areas (see section 3.3.2). The values have been adjusted to reflect changes in price level and income per capita.[52] Based upon this approach the value of provisioning from forest areas is estimated 160 US$/ha in the Sompoi landscape. Only forested areas additional to the NbS scenario were considered. This includes reforestation of 26 ha, and restoration of degraded 637 ha of degraded forests. For measures to restore degraded forest area, additional benefits were assumed to be 50% of the benefits from the provision of new forest area. As with ATT, although buffer strips may offer some fraction of this value these were excluded from the valuation. The additional value of provisioning attributable to NbS measures is estimated to be approximately US$ 55,000 annually. As with the benefits of reduced sedimentation, provisioning benefits were calculated based upon the assumption that on planting afforested areas yield 10% of provisioning benefits, increasing to 100% of benefits by 10 years after planting.

**Carbon sequestration** – the value of additional carbon sequestration for the NbS scenario was estimated based upon annual carbon stored in additional biomass from afforestation of 109 ha of land. This includes afforestation in selected highly degraded forest areas (26 ha) and the various buffer strips along-side field edges, riparian corridors and infrastructure in the catchment (83 ha). In addition, forest restoration measures covering 637 ha of the catchment were also considered to result in additional carbon sequestration. Annual sequestration for newly grown tropical forest assumed to be 3.5 tC/ha/year based upon FAO figures,[53] equivalent to 12.8 t $CO_2$/ha/year.[54] It was conservatively assumed that restored forest areas would offer 50% of sequestration benefits (6.4 t $CO_2$/ha/year) and buffer strips would offer 10% of these sequestration benefits (1.3 t $CO_2$/ha/year). Emissions were valued using IMF's suggested carbon price floor for middle income countries of 50 US$/t$CO_2$.[55] Total annual $CO_2$ sequestration was estimated to be 4,531 t/year, with an annual value of approximately US$ 227,000.

**Figure 21. Approximate average annual benefits over lifetime of the project at Sompoi**

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[51] Kibria, A. S., Behie, A., Costanza, R., Groves, C., & Farrell, T. (2017). The value of ecosystem services obtained from the protected forest of Cambodia: The case of Veun Sai-Siem Pang National Park. *Ecosystem Services*, *26*, 27-36.

[52] GDP per capita in Thailand was approximately 4.6 times that of Cambodia in 2017 the value of provisioning from the forest area is adjusted to reflect this difference.

[53] FAO, 2020, Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca9825en/CA9825EN.pdf

[54] Using a conversion factor of 3.67.

[55] IMF, 2022, website retrieved from https://www.imf.org/en/Blogs/Articles/2022/05/19/blog-why-countries-must-cooperate-on-carbon-prices

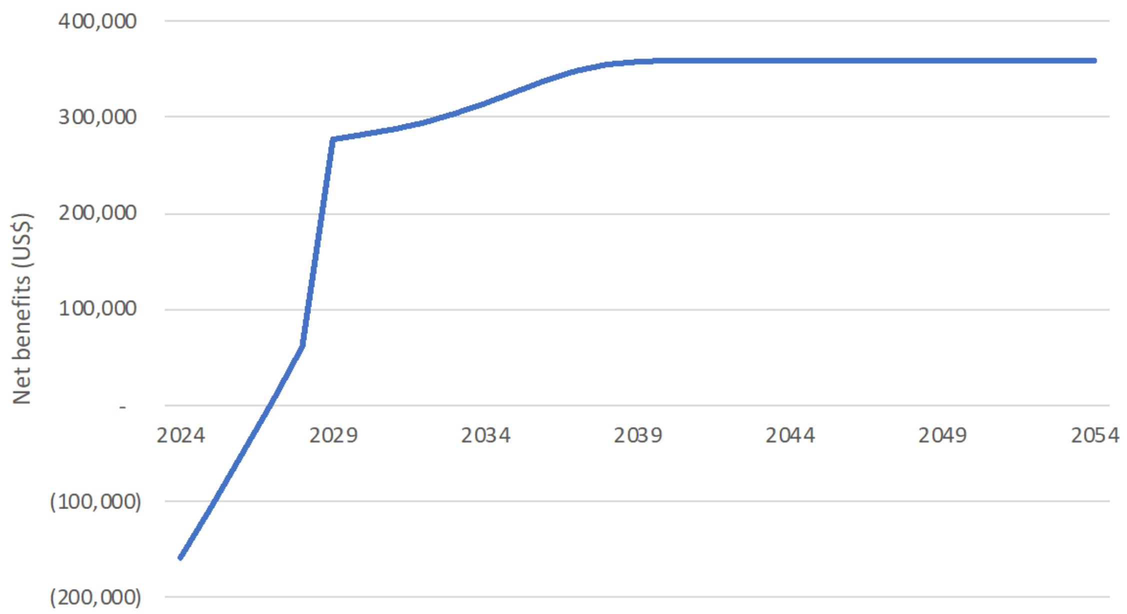
## 4.4 Cost-benefit analysis

In all cases the benefits of proposed NbS interventions substantially outweighed the costs (Table 9). In the base case the net present value (NPV) was estimated to be US$ 1.9 million for a discount rate of 9%, and the ratio of benefits to costs was estimated to be 3.75. Sensitivity analysis was conducted around these results to test the robustness of the analysis, and reflect substantial uncertainties surrounding estimates of both costs and benefits, as well as highlighting the effect of differing discount rate assumptions. In all cases considered NPVs were substantial and BC ratios exceeded 1. Even in the case where benefits were considered to decrease by 50%, the proposed interventions had a BC ratio of 1.86 and a NPV of US$ 300,000. Figure 20 shows the development of net benefits over time, this shows maximum benefits are not expected to be reached until around 2040. As with ATT, this evaluation is based on conservative assumptions, including no provisioning benefits from buffer strips and a low value for carbon sequestration. There was no accounting for benefits for which data was not available, such as water quality improvement, nutrient recycling, biodiversity and recreational benefits.

**Table 11. Sompoi cost benefit analysis and sensitivity analysis results**

| | NPV for different discount rates (million US$) | | | BC ratio |
|---|---|---|---|---|
| **Case** | 6% | 9% | 12% | |
| **Base case** | 3.0 | 1.9 | 1.2 | 3.73 |
| **20% increase in investment costs** | 2.8 | 1.7 | 1.1 | 3.16 |
| **20% increase in O&M costs** | 3.0 | 1.9 | 1.2 | 3.65 |
| **20% increase in all costs** | 2.8 | 1.7 | 1.1 | 3.11 |
| **50% decrease in project benefit's** | 1.1 | 0.6 | 0.3 | 1.86 |

**Figure 22. Net benefits over time**




### *4.4.1 Distributional considerations*

The likely distributional implications of NbS in the Sompoi landscape are briefly summarized in Table 12. As with other interventions, investment costs will to be borne by the central government and O&M costs by provincial governments. The only other substantial costs are likely to be those associated with changes in land use in the catchment in taking agricultural land out of use for the creation of buffer strips.

Measures to restore forested areas in the north of the catchment are likely to have minimal impacts on households using the area for NTFPs. There may be some minor impacts on households using the areas for grazing animals, which will with NbS measure in place be prevented from using these areas for grazing. Unlike the situation in Cambodia, the threat of extensive agricultural expansion into forested areas is minimal, and there does not seem to be a substantial population involved in this type of activity.

Famers and land holders may lose land to the creation of buffer strips. Much of this is expected to be land of more marginal quality, moreover this maybe offset to some extent by reducing erosion and improving nutrient retention in the remaining crop land. Smaller landholders may be more adversely affected as in some cases they may stand to lose a significant portion of their land holding. As was the case in ATT, it will be important to ensure that landholders are fully compensated for any losses, but in cases where a significant portion of household land is required, additional livelihood restoration support will also need to be considered.

Amongst government administrative bodies those responsible for maintenance of water supply and irrigation will see a reduction in O&M costs, largely from reduced sedimentation and improved water quality. Similarly, reduced erosion in the catchment will reduce O&M costs for the road network. On the other hand, there may be some increased monitoring costs for PA authorities as they seek to maintain the extended areas.

Reduced carbon emissions represent the single largest benefit. However, without an effective payment for ecosystem services scheme in place there is no way of returning some of this value to local communities and so incentivising support for NbS interventions. The longer-term sustainability of afforestation measures in the area is likely to depend upon the establishment of suitable incentive mechanisms to encourage communities to better preserve forest areas. Development of institutional arrangements that can distribute funds for carbon sequestration and storage (though REDD+, VCM or similar mechanisms).

As was the case with ATT, substantial gendered impacts are not expected to be associated with the proposed interventions, although further specific analysis of the potential for gender differentiated outcomes is warranted.

**Table 12. Distributional considerations for NbS interventions in the Sompoi landscape**

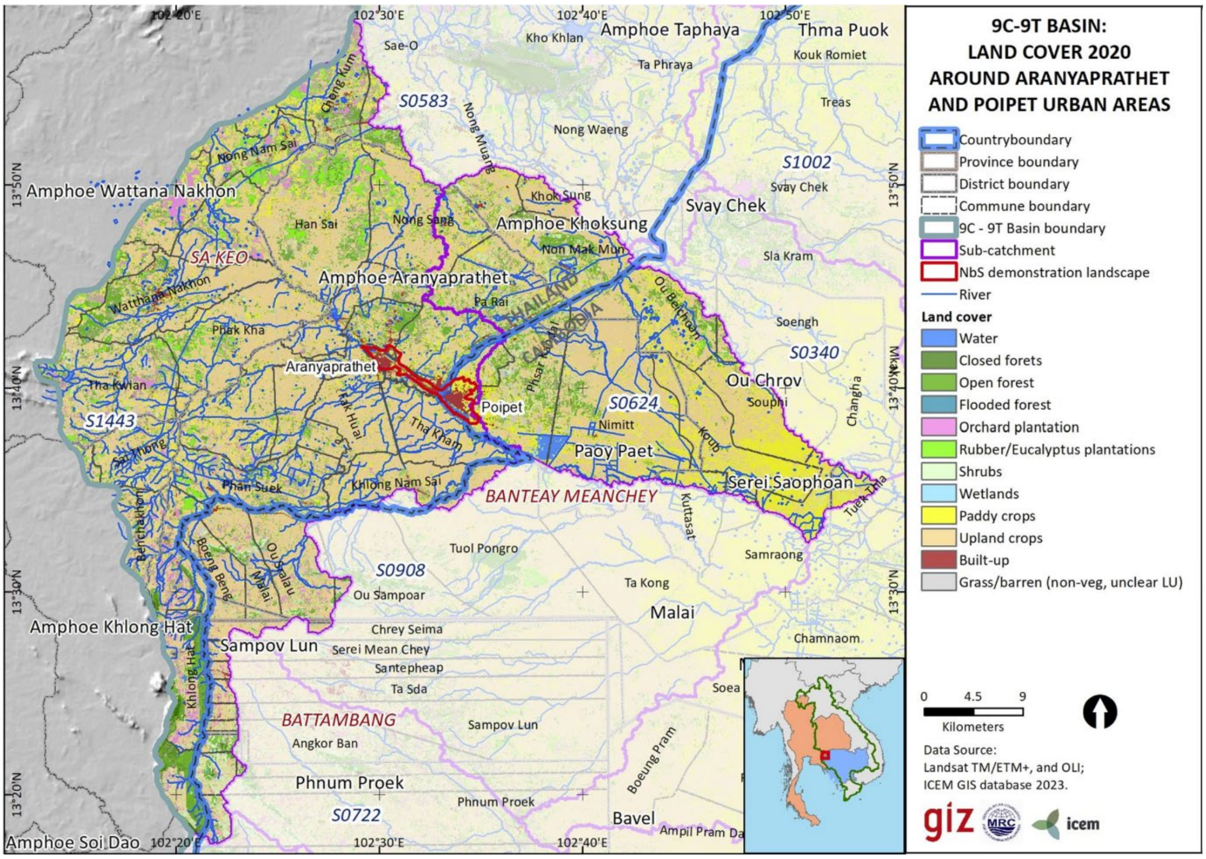
| NbS intervention | Benefits | Costs |
|---|---|---|
| **Forest restoration** | • Employment in forest restoration<br>• Provision of NTFPs at a sustainable level to communities<br>• Reduction in sedimentation benefiting Provincial Irrigation Office and irrigation users<br>• Increased carbon storage and biodiversity giving national and international benefits | • Restriction on use of forests and scrub land affecting communities in upper catchment<br>• Costs of afforestation and maintenance borne by central government and provincial authorities |
| **Riparian, field edge and infrastructure buffers** | • Employment in forest restoration and protection<br>• Reduction in sedimentation benefiting Provincial irrigation office | • Some loss of agricultural land for land holders in the catchment<br>• Costs of maintaining buffers borne by provincial authorities |
| **Restoration of former drainage channels** | • Reduction in sedimentation benefiting Provincial Irrigation Department | • Costs of investment and O&M borne by government |
| **Irrigation ponds** | • Irrigation users in the middle catchment | • Central government will bear costs of construction |

# 5 NBS IN A TRANSBOUNDARY URBAN AREA

## 5.1 Overview of the Aranyaprathet and Poipet landscape

Aranyaprathet and Poipet are neighbouring towns on either side of the Thai-Cambodian border (Figure 23).

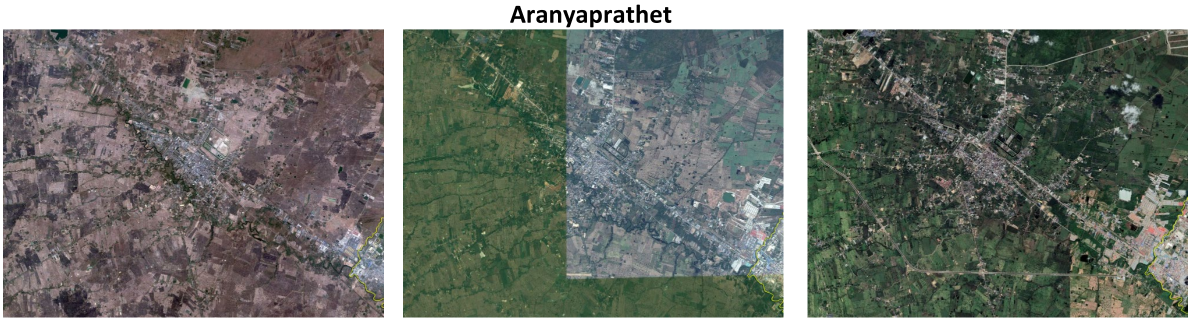
**Figure 23. Location and land cover of Aranyaprathet and Poipet 2020**




Both are fast growing cities (Figure 24) with expanding Special Economic Zones, with incoming residents and new development areas and industries. Aranyaprathet is in Amphoe Aranyaprathet district, Sa Kaeo province and Poipet is situated within the district boundaries of Poi Pet in Banteay Meanchey province.

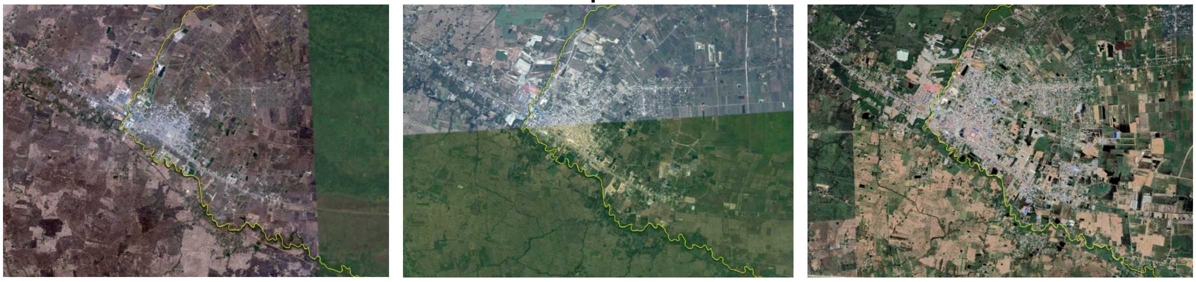
**Figure 24. Rapid development over time at Aranyaprathet and Poipet urban areas**

| 2005 | 2015 | 2021 |
|---|---|---|
| | **Aranyaprathet** | |



**2005** **2015** **2021**

**Poipet**



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 Chhrov 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.

### *5.1.1 Overview of catchment*

The area is subject to increasing water management issues with cross-border implications. As a partial consequence of the dynamic growth of the urban areas in the conurbations, both cities have serious flooding problems. Fluvial flooding from overbank flows inundating residential and industrial areas situated next to the river can be observed most years in both urban areas. In addition, municipal wastewater emissions from both urban areas cause very poor water quality in the river. In Poipet there is no wastewater treatment, with untreated municipal wastewater entering the drainage system, and the river system causing very poor water quality. Upstream in Aranyaprathet, urban run-off also enters the river system and leachate from the municipal solid waste site leaks directly into the river. Both urban areas also suffer from problems with pluvial flooding and localised drainage.

Some investment measures have already been planned to address these issues. An investment loan project funded by the ADB is planned for Poipet to address solid waste management and drainage issues, including a new drainage network for part of the city with storm water discharges into the river.[56] In Aranyaprathet, there are plans for a large flood diversion canal and concrete flood wall adjacent to the existing river channel to protect Aranyaprathet from flooding – but which has been designed without consideration of possible downstream implications. Neither of these planned investments take transboundary issues into account, and there is no apparent coordination on flood or water quality management between the two areas.

### *5.1.2 Socio-economic conditions*

As noted above, the cross-border urban agglomeration has grown rapidly in recent years. With the population in Aranyaprathet growing from 16,937 in 2005 to 93,343 in 2022, and that of Poipet from 43,366 in 1998 to 104,156 by 2018.[57] The cross-border area has seen high levels of immigration and rapid economic growth, based around the vibrant cross border trade, and as service centres to their large rural hinterlands. In Aranyaprathet in the centre of the urban area is Rongkluea market which attracts a large number of day-visitors from Cambodia, a number of industrial areas have also developed just on the Thai side of border which rely on Cambodian migrant labour. Along with rapid population and economic growth Aranyaprathet has experienced a rapid expansion of its physical area (as noted above).

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

[57] Thai Census data; ADB 2022, Feasibility Study for Cambodia: Livable Cities Investment Project (Poipet). Volume 1: Urban Development Scenarios

Poipet has seen similar factors driving its economic development and physical expansion. The city has become a centre for gaming, which has led to the rapid development of tourism, casinos and hotels, the border post in the city saw around 600,000 tourists visiting in 2017, approximately 10% of tourist arrivals to Cambodia[58] as well as the development of manufacturing industry housed in two industrial zones.

### *5.1.3 Natural hazards, ecosystem services and livelihoods*

Unlike the rural areas, in the urban landscape livelihoods are typically not directly dependent upon ecosystem services as most urban employment is in industrial and services sectors.[59] However, both cities face environmental issues which can be characterised as relating to natural hazards or as related to the degradation and loss of important ecosystem services.

The urban areas in question are already highly degraded and ecosystem services are limited. Flooding may be a natural, seasonal function of flood plains in the riverine areas in which the cities are built, but in the urban environment fluvial flooding represents a natural hazard, causing livelihood disruption, damage to physical assets and increased incidence of disease. 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.

Pluvial flooding is more closely related to the loss of ecosystem function, impermeable surfaces in urban areas create more run-off and prevents infiltration, causing flooding. This is compounded poor solid waste management resulting in drainage channels are often blocked by rubbish. The water quality of water bodies in both urban areas is very poor, municipal wastewater is subject to limited or no treatment before being emitted into the river. In Aranyaprathet, 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 polluting the river with effluent from the solid waste site. The wetland is operating with sewage- and stormwater and also flooded regularly during high flow which damages the planting efforts during the wet season and degrades the effect of water treatment. In Poipet, there is no sewage system and household wastewater flows diretly in the storm water drainage system and then into the river.

In addition to water related issues, urban heat-island effects are also caused by a lack of green space, and affect residents' health, lead to higher building cooling costs and reduce urban liveability. Increased traffic, construction, electricity generation and open burning of solid waste cause air quality problems, which could be ameliorated by greater provision of greenspace and vegetation. Moreover, the lack of urban green space in both urban areas mean the liveability of the urban areas in general is compromised.

### *5.1.4 Proposed NbS project concepts*

The landscape has water management issues with immediate cross-border implications. The project objectives address these concerns by focusing on (also see Figure 25):

- Cross-border stormwater management, to achieve an integrated transboundary approach;
- Urban greening; and
- River restoration, sediment traps, nature-based retention, and drainage improvements.

[58] ADB, 2022. Feasibility Study for Cambodia: Liveable Cities Investment Project (Poipet).
[59] Agricultural sector employment is important in the rural areas of the urban administrations, and in the broader rural hinterland, this is not the focus of the NBS measures evaluated in this landscape.

**Figure 25. Proposed Aranyaprathet and Poipet project concept and NbS measures**


| 1. Retention and infiltration of rooftop runoff | 2. Permeable surfaces | 3. Retention and infiltration of surface runoff | 4. Constructed wetlands | 5. River channel widening and rehabilitation | 6. River bank stabilization and rehabilitation | 7. Urban greening |
|---|---|---|---|---|---|---|

Table 13 summarises the challenges in the transboundary urban landscape and the proposed NbS conceptual designs to address these issues. More details on the project concept and NbS measures is available in Project concepts report.[60]

**Table 13. Summary of Aranyaprathet and Poipet – drivers of environmental degradation, impacts, NbS measures and expected range of benefits**

| Drivers |
|---|
| • Uncoordinated urban development<br>• Waste problem<br>• No maintenance of the river<br>• Inappropriate hydraulic structures<br>• Landfill discharging directly into the river<br>• Lack of an observation stations and early warning system |

[60] MRC. 2022. A Network of Nature based Solutions for Flood and Drought Resilience of the 9C-9T Sub-basin. Project Concepts. Mekong River Commission - Joint Project on Flood and Drought Management. Vientiane, Lao PDR

| **Impacts** |
|---|
| • Regular flooding<br>• Poor water quality |
| **NbS measures** |
| • Retention and infiltration of rooftop runoff<br>• Permeable surfaces<br>• Retention and infiltration of surface runoff<br>• River channel widening and rehabilitation and river bank stabilization and rehabilitation<br>• Urban greening |
| **Expected benefits** |
| • A significant reduction in flood risk for the two cities post-implementation of channel and bank rehabilitation<br>• Rehabilitation of over 60 ha of existing park land and the establishment of new green spaces and green corridors in both cities<br>• A significant reduction in runoff and excess drainage, through a network of decentralized urban rainwater retention measures |

## 5.2 Poipet

### 5.2.1 NbS measures and estimated costs

Table 14 gives details of the proposed NbS measures for Poipet as well as estimated investment, O&M and opportunity costs. Total estimated investment costs are approximately US$ 3.6 million. The largest single cost is the reprofiling of the river and restoration of the flood plain at a total cost of approximately US$ 3.36 million. Other greening measures were considered on an area basis, i.e., in order to achieve a 15% of urban land and 10% tree canopy cover. The main components of O&M costs are those for maintenance of the restored river section (US$ 66,000 per year) and tree maintenance costs (replacing dead trees, pruning etc) (US$ 25,000). Most works are deemed to be undertaken on public land not suitable for other uses, so opportunity costs are limited to those associated with the loss of cropland for floodplain restoration. The full rental cost of land for agricultural production of 200 US$/ha was used as an estimate. Further details on the sources of costs estimates are given at the foot of the table.

**Table 14. NbS measures and estimated costs**

| Measure | Details | Investment costs (US$)[a] | O&M costs (US$) | Opportunity costs (US$) |
|---|---|---|---|---|
| **1. Drainage channel rehabilitation and riparian buffers** | Channel reprofiling for 6.62 km, 500 US$/m. Including bank stabilisation with vegetated gabions [b] | 3,310,000 | 66,200[c] | - |
| **2.Floodplain restoration** | 64.44 ha of flood plain restoration on [d] Cost equivalent to afforestation and forest maintenance costs. | 50,714 | 13,339[e] | 12,888[f] |
| **3. Urban greening (tree planting)** | 10,097 trees planted inclusive of tree pits and protection measures, for an estimated total cost per tree of US$25.[g] | 252,425 | 25,243 | - |
| **Total** | | 3,613,139 | 104,782 | 12,888 |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for river channel reprofiling were estimated based upon local consultations including excavator costs ; [c] Estimated to be 2% of capital costs; [d] Costs planning and flood plain restoration assumed to be the same as afforestation costs at THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices – based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector [e] Maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in*

*2023 prices respectively; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha; [g] Provision of tree sapling, planning and provision of suitable growing medium, based upon local consultations and Soonsawad, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis.*

### 5.2.2 NbS benefits

The proposed NbS measures for Poipet provide a number of benefits, including avoided flood damages, reduced urban run-off, shading and reduced ambient air temperatures, carbon sequestration and improved air quality. A summary of all benefit streams and those assessed for the purposes of the CBA is given in Table 15. The details of these benefit streams and the approach taken to their estimation is given below.

**Table 15. NbS benefit streams and those valued**

| Benefits | Assessed | Notes |
|---|---|---|
| Avoided flood damages | Yes | Assessed using flood modelling, and damage functions for Cambodia |
| Carbon sequestration | Yes | Assessed as part of the iTree model |
| Air purification | Yes | |
| Reduced run-off | Yes | |
| Reduced air temperature | Yes | |
| Improved water quality | No | No, reliable estimates of water quality improvement not available |
| Improved urban amenity | No | No reliable transfer pricing for urban trees available |

**Avoided flood damages –** As regards flood damage, flood damages can be categorised into a number of different groups presented in Table 16.

**Table 16. Direct and indirect costs of flooding. Source: World Bank (2020)[61]**

| | Tangible | Intangible |
|---|---|---|
| **Direct Costs** | Cleaning costs associated with physical damage to assets<br>Public infrastructure<br>Hospitals<br>Commercial and residential buildings<br>Inventory of residential buildings<br>Vehicles<br>Loss of productive land and livestock<br>Crop loss | Loss of human life<br>Loss of ecological goods<br>Injuries<br>Loss of cultural (e.g., archaeological, religious, etc.) resources |
| **Indirect costs** | Loss of industrial production or revenues in project area<br>Loss of industrial production or revenues outside project area<br>Increased costs for commercial entities<br>Lost earnings/wages<br>Time cost from traffic disruption<br>Post-flood proofing investments by the private sector<br>Emergency flood management costs to the public sector | Long-term health costs from pollution or flood injuries<br>Post-flood recovery inconvenience and vulnerability<br>Well-being, psychological impact of flooding (increased anxiety due to raised perceptions of risk)<br>Decreased investment due to private sector perceptions of risk |

Given the limited availability of detailed data for the project area on historical flood damages and limited quantified data on socio-economic systems in the area, in line with international best practice[62], an approach focussing on direct damage and tangible impacts has been adopted. The estimation of annual expected direct damages was based upon (i) expected patterns of inundation

[61] World Bank (2020). Development of Coastal Multi-Hazard Mapping, Vulnerability and Risk Assessments and Investment Framework for Coastal Interventions in Selected Coastal Communities in Vietnam
[62] Approaches as described in the Multicoloured Manual 2010 used by the UK government and in the FLOODsite reports (see www.floodsite.net).

derived from modelling; (ii) patterns of current and expected land use; and, (iii) damage functions derived from the international literature which describe the relationship between inundation levels and expected damages for different land uses. Expected GDP growth (for a range of values) was also taken into account to capture expected increases in value-added in the affected areas. Indirect, tangible impacts were also deemed to be important, therefore, based upon the results of analysis of flood damage globally an indirect damage multiplier (ranging between 50% and 150%) was applied to arrive at an estimation of total tangible damages.

**Avoided direct flood damages –** avoided direct flood damages were estimated using a flood model developed for the area. Time series hydrological data was only available for seven years, but based upon this and local consultations, the maximum flood in this period was deemed to approximate a 1 in 10-year flood event. Shorter return period flood events were also approximated from this model. Model runs were conducted for the business-as-usual conditions without NbS interventions. The results were generated as flood maps showing the expected depth of floods over the susceptible area.

Flood damages were estimated based upon a damage function developed for the region in Huizinga et al.[63] Damage factors were defined in terms of percentage of maximum possible damages for different land uses, for example damage factors for residential areas in Asia are given in Table 17.

**Table 17. Average continental damage function for Asia – residential buildings. Source: Huizinga et al. 2017**

| Flood water depth (m) | Damage factor |
|---|---|
| **0** | 0 |
| **0.5** | 0.33 |
| **1** | 0.49 |
| **1.5** | 0.62 |
| **2** | 0.72 |
| **3** | 0.87 |
| **4** | 0.93 |
| **5** | 0.98 |
| **6** | 1.00 |

Maximum damages for Cambodia also given in the same database for 2010 for different land uses, these were adjusted to reflect changes in price level and economic activity in 2023.[64] Total damages for a 1 in 10-year flood were estimated based upon the sum of flooded area for each land type and flood depth. A similar exercise was conducted for the shorter return period floods also considered. Total expected annual flood damages were calculated by multiplying the probability of the flood occurring in any one year (for example 0.1 for a 1 in 10-year flood), by the damages for different return period floods. It was assumed that each assessed return period flood represented the maximum flood in that year, therefore when calculating total expected annual damages only incremental damages were included. Table 18 gives the total expected flood damages in 2023 with and without NbS intervention and from these the avoided flood damages benefit attributable to the NbS intervention. To calculate future expected avoided flood damages GDP growth rates were applied to reflect expected annual changes in economic activity. Over the 30-year time horizon of the economic assessment the average annual expected avoided direct flood damages are estimated to be approximately US$ 2.2 million.

**Table 18. Flood damages and avoided flood damages 2023**

| | Annual expected flood damage (US$) |
|---|---|
| **1. BAU** | 1,189,186 |
| **2. NbS** | 157,336 |
| **3. Avoided flood damages (1-2)** | 1,031,850 |

[63] Huizinga, J., Moel, H. de, Szewczyk, W. (2017). Global flood depth-damage functions. Methodology and the database with guidelines. EUR 28552 EN. doi: 10.2760/16510
[64] GDP growth was used to estimate approximate changes in economic activity and maximum damage values, with 3% AAGR assumed for agricultural land uses and 5% for urban land use.

**Avoided flood damages (indirect) –** Indirect damages are an important part of flood damage. Indirect damage due to flooding consisting of disruption to productive activities, employment, travel and additional costs associated with flood management and flood proofing the private sector (Table 16). Indirect damages are frequently calculated as a proportion of direct damages using a multiplier. While this relationship is relatively well established, the size of the multiplier differs significantly between various studies (Table 19). It should also be noted that some of these losses are associated with extreme weather events such as typhoons rather than flooding in isolation. Nevertheless, some of the largest indirect damage multipliers are associated with flood events, indicating the possible significance of indirect economic disruption and cost due to flooding alone.

**Table 19: Indirect Damages as Fraction of Direct Damages. Source: Bruijn, K. et al, 2015, Updated and improved method for flood damage assessment. DELTARES; Khanh Hao Provincial People's Committee, 2018, 2017 Vietnam Post Typhoon Damrey Rapid Damage and Needs Assessment**

| Event/model | Fraction of direct damage |
|---|---|
| Elbe floods 2002 | 5% |
| UK Floods 2007 | 12% |
| Hurricane Katrina 2005 | 30% |
| ARIO (input-output model) | 30% |
| Hurricane Sandy 2012 | 37% |
| Japan Tsunami 2011 | 50% |
| Typhoon Damrey 2017 | 100% |
| Thailand flood 2011 | 125% |

For the purposes of this study indirect damages due to flooding are assumed to be 100% of direct damages in the base case. Given the uncertainty surrounding this value, sensitivity analysis has been conducted for multiplier values of 50%, 100% and 150% (Table 21). Based upon this assumption the expected value of annual indirect avoided flood damages of NbS interventions is approximately US$ 1.03 million in 2023, and total expected avoided flood damages are estimated to be US$ 2.06 million.

**Urban greening (tree planting)** – in the case of Poipet the approach to the economic valuation of urban greening focussed upon the provision of additional tree cover in the urban area using a transfer pricing approach. Transfer prices were based upon a recent study of the value of urban trees in Bangkok[65] using the iTree model street model,[66] which enables the monetary valuation of ecosystem services provided by urban trees.

The model includes a range of benefits including reduced storm water run-off, air pollution reduction, greenhouse gas (GHG) emissions reduction and energy savings. Run-off reduction is a function of rainfall interception by tree leaves and stems, as well as the porous surface around the foot of the tree which allows water infiltration. Run-off reduction is estimated to account for approximately 75% of the monetary benefit of urban trees in Poipet. Air pollution removal is due to the deposition of air pollutants ($O_3$, $NO_x$, $SO_x$, and $PM_{10}$) on tree leaves and reduced air pollution emissions from reduced electricity use (due to urban cooling effects). Similarly, GHG emissions reductions are estimated based upon sequestration in additional biomass as trees grow, and reduction in emissions due to reduced cooling and therefore electricity demand.[67] Energy savings are derived from the cooling effect of urban trees reducing the heat-island effect associated with urban areas, and reducing demand for energy use for cooling buildings.

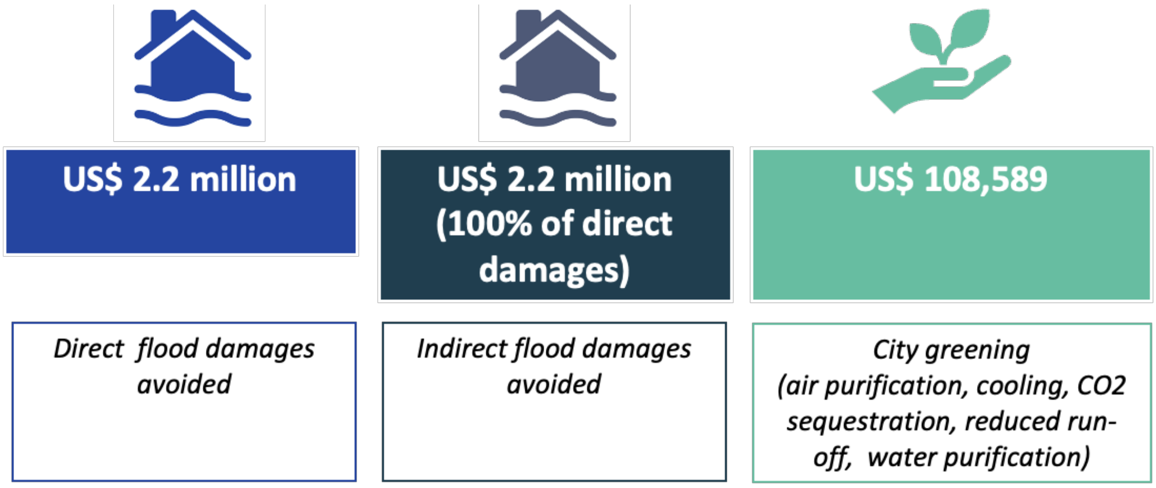
[65] Soonsawad, M, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis. University of California, Riverside.
[66] See https://www.itreetools.org/tools/i-tree-streets
[67] Given the continuing prevalence of diesel generation in urban areas of Cambodia, and likely higher electricity emissions factors than Thailand, GHG benefits and air pollution benefits associated with reduced electricity demand may be underestimated.

Study values for the monetary benefits of environmental services were adjusted using the ratio of estimated Cambodian per capita GDP to estimated Thai per capita GDP in 2023 of 0.41. The annual benefit for each tree was estimated to be US$ 10.75 and for all the proposed trees in Poipet, approximately US$ 109,000 per year. To estimate total benefit of the NbS, it was assumed that trees would be planted over a five-year period, and only yield 10% of benefits in the year after planting, increasing to 100% of benefits in year 10, it was also assumed that benefits would increase each year in line with GDP growth of 5%.

**Table 20. Estimated value of urban tree benefits 2023**

| Urban trees | Value (US$) | Share |
|---|---|---|
| **Energy saving** | 22,627 | 21% |
| GHG emissions reduction | 1,393 | 1% |
| Air pollution reduction | 3,405 | 3% |
| Storm water run-off reduction | 81,163 | 75% |
| **Total** | 108,589 | 100% |

**Figure 26. Approximate average annual benefits over lifespan of the project at Poipet**




### 5.2.3 Cost-benefit analysis

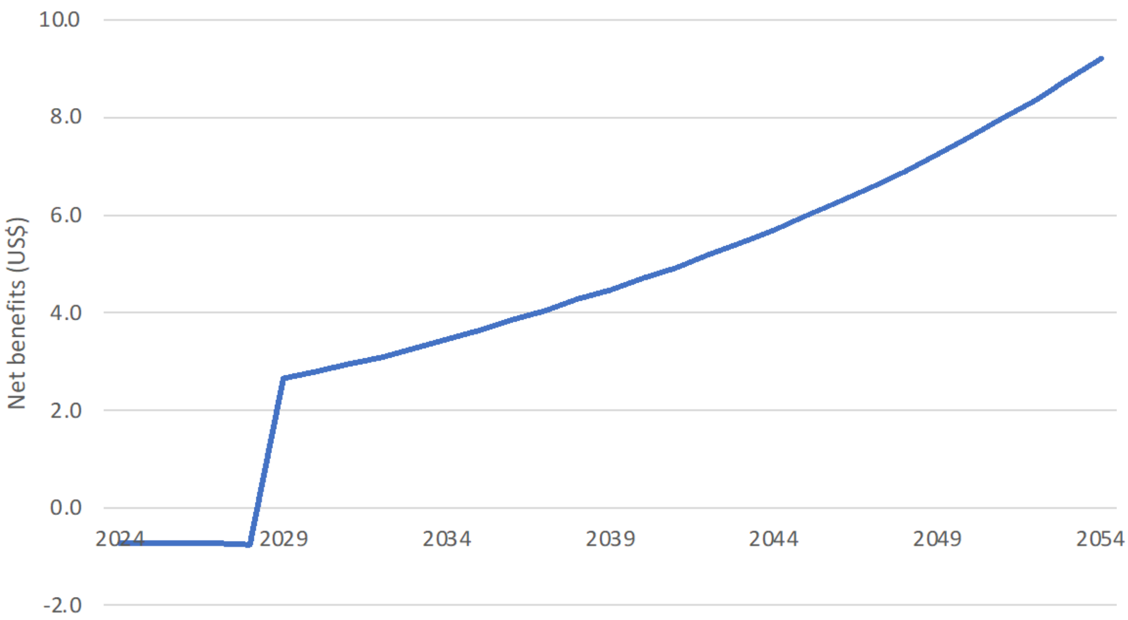
In all cases the benefits of proposed NbS interventions substantially outweighed the costs (Table 21). In the base case the NPV was estimated to be US$ 24.6 million for a discount rate of 9%, and the ratio of benefits to costs was estimated to be 6.9. Sensitivity analysis was conducted around these results to test the robustness of the analysis, and reflect substantial uncertainties surrounding estimates of both costs and benefits, as well as highlighting the effect of differing discount rate assumptions. In all cases considered NPV were substantial and BC ratios exceeded 1. With a 50% decrease in benefits and avoided indirect flood damage estimated to be 50% of direct damages proposed interventions pass common investment thresholds. Figure 24 shows the development of net benefits over time. These increase considerably from the completion of project investments largely in response to economic growth in the urban area leading to growth in avoided flood damages.

**Table 21. Poipet cost benefit analysis and sensitivity analysis results**

| | NPV for different discount rates (million US$) | | | BC ratio |
|---|---|---|---|---|
| **Case** | 6% | 9% | 12% | |
| **Base case** | 41.3 | 24.6 | 15.3 | 7.98 |
| **20% increase in investment costs** | 40.7 | 24.0 | 14.7 | 6.89 |
| **20% increase in O&M costs** | 41.1 | 24.5 | 15.2 | 7.67 |

| | | | | |
|---|---|---|---|---|
| **20% increase in all costs** | 40.5 | 23.9 | 14.6 | 6.65 |
| **50% decrease in project benefits** | 18.6 | 10.5 | 6.1 | 3.99 |
| **Indirect avoided flood damages 50% of direct** | 30.5 | 17.9 | 10.8 | 6.07 |
| **Indirect avoided flood damages 150% of direct** | 52.2 | 31.4 | 19.7 | 9.90 |

**Figure 27. Net benefits over time**




This represents a conservative estimate of the potential benefits of the proposed interventions. Several potentially important benefits have not included due to lack of data, probably most important amongst these are increased liveability and amenity value. This is often valued based upon the uplift in property prices, associated with proximity to urban green spaces or general improvements to the public realm in urban areas.[68]

In high income country contexts these values can be large, with property values being 15% higher within walking distance of urban green space, representing the capitalisation of a portion of the benefits of green space into the value of private properties. It is unclear whether a similar uplift would be attributable to the provision of green space in the context of Poipet. Although some significant uplift would be likely in the long term. However, to establish the extent of this effect would require detailed property price surveys in similar locations, which has not been possible in the context of this study.

### 5.2.4 Distributional considerations

NbS interventions in Poipet are unlikely to have significant distributional implications. Project costs and O&M costs will be covered by public funds, and no additional land will be required for the provision of NbS investments, with most of the river rehabilitation work taking place within the current channel of the river and urban greening taking place on public land in the city. The exception to this is the land required for floodplain restoration on the right bank of the river, which is within Thailand. However, in this case land holders can be fully compensated for land losses along the river.

[68] See Olmsted, F.L. In Crompton, J.L. (2007). The role of the proximate principle in the emergence of urban parks in the United Kingdom and the United States. Leisure Studies, 26(2) pp.213-234; and, Neill Dunse. (2007). Urban parks, open space and residential property values, RICS.

City residents and businesses will benefit directly from reduced fluvial flood damages and disruption, reduced pluvial flooding, improved air quality, reduced urban temperature and as a consequence building cooling costs. In addition to the evaluated benefit, there are likely to be substantial benefits to urban greening through improved liveability and attractiveness of the urban area. Many of these benefits are likely to be capitalised into private property prices, particularly in areas that benefit from flood reduction and greening measures.

On the other hand, urban greening measures in particular may benefit poorer households which have limited access to private space and facilities, and will be free to enjoy the benefits of improved public spaces in the urban area.

Women in Cambodian household are typically responsible for caring for the sick. Therefore, women may also stand to benefit from the interventions, mainly as a consequence of a reduced care burden due to decreases in morbidity due to water-borne diseases associated with flooding.

**Table 22. Distributional considerations for NbS interventions in Poipet**

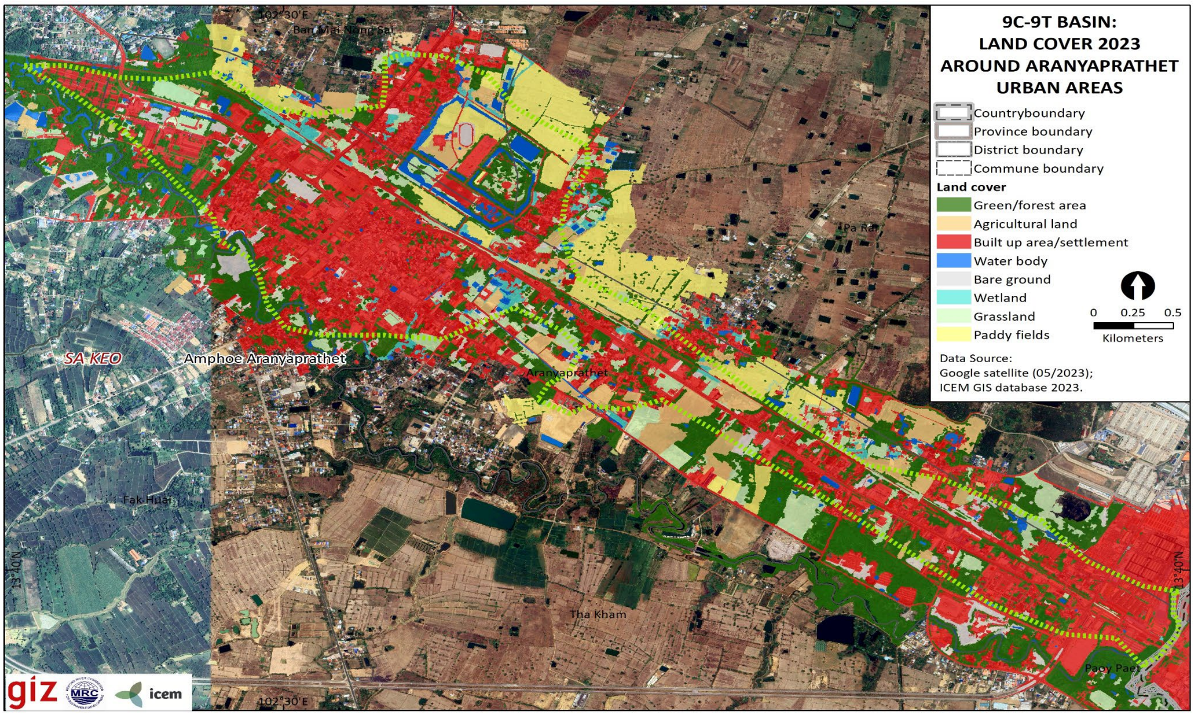
| NbS intervention | Benefits | Costs |
|---|---|---|
| **Drainage channel rehabilitation and riparian buffers** | • Employment in river restoration<br>• Reduced fluvial flooding and disruption for communities and businesses in the city<br>• Poorer households living in proximity to the river likely to benefit<br>• Lower disease/morbidity burden on women | • Costs of investment borne by national government<br>• Costs of O&M borne by provincial government |
| **Floodplain restoration** | • Employment in flood plain restoration<br>• Reduction in fluvial flooding as above. | • Some loss of agricultural in floodplain<br>• Cost of flood plain restoration |
| **Urban greening (tree provision)** | • City residents benefit from, reduced pluvial flooding, reduced urban temperatures and cooling requirements, improved air quality<br>• National/international benefits from reduced GHG emissions<br>• Lower disease/morbidity burden on women | • Costs of investment and O&M borne by government |

## 5.3 Aranyaprathet

### 5.3.1 NbS scenario and costs

Table 14 gives details of the proposed NbS measures for Aranyaprathet as well as estimated investment, O&M and opportunity costs. A high-resolution land cover map was developed for the Aranyaprathet study area to identify existing land use types (Figure 28). This was a key input to the hydrological modelling of proposed NbS interventions for Aranyaprathet.

**Figure 28. Land cover map for Aranyaprathet**




Total estimated investment costs are approximately US$ 49.2 million. The largest single cost are the retention and infiltration of rooftop and surface runoff measures applied to an estimated 15% of the built-up urban area or approximately 77 ha. These include provision of green roofs (11.5 ha), rain gardens (3.8 ha), porous pavements (53.9 ha), vegetated swales (3.8 ha) and bioretention areas (3.8ha), with an average weighted cost of US$ 63.69 per $m^2$. Tree planting was also considered in order to achieve an additional canopy cover of 98 ha, or 20% of the urban area, requiring 12,479 trees.

The main components of O&M costs are those for maintenance of the various greening measures estimated to be 5% of capital costs or approximately US$ 2.4 million per year. Works are assumed to be undertaken on public land, so opportunity costs are limited to those associated with the loss of cropland for floodplain restoration. The full rental cost of land for agricultural production of 200 US$/ha was used as an estimate. Further details on the sources of costs estimates are given at the foot of the table.

**Table 23. NbS measures and estimated costs**

| Measure | Details | Investment costs (US$)[a] | O&M costs (US$) | Opportunity costs (US$) |
|---|---|---|---|---|
| 1. Retention and infiltration of rooftop and surface runoff | 77 ha of runoff reduction measures at a weighted costs of approximately US$ 63.6 $m^2$ [b] | 48,923,654 | 2,446,183[c] | - |
| 2. Riparian buffer strip (and floodplain restoration) | 45.7 ha of floodplain restoration on [d] Cost equivalent to afforestation and forest maintenance costs | 35,982 | 9,464[e] | 9,144[f] |
| 3. Urban greening (tree planting) | 12,479 trees planted inclusive of tree pits and protection measures, for an estimated total cost per tree of US$25.[g] | 311,975 | 31,198 | - |
| **Total** | | 3,613,139 | 104,782 | 12,888 |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for green measures were taken from a recent literature review of the implementation of NbS in urban areas, values were adjusted to reflect differences in GDP per capita between Thailand and the referenced study site and subsequent changes in price levels, see Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M., ... & Lopez-Gunn, E. (2020).*

*Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Natural Hazards and Earth System Sciences, 20(1), 243-270. ; [c] Estimated to be 5% of capital costs; [d] Costs planning and flood plain restoration assumed to be the same as afforestation costs at THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices - based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector [e] Maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in 2023 prices respectively; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha; [g] Provision of tree sapling, planning and provision of suitable growing medium, based upon local consultations and Soonsawad, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis.*

### 5.3.2 NbS benefits

The proposed NbS measures for Aranyaprathet provide a number of benefits, including avoided flood damages from pluvial flooding, reduced urban run-off, shading and reduced ambient air temperatures, carbon sequestration and improved air quality. A summary of expected benefits from the NbS interventions and which were assessed as part of the CBA exercise is included in Table 24. The details of these benefit streams and the approach taken to their estimation is given below.

**Table 24. NbS benefit streams and those valued**

| Benefits | Assessed | Notes |
|---|---|---|
| Avoided flood damages | Yes | Assessed using GIS assessment of run-off and pluvial flooding, and damage functions for Thailand |
| Carbon sequestration | Yes | Assessed as part of the iTree model |
| Air purification | Yes | |
| Reduced run-off | Yes | |
| Reduced air temperature | Yes | |
| Improved water quality | No | No, reliable estimates of water quality improvement not available |
| Improved urban amenity | Yes | Assessed based upon transfer pricing for urban greening measures |

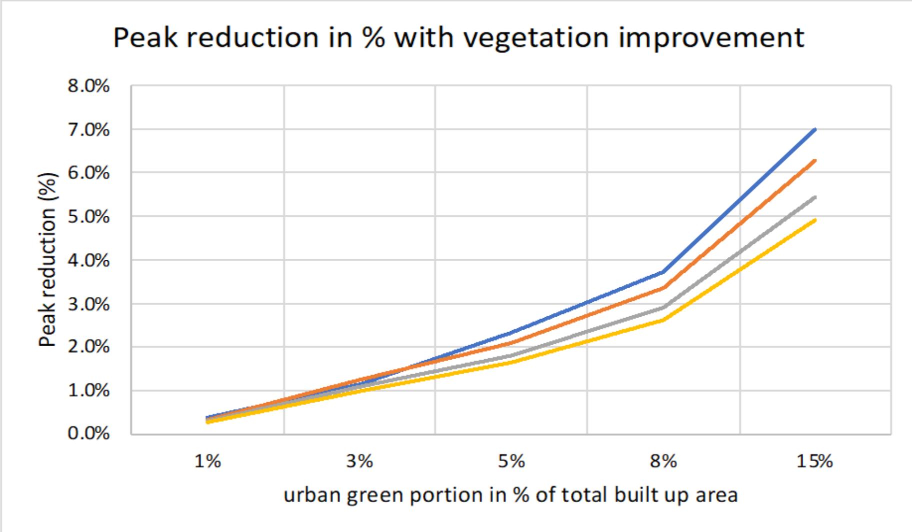
**Avoided direct flood damages** – based upon local consultations, pluvial flooding from urban run-off and inadequate drainage is a serve issue in built-up areas of Aranyaprathet. Quantified details of flood and damage extent have not been available, nor have details to allow the development of pluvial flood maps from available hydrological data. Hydrological modelling was conducted to demonstrate the relationship between increased NbS, increased urban green area and reduced run-off.

Infiltration trenches and swales along roads have a potential to reduce runoff volume by 4% for storm events > 60 minutes up to 30% for storm events <= 15 minutes (high confidence). It depends on the investment how many trenches and swales will be implemented. A flood peak reduction is very unlikely (high confidence). Similarly, modelling shows that retention and infiltration of rooftop and surface runoff measures (vegetation enhancement on parks, open spaces, roofs, etc.) have the potential to reduce runoff peaks and volume. It depends on the area of greening. 1% of the built-up area brings a reduction of <1%, 15% of the built-up area achieves up to 7% reduction.

Given the absence of adequate data to allow flood modelling, it was assumed that the reduction in flood extent due to the implementation of various NbS measures (excluding urban trees which were addressed separately) was roughly double the reduction in run-off or 15%. It was conservatively assumed that 10% of the urban area was subject to pluvial flooding to a depth of up to 0.5 m. Based upon available damage functions for residential areas in Asia (see table 14), and maximum damage values for residential areas in Thailand adjusted for price changes and GDP growth of US$ 89.2/$m^2$ an annual expected direct damage value from pluvial flooding of US$ 23.8 was estimated.[69] This was estimated to increase at 2.7% per year in line with GDP growth. A 15% reduction in this attributable to NbS measures was estimated to be US$ 3.3 million per year on average between 2024 and 2054.

[69] As with Poipet, the reference of this was Huizinga, J., Moel, H. de, Szewczyk, W. (2017). Global flood depth-damage functions. Methodology and the database with guidelines. EUR 28552 EN. doi: 10.2760/16510

**Figure 29. Modelled relationship between peak run-off and share of urban green area for different return period precipitation events**




**Avoided indirect flood damages** – as with Poipet avoided indirect flood damages were estimated to be 100% of direct damages of US$ 3.3 million per year (see section 5.2.2 for a more detailed account).

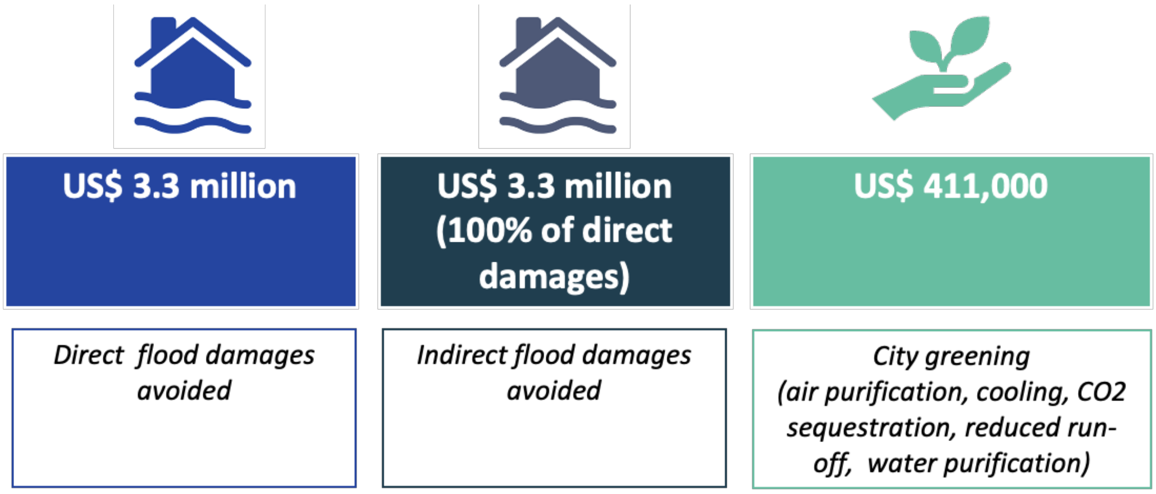
**Urban tree planting –** tree planting was evaluated independently of the retention and infiltration of rooftop and surface runoff measures, as transfer pricing was available for urban trees from a relatively recent study conducted in Bangkok,[70] as referred to in the Poipet valuation, using the iTree model street model,[71] which enables the monetary valuation of ecosystem services provided by urban trees.

As noted in the case of Poipet, the model includes a range of benefits including reduced storm water run-off, air pollution reduction, GHG emissions reduction and energy savings (see section 5.2.2 above). All benefits are deemed additional to benefits provided by other green measures. The value of benefits provided per tree at current prices was estimated to be US$ 26.52 per year, and in total benefits were estimated to be worth on average US$ 520,000 per year. To estimate total benefit of the NbS, it was assumed that trees would be planted over a five-year period, and only yield 10% of benefits in the year after planting, increasing to 100% of benefits in year 10, it was also assumed that benefits would increase each year in line with GDP growth of 2.7%.

**Urban amenity value** – given the importance of urban greening measures to the NbS scheme in Aranyaprathet, the estimated value of urban amenity has also been attempted using transfer pricing from a recent study of urban green spaces in Beijing, China.[72] In the context of Beijing these 'cultural services' were valued to be worth RMB 16.7/m$^2$/year in 2021, equivalent to approximately US$ 2.78/m$^2$/year in Thailand, adjusting for changes in price levels and differences in per capita GDP. It was assumed that amenity values would be available from the project immediately following construction, and that they would increase in line with GDP growth at 2.7% per year. In total amenity value for the additional 77 ha of green area, excluding urban trees, was estimated to be worth on average US$ 2.02 million per year.

[70] Soonsawad, M, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis. University of California, Riverside.
[71] See https://www.itreetools.org/tools/i-tree-streets
[72] Xu, H., & Zhao, G. (2021). Assessing the value of urban green infrastructure ecosystem services for high-density urban management and development: Case from the capital core area of Beijing, China. *Sustainability*, *13*(21), 12115.

**Figure 30. Approximate average annual benefits of proposed NbS measures for Aranyaprathet**



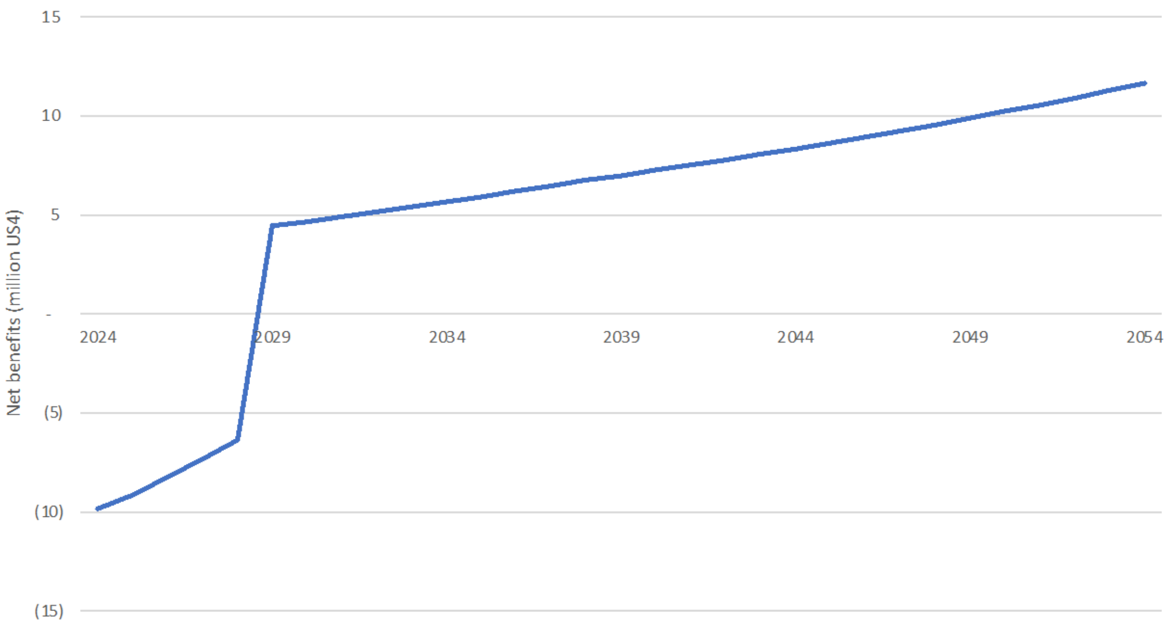

### *5.3.3 Cost-benefit analysis*

The high up-front costs of proposed retention and infiltration of rooftop and surface runoff measures meant that in the case of Aranyaprathet the outcome of the CBA was particularly sensitive to discount rates and changes in investment and O&M cots (Table 25). In the base case the NPV was estimated to be US$ 9.7 million for a discount rate of 9%, and the ratio of benefits to costs was estimated to be 1.2. Sensitivity analysis was conducted around these results to test the robustness of the analysis, and reflect substantial uncertainties surrounding estimates of both costs and benefits, as well as highlighting the effect of differing discount rate assumptions. In particular, the literature indicated quite high costs for proposed NbS interventions, even when these were adjusted downward to reflect economic conditions in Thailand. With this in mind an additional sensitivity case was added considering project costs 50% lower than those currently estimated, which as expected shows much better performance. Figure 31 shows the development of net benefits over time, as with Poipet, the rapid growth in net benefits is related to economic growth and growing avoided flood damages.

**Table 25. Aranyaprathet cost benefit analysis and sensitivity analysis results**

| | NPV for different discount rates (million US$) | | | BC ratio |
|---|---|---|---|---|
| **Case** | 6% | 9% | 12% | |
| **Base case** | 32.1 | 9.7 | -2.3 | 1.17 |
| **20% increase in investment costs** | 23.8 | 2.1 | -9.4 | 1.03 |
| **50% decrease in investment costs** | 52.9 | 28.9 | 15.4 | 1.75 |
| **20% increase in O&M costs** | 26.5 | 5.8 | -5.2 | 1.09 |
| **20% increase in all costs** | 18.2 | -1.9 | -12.3 | 0.97 |
| **50% decrease in project benefits** | -18.7 | -24.1 | -26.1 | 0.58 |
| **Indirect avoided flood damages 50% of direct** | 13.2 | -2.9 | -11.2 | 0.95 |
| **Indirect avoided flood damages 150% of direct** | 42.7 | 14.6 | -0.6 | 1.22 |

**Figure 31. Net benefits over time**




Overall, as with the other valuations this represents a conservative estimate of benefits. The lack of data on the extent of flooding in the urban area is a particular weakness in the valuation which can only be addressed with more data on flood characteristics and accurate elevations of the drainage areas in the city.

### *5.3.4 Distributional considerations*

NbS interventions in Aranyaprathet, similar to those in Poipet, are unlikely to have significant distributional implications. Project costs and O&M costs will be covered by public funds, and no additional land will be required for the provision of NbS investments. Runoff reduction and urban greening is expected to be implemented on public land in the city. The exception to this is the land required for floodplain restoration on the right bank of the river. However, in this case land holders can be fully compensated for land losses along the river.

City residents and businesses will benefit directly from reduced pluvial flood damages and disruption, reduced pluvial flooding, improved air quality, reduced urban temperature and as a consequence building cooling costs. There are estimated to be substantial benefits to urban greening through improved liveability and attractiveness of the urban area. Many of these benefits are likely to be capitalised into private property prices, which as with Poipet may favour land holders. These drivers of inequality could however be addressed through effective land or property value taxes, which could also help recoup public investment in NbS measures and fund ongoing O&M.

Urban greening measures in particular may benefit poorer households which have limited access to private space and facilities, and will be free to enjoy the benefits of improved public spaces in the urban area.

**Table 26. Distributional considerations for NbS interventions in Aranyaprathet**

| NbS intervention | Benefits | Costs |
|---|---|---|
| **Retention and infiltration of rooftop and surface runoff** | • Employment in runoff reduction measures<br>• Reduced pluvial flooding and disruption for communities and businesses in the city<br>• Poorer households living in poorly drained areas<br>• Lower disease/morbidity burden on women | • Costs of investment borne by national government and provincial<br>• Costs of O&M borne by provincial government |
| **Riparian buffer strips (and floodplain restoration)** | • Employment in flood plain restoration | • Some loss of agricultural in floodplain<br>• Cost of flood plain restoration |
| **Urban greening (tree provision)** | • City residents benefit from reduced pluvial flooding, reduced urban temperatures and cooling requirements, improved air quality<br>• National/international benefits from reduced GHG emissions<br>• Lower disease/morbidity burden on women | • Costs of investment and O&M borne by government |

# 6 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Key conclusions

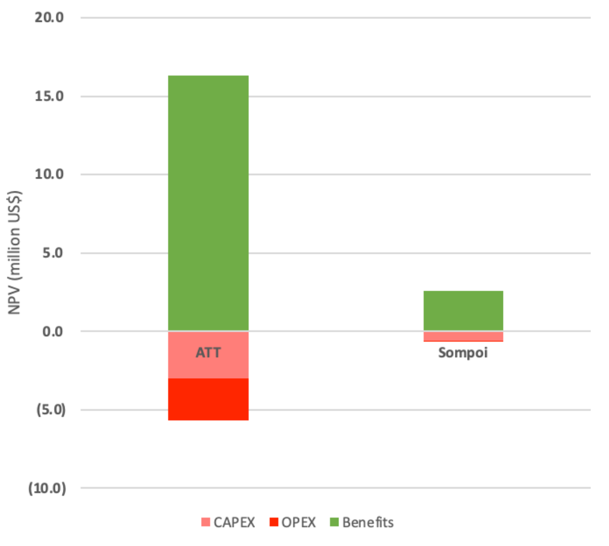
This report gives an initial economic valuation of proposed NbS measures in three landscapes across the 9C-9T river basin. The assessment approach in each landscape differed depending on data and modelling availability, the types of NbS measures in question and the expected benefits of the proposed NbS measures. In the two rural catchments, modelling of changes in land use between BAU and NbS scenarios allowed the estimation of changes to sediment load and the attribution of impacts to changes in land use. These impacts and other co-benefits were assessed using market-based pricing, transfer pricing or replacement cost pricing where appropriate.

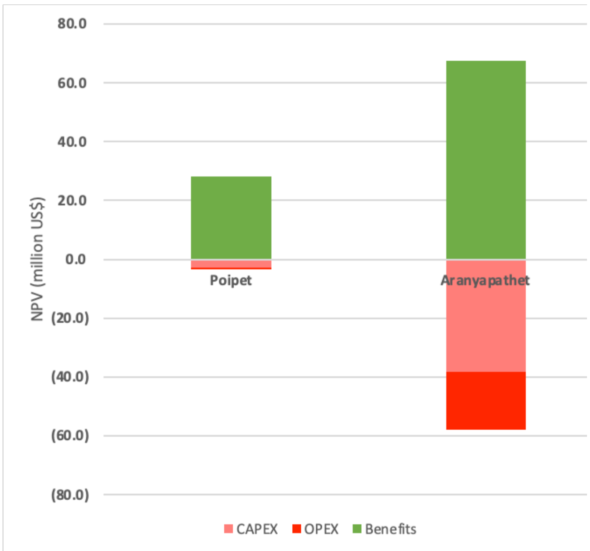
In Poipet, the development of a flood model allowed the identification of NbS flood mitigation benefits which were considered along-side the broader benefits of urban greening (tree planting). In Aranyaprathet, GIS based modelling of changes in run-off due to NbS interventions was conducted. Costs were based upon local consultations and secondary literature. Due to data availability limitations and resource constraints estimates generated in the economic assessment are best regarded as *rough order of magnitude* estimates, to be used to provide a preliminary understanding of the scale and feasibility of a project before more detailed analysis and cost estimation can be conducted.

The evaluation of NbS interventions in the four locations found that the proposed measures perform relatively well. In the ATT landscape the base case shows an NPV of US$ 10.6 million and a BC ratio of 2.59. Sensitivity analysis was conducted to test the results of the analysis in respect of changes in key parameters including increases in investment costs for NbS measures, increases in O&M costs for the proposed measures and, reductions in the level of benefits. In all sensitivity cases considered, NPV is at least US$ 1.7 million and the BC ratio at least 1.43 (in the most extreme case of a reduction in benefits of 50%). This is without taking account of any benefits from biodiversity that may be attributable to the interventions. Similarly, in the Sompoi landscape proposed NbS investments in the base case have an NPV exceeding US$ 1.9 million, albeit with a higher BC ratio of 3.73. Sensitivity analysis also demonstrates that the positive performance is generally robust to most changes in valuation parameters, again even in the most extreme case considered, or a 50% reduction in project benefits NPV is still US$ 300,000 and the BC ratio is 1.86.

The proposed NbS measures in Poipet also perform well with a significant reduction in flooding, with an NPV in the base case of US$ 24.5 million and a BC ratio of 7.98. For Poipet, the economic performance remains positive in all considered sensitivity cases. The proposed interventions in Aranyaprathet have a higher estimated upfront cost and O&M costs than the other projects, this is to some extent off-set by larger benefits, but means the results of the CBA are sensitive to the discount rate. In the base case the project is estimated to have a NPV of US$ 9.7 million and a BC ratio of 1.17. Care needs to be taken with the estimates for Aranyaprathet in particular as the results are based upon the likely impact of NbS on the extent of flooding that has been assumed and needs to be verified. The estimated costs of NbS are also based upon secondary studies largely conducted outside the region and need to be verified for the Thai context.

**Figure 32. Summary of CBA results showing estimated NPV for CAPEX. OPEX and benefits of NbS measures, rural reservoirs (left), urban (right)**



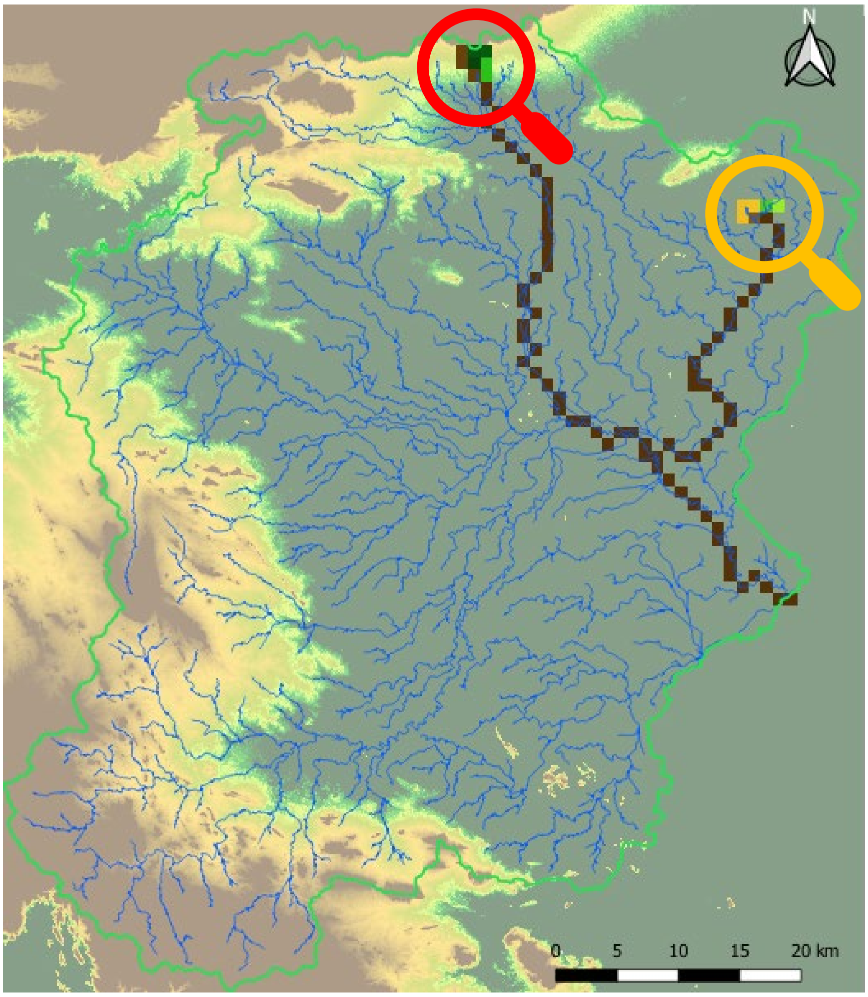

The distributional implications of the NbS scenarios in the two rural landscapes are similar. NbS interventions do imply government investment and ongoing provincial government expenditures in various O&M activities to ensure the continuing effectiveness of NbS interventions. The communities most likely to be adversely affected by NbS in the upper parts of the watersheds are those currently making unsustainable use of forest resources, such as clearing forest land for charcoal or agricultural use, or households grazing cattle in these areas, which would face restrictions on these activities. In contrast, aside from some loss of crop land for the provision of retention basins and riparian corridors – which could be fully compensated – rice farmers and their communities in the middle and lower areas of the two rural landscapes stand to benefit from the NbS measures. This includes benefits from greater water availability for dry season crops and improved fisheries.

The largest benefit in both cases is, however, GHG emissions reduction which is a global benefit, it is a benefit which will not be enjoyed proportionately or directly households in these areas. It is likely to require some incentive structure to be created to incentivise the protection of forested areas through participation in a payments scheme.

In the case of the urban areas, the distributional implications are mixed. Costs for the provision and maintenance of NbS will be borne by government. Significant benefits are expected to be realised for urban residents through reduced flooding, reduced runoff and urban greening benefits. These will be available to all residents. On one hand, poorer households, without access to adequate private space or effective cooling, are likely to benefit significantly from the improvement of public spaces which they can enjoy freely. On the other hand, a large share of benefits is likely to be captured by wealthier land-owners and property speculators in these urban areas as the value of NbS improvements to the urban areas is capitalised into property prices. This may be addressed though effective property taxation measures which can offset the public investment in NbS measures.

The transboundary implications of the proposed NbS measures are also important to consider. Upstream interventions are likely to have important implications for the basin downstream, in particular, as regards improved water quality, reduced sedimentation and improved water regulation and catchment yields. These will become more important as NbS interventions are implemented at scale (Figure 33). In the Aranyaprathet – Poipet cross-border conurbation, NbS measures in Aranyaprathet to reduce urban run-off and other wastewater emissions will have positive impacts on water quality in Poipet and further down the basin. While it was not possible to model the cross-border implications of fluvial flooding reduction measures in Aranyaprathet for flooding in Poipet within the scope of this study, it is likely that NbS measures to ameliorate flooding would have positive impacts on the extent of fluvial flooding in Poipet. Finally, it should be noted that the river reprofiling and floodplain restoration NbS measure themselves have transboundary implications, with the proposed floodplain restoration taking place in Thailand. These considerations serve to emphasise the importance of transboundary cooperation in the management of the 9C-9T basin.

**Figure 33. Modelled transboundary flow and sediment implications of proposed NbS measures across project landscapes – downstream linkages for ATT (R – yellow) as a result of upstream interventions at Sompoi (L – red)**




## 6.2 Recommendations

The following recommendations are based upon the experience of this study, and make proposals for further activities to be conducted in the three catchments are made for consideration in the implementation of the 9C-9T master planning process:

- As noted in the introduction to this report, the CBA estimates included here are best regarded as rough-order of magnitude estimates, conduced with limited information for conceptual designs and sufficient to establish proof of concept. There is a need for more detailed follow - up studies as the detailed designs for the proposed NbS projects are developed.
- In both rural landscapes, the CBA presents a strong case for investment in NbS, proving that investments in NbS make economic sense. In consequence, efforts to integrate NbS measures systematically into river basin planning in both Thailand and Cambodia are recommended. This will include the development of design concepts and standards for NbS measures, and training of planners, engineers, economists and policy makers on NbS concepts, evaluation and planning for rural environments.
- In the case of urban areas NbS measures should also be considered systematically as part of the planning process. However, constraints on land use in urban areas and poor land development controls may well obstruct the effective implementation of NbS measures. Because of this, it is

probably best to concentrate efforts on a selected number of sites, which can serve to illustrate the public and private benefits of NbS provision and build a consensus in urban communities around their development.

- As noted above, given the lack of community incentive for forest protection in the rural landscapes, the possibilities for obtaining funds for afforestation and forest protection (through for example REDD+, VCMs) should be explored. This will also require institutional arrangements to ensure effective monitoring of forest areas and dispersal of funds to affected communities.
- The study has been hampered by lack of data particularly relating to the hydrology of the three landscapes. The absence of sufficient data to allow an assessment of the impacts of fluvial flooding in Aranyaprathet and flash-flooding impacts in Sompoi stand out. As does the lack of sufficient data to establish a water balance in the two rural locations. If further investments are to be considered for these areas, good-quality and reliable data must be provided, and it is particularly important that a more concerted effort be undertaken to understand the hydrology including the modelling of flooding and water balance.
- There is a need to better integrate the impacts of climate change into the hydrological analysis to understand what this will mean for the watersheds over the next thirty years. At present this is absent from the economic analysis due to data and resource constraints, but it will need to be considered in greater detail in any follow-up activities.
- The conduct of a financial cost benefit analysis should be considered to quantify in greater detail the likely impact of NbS measures on different stakeholder and community groups within the catchments. This is likely to be more important for the rural catchments where NbS measures are likely to have implications for household production and patterns of land use. To conduct this analysis more information on household incomes and production will be needed and may imply the conduct of more detailed primary data collection exercises that were not possible within the remit of this study.

# ANNEX I: COST TABLES

**Table 27: Full cost calculations for ATT**

| Measure | Details | Investment costs [a] (US$) | | O&M costs (US$) | | Opportunity costs (US$) | |
|---|---|---|---|---|---|---|---|
| **1. Sreng natural channel buffer and wetland corridor** | Using native species, cost of US$ 944/ha [b] Area is 50 m either side of channel for 6.95 Km total area 69.42 Ha. Maintenance costs US$ 100/ha for first 10 years. | 944 US$/ha x 69.42 ha | 65,532 | 100 US$/ha x 69.42 ha | 6,942 | 150 US$/ha x 69.42 ha | 10,413[c] |
| **2. Decentralised irrigation/fishponds** | 200 fishponds constructed in upper catchment of capacity 4,000 m3 (100 m x 20 m x 2 m). Including bank stabilisation measures and 5 m buffer equivalent to 0.12 ha per pond or 24 ha over 200 ponds. Maintenance costs as in 1. | Fishponds:<br>1.5 US$/m3 x 4,000 x 200<br>Buffer:<br>944 US$/ha x 0.12 ha x 200 | 1,222,656[d] | 100 US$/ha x 0.12 ha x 200 | 2,400 | | - |
| **3. Restoration of former drainage channels** | 30 m restoration either side of channels for 40 Km equivalent to 240 ha with costs as in 1.[e] Plus 5-10 leaky weirs in each channel, or 60 in total. | Buffer:<br>944 US$/ha x 240 ha<br>Leaky weirs:<br>500 US$ x 60 | 256,560 | 100 US$/ha x 240 ha | 24,000 | | -[f] |
| **4. Agricultural field edge buffers and connectivity** | 20 m field buffers for approximately 336.4 km of field edges equivalent to 673 ha. Planting and maintenance costs as in 1. | 944 US$/ha x 673 ha | 635,123 | 100 US$/ha x 673 ha | 67,280 | 150 US$/ha x 673 ha | 100,860 |
| **5. Reforestation of flooded forest** | Planting and maintenance of restored area of 734 ha costs as in 1. | 944 US$/ha x 734 ha | 692,896 | 100 US$/ha x 734 ha | 73,400 | 150 US$/ha x 734 ha | 110,100 |
| **6. Forest rehabilitation and reforestation areas** | Planting and maintenance of restored area of 1,017.8 ha on southern edge of community forest and road buffer strip. Costs as in 1. | 944 US$/ha x 1,018 ha | 960,803 | 100 US$/ha x 1018 ha | 101,780 | 150 US$/ha x 1018 ha | 122,670 |
| **Total** | | | **3,833,571** | | **275,802** | | **344,043** |

Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] 944 US$ planting costs per Ha (0.6 US$ per seedling, 0.25US$ planting costs, for 1,110 seedlings per ha);[c] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 150 US$/ha; [d] Construction costs for ponds estimated based upon earth removal costs of 1.5 US$/$m^3$; [e] all afforestation costs, for reestablishment of upper catchment forests, flooded forest and buffer strips are assumed to have the same unit investment and maintenance costs; [f] restoration of relic drainage channels was assumed to require no additional land take

**Table 28: Full cost calculations for Sompoi**

| Measure | Details | Investment costs (US$) [a] | | O&M costs (US$) | | Opportunity costs (US$) | |
|---|---|---|---|---|---|---|---|
| **1. Drainage channel rehabilitation and riparian buffers** | 34.95 ha of existing and relic drainage corridors and their buffers at 787 US$/ha [b] With 15 m riparian buffer width either side of channel. With bank stabilisation and mixed native species. No agricultural encroachment. | 787 US$/ha x 35 ha | 27,491 | Year 2-6:<br>207 US$/ha x 35 ha<br>Year 7-10:<br>100 US$/ha x 35 ha | 7,235[c] | | - |
| **2.Check dams and leaky weirs** | 70 leaky weirs on drainage channels. | 500 US$ x 70 | 35,000[d] | 2% x 35,000 US$ | 700 | | - |
| **3. Decentralised irrigation ponds** | 50 decentralised irrigation ponds of 4,000 $m^3$, 100 m x 20 m x 2 m [e] Including bank stabilisation measures and 5 m buffer equivalent to 0.12 ha per pond or 6 ha over 50 ponds. Investment and maintenance costs for buffers as in 1. | Irrigation ponds:<br>2.07 US$/m3 x 4,000 x 50<br>Buffer:<br>787 US$/ha x 0.12 ha x 50 | 418,722 | Year 2-6:<br>207 US$/ha x 6 ha<br>Year 7-10:<br>100 US$/ha x 6 ha | 1,242 | | - |
| **4. Agricultural field edge buffers and connectivity** | 20 m field buffers for an area of approximately 33.1 ha. Planting and maintenance costs as in 1. | 787 US$/ha x 33.1 ha | 26,050 | Year 2-6:<br>207 US$/ha x 33.1 ha<br>Year 7-10:<br>100 US$/ha x 33.1 ha | 6,852 | 200 US$/ha x 33.1 ha | 6,620[f] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **5. Forest rehabilitation and reforestation areas** | 636.5 ha for protection and rehabilitation of National Park foothills and buffer zone. Planting and maintenance costs assumed to be 50% of 1. | 787 US$/ha x 636.5 ha x 50% | 250,463 | Year 2-6: 207 US$/ha x 636.5 ha x 50% Year 7-10: 100 US$/ha x 636.5 ha x 50% | 65,878 | | - |
| **6. Reforestation of selected degraded sites** | Reforestation of 26.1 ha of degraded forest pocket sites within National Park for reforestation. Planting and maintenance costs as in 1. | 787 US$/ha x 26.1 ha | 20,541 | Year 2-6: 207 US$/ha x 26.1 ha Year 7-10: 100 US$/ha x 26.1 ha | 5,403 | | - |
| **7. Lalu vegetated edge buffer** | 5.4 ha of vegetated buffer to southern boundary of Lalu site. Planting and maintenance costs as in 1. | 787 US$/ha x 5.4 ha | 4,250 | Year 2-6: 207 US$/ha x 5.4 ha Year 7-10: 100 US$/ha x 5.4 ha | 1,118 | 200 US$/ha x 5.4 ha | 1,080 |
| **8. UN Road drainage and buffer** | 3.75 ha of road buffer (also extending north to protected area boundary). Planting and maintenance costs as in 1. | 787 US$/ha x 3.75 ha | 2,951 | Year 2-6: 207 US$/ha x 3.75 ha Year 7-10: 100 US$/ha x 3.75 ha | 776 | 200 US$/ha x 3.75 ha | 750 |
| **Total** | | | **785,467** | | **89,203** | | **8,450** |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for afforestation and creation of buffer strips assumed to be THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices - based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector; [c] Forest and buffer strip maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in 2023 prices respectively; [d] Leaky weirs estimated to cost US$ 500 each plus an average annual 2% maintenance cost; [e] earth moving and dredging costs range from between THB 45 – 97 /$m^3$ costs assumed to be in middle of this range equivalent to 2.07 US$/$m^2$; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha.*

**Table 29: Full cost calculations for Poipet**

| Measure | Details | Investment costs (US$)[a] | | O&M costs (US$) | | Opportunity costs (US$) | |
|---|---|---|---|---|---|---|---|
| **1. Drainage channel rehabilitation and riparian buffers** | Channel reprofiling for 6.62 km, 500 US$/m. Including bank stabilisation with vegetated gabions [b] | 500 US$/m x 6.62 km x 1000 | 3,310,000 | 3,310,000 US$ x 2% | 66,200[c] | | - |
| **2. Floodplain restoration** | 64.44 ha of flood plain restoration on [d] Cost equivalent to afforestation and forest maintenance costs. | 787 US$/ha x 64.44 ha | 50,714 | Year 2-6: 207 US$/ha x 64.44 ha Year 7-10: 100 US$/ha x 64.44 ha | 13,339[e] | 200 US$/ha x 64.44 ha | 12,888[f] |
| **3. Urban greening (tree planting)** | 10,097 trees planted inclusive of tree pits and protection measures, for an estimated total cost per tree of US$25.[g] | 25 US$/tree x 10,097 | 252,425 | 252,425 x 10% | 25,243 | | - |
| **Total** | | | 3,613,139 | | 104,782 | | 12,888 |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for river channel reprofiling were estimated based upon local consultations including excavator costs ; [c] Estimated to be 2% of capital costs; [d] Costs planning and flood plain restoration assumed to be the same as afforestation costs at THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices – based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector [e] Maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in 2023 prices respectively; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha; [g] Provision of tree sapling, planning and provision of suitable growing medium, based upon local consultations and Soonsawad, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis.*

**Table 30: Full cost calculations for Aranyaprathet**

| Measure | Details | Investment costs (US$)[a] | | O&M costs (US$) | | Opportunity costs (US$) | |
|---|---|---|---|---|---|---|---|
| **1. Retention and infiltration of rooftop and surface runoff** | 77 ha of runoff reduction measures at a weighted cost of approximately US$ 63.6 $m^2$ [b] | 63.6 US$/m3 x 77 x 10,000 | 48,923,654 | 48,923,654 x 5% | 2,446,183[c] | | - |
| **2. Riparian buffer strip (and floodplain restoration)** | 45.7 ha of floodplain restoration on [d] Cost equivalent to afforestation and forest maintenance costs | 787 US$/ha x 45.7 ha | 35,982 | Year 2-6: 207 US$/ha x 45.7 ha Year 7-10: 100 US$/ha x 45.7 ha | 9,464[e] | 200 US$/ha x 45.7 ha | 9,144[f] |
| **3. Urban greening (tree planting)** | 12,479 trees planted inclusive of tree pits and protection measures, for an estimated total cost per tree of US$25.[g] | 25 US$/tree x 12,479 | 311,975 | 311,975 x 10% | 31,198 | | - |
| **Total** | | | 3,613,139 | | 104,782 | | 12,888 |

*Notes: [a] Unless otherwise indicated investment cost estimates have been based upon local consultations with government, local contractors and other stakeholders; [b] Costs for green measures were taken from a recent literature review of the implementation of NbS in urban areas, values were adjusted to reflect differences in GDP per capita between Thailand and the referenced study site and subsequent changes in price levels, see Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Leo, L. S., Capobianco, V., Oen, A. M., ... & Lopez-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. Natural Hazards and Earth System Sciences, 20(1), 243-270. ; [c] Estimated to be 5% of capital costs; [d] Costs planning and flood plain restoration assumed to be the same as afforestation costs at THB 4020 per 0.16 ha in 2021, equivalent to USD 787 per ha in 2023 prices - based upon Rojanakan et al, 2022, Ecosystem based adaptation code of practice Compendium for the Thai water sector [e] Maintenance costs THB 1,060/ 0.16 ha/ year for second to sixth year, and THB 510/0.16 ha/year for the seventh to the tenth years. This is equivalent to USD 207 and USD 100 in 2023 prices respectively; [f] the opportunity cost of land is assumed to be equivalent to its full rental value under its alternative use – which in this case is rice cultivation – of 200 US$/ha; [g] Provision of tree sapling, planning and provision of suitable growing medium, based upon local consultations and Soonsawad, 2014, An Assessment of Ecosystem Services Provided by Street Trees in Bangkok, Thailand. PhD thesis.*

## Figure 34. Cost benefit calculation for ATT

| Year | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | | |
| 1. Sreng natural channel buffer and wetland corridor | 65,532 | 13,106 | 13,106 | 13,106 | 13,106 | 13,106 | | | | | | | | | | | |
| 2. Decentralised irrigation/fish ponds | 1,222,656 | 244,531 | 244,531 | 244,531 | 244,531 | 244,531 | | | | | | | | | | | |
| 3. Restoration of former drainage channels | 256,560 | 51,312 | 51,312 | 51,312 | 51,312 | 51,312 | | | | | | | | | | | |
| 4. Agricultural field edge buffers and connectivity | 635,123 | 127,025 | 127,025 | 127,025 | 127,025 | 127,025 | | | | | | | | | | | |
| 5. Reforestation of flooded forest | 692,896 | 138,579 | 138,579 | 138,579 | 138,579 | 138,579 | | | | | | | | | | | |
| 6. Forest rehabilitation and reforestation areas | 960,803 | 192,161 | 192,161 | 192,161 | 192,161 | 192,161 | | | | | | | | | | | |
| **I. Total** | **3,833,571** | **766,714** | **766,714** | **766,714** | **766,714** | **766,714** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | | |
| O&M costs | 275,802 | - | 55,164 | 110,329 | 165,493 | 220,658 | 275,822 | 275,822 | 275,822 | 275,822 | 275,822 | 275,822 | 220,658 | 165,493 | 110,329 | 55,164 | - |
| Opportunity cost of agricultural land | 344,043 | - | 68,809 | 137,617 | 206,426 | 275,234 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 |
| **II. Total** | **619,845** | **-** | **68,809** | **137,617** | **206,426** | **275,234** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** |
| | | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | | |
| Carbon sequestration in additional biomass | | - | 237,946 | 475,892 | 713,839 | 951,785 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 |
| Provisioning from forested area | | - | 1,343 | 3,078 | 5,319 | 8,212 | 11,950 | 15,434 | 19,934 | 25,746 | 33,252 | 42,946 | 51,551 | 58,749 | 64,128 | 67,160 | 67,160 |
| Fisheries | | - | 151,515 | 303,029 | 454,544 | 606,059 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 |
| Additional water supply for irrigation | | - | 14,400 | 28,800 | 43,200 | 57,600 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 |
| Sediment reduction | | - | - | 383 | 864 | 1,471 | 2,235 | 3,196 | 4,023 | 5,065 | 6,376 | 8,027 | 10,106 | 12,723 | 15,026 | 16,935 | 18,347 |
| **III. Total incremental output** | **-** | **-** | **405,204** | **811,182** | **1,217,766** | **1,625,127** | **2,033,489** | **2,037,934** | **2,043,261** | **2,050,115** | **2,058,932** | **2,070,278** | **2,080,961** | **2,090,775** | **2,098,458** | **2,103,399** | **2,104,812** |
| | | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **(766,714)** | **(430,319)** | **(93,149)** | **244,626** | **583,178** | **1,689,446** | **1,693,891** | **1,699,218** | **1,706,072** | **1,714,889** | **1,726,235** | **1,736,918** | **1,746,732** | **1,754,415** | **1,759,356** | **1,760,769** |

| Year | | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | |
| 1. Sreng natural channel buffer and wetland corridor | 65,532 | | | | | | | | | | | | | | | |
| 2. Decentralised irrigation/fish ponds | 1,222,656 | | | | | | | | | | | | | | | |
| 3. Restoration of former drainage channels | 256,560 | | | | | | | | | | | | | | | |
| 4. Agricultural field edge buffers and connectivity | 635,123 | | | | | | | | | | | | | | | |
| 5. Reforestation of flooded forest | 692,896 | | | | | | | | | | | | | | | |
| 6. Forest rehabilitation and reforestation areas | 960,803 | | | | | | | | | | | | | | | |
| **I. Total** | **3,833,571** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | |
| O&M costs | 275,802 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Opportunity cost of agricultural land | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 | 344,043 |
| **II. Total** | **619,845** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** | **344,043** |
| | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | |
| Carbon sequestration in additional biomass | | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 | 1,189,731 |
| Provisioning from forested area | | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 | 67,160 |
| Fisheries | | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 | 757,573 |
| Additional water supply for irrigation | | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 | 72,000 |
| Sediment reduction | | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 | 19,134 |
| **III. Total incremental output** | - | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** | **2,105,599** |
| | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** | **1,761,556** |

| | | |
|---|---|---|
| **Discount rate** | 9% | 6% |
| **Net present value (NPV)** | 24,608,751 | 25,488,508 |
| **Economic Internal rate of return (EIRR)** | 39.2% | |
| **Total discounted costs** | 3,523,497 | |
| **Total discounted benefits** | 28,132,248 | |
| **Benefit-cost ratio** | 7.98 | |

## Figure 35. Cost benefit calculations for Sompoi

| Year | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | |
| 1. River channel reprofiling | 27,491 | 5,498 | 5,498 | 5,498 | 5,498 | 5,498 | | | | | | | | | | |
| 2. Check dams and leaky weirs | 35,000 | 7,000 | 7,000 | 7,000 | 7,000 | 7,000 | | | | | | | | | | |
| 3. Decentralised irrigation ponds | 418,722 | 83,744 | 83,744 | 83,744 | 83,744 | 83,744 | | | | | | | | | | |
| 4. Agricultural field edge buffers and connectivity | 26,050 | 5,210 | 5,210 | 5,210 | 5,210 | 5,210 | | | | | | | | | | |
| 5. Forest rehabilitation and reforestation areas | 250,463 | 50,093 | 50,093 | 50,093 | 50,093 | 50,093 | | | | | | | | | | |
| 6. Reforestation of selected degraded sites | 20,541 | 4,108 | 4,108 | 4,108 | 4,108 | 4,108 | | | | | | | | | | |
| 7. Lalu vegetated edge buffer | 4,250 | 850 | 850 | 850 | 850 | 850 | | | | | | | | | | |
| 8. UN Road drainage and buffer | 2,951 | 590 | 590 | 590 | 590 | 590 | | | | | | | | | | |
| **I. Total** | **785,467** | **157,093** | **157,093** | **157,093** | **157,093** | **157,093** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | |
| 1. Forest maintainance costs | - | - | 30,876 | 61,752 | 92,628 | 123,504 | 154,381 | 138,420 | 122,460 | 106,500 | 90,540 | 59,664 | 44,748 | 29,832 | 14,916 | - |
| 2. Opportunity cost of agricultural land | 8,450 | 1,690 | 3,380 | 5,070 | 6,760 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 |
| **II. Total** | **8,450** | **1,690** | **3,380** | **5,070** | **6,760** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** |
| | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | |
| 1. Carbon sequestration in additional biomass | | - | 45,308 | 90,615 | 135,923 | 181,230 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 |
| 2. Provisioning from forested area | | - | 1,105 | 2,532 | 4,375 | 6,756 | 9,831 | 12,697 | 16,399 | 21,180 | 27,355 | 35,330 | 42,409 | 48,330 | 52,756 | 55,251 |
| 3. Additional water storage | | - | 8,829 | 17,658 | 26,488 | 35,317 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 |
| 4. Erosion prevention | | - | - | 839 | 1,896 | 3,226 | 4,900 | 7,008 | 8,823 | 11,107 | 13,983 | 17,604 | 22,162 | 27,900 | 32,952 | 37,138 |
| **III. Total incremental output** | **-** | **-** | **55,242** | **111,645** | **168,681** | **226,529** | **285,415** | **290,389** | **295,906** | **302,971** | **312,022** | **323,618** | **335,255** | **346,915** | **356,391** | **363,072** |
| | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **(158,783)** | **(105,232)** | **(50,519)** | **4,828** | **60,985** | **276,965** | **281,939** | **287,456** | **294,521** | **303,572** | **315,168** | **326,805** | **338,465** | **347,941** | **354,622** |

| Year | | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | | |
| 1. River channel reprofiling | 27,491 | | | | | | | | | | | | | | | | |
| 2. Check dams and leaky weirs | 35,000 | | | | | | | | | | | | | | | | |
| 3. Decentralised irrigation ponds | 418,722 | | | | | | | | | | | | | | | | |
| 4. Agricultural field edge buffers and connectivity | 26,050 | | | | | | | | | | | | | | | | |
| 5. Forest rehabilitation and reforestation areas | 250,463 | | | | | | | | | | | | | | | | |
| 6. Reforestation of selected degraded sites | 20,541 | | | | | | | | | | | | | | | | |
| 7. Lalu vegetated edge buffer | 4,250 | | | | | | | | | | | | | | | | |
| 8. UN Road drainage and buffer | 2,951 | | | | | | | | | | | | | | | | |
| **I. Total** | **785,467** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | | |
| 1. Forest maintainance costs | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 2. Opportunity cost of agricultural land | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 | 8,450 |
| **II. Total** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** | **8,450** |
| | | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | | |
| 1. Carbon sequestration in additional biomass | | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 | 226,538 |
| 2. Provisioning from forested area | | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 | 55,251 |
| 3. Additional water storage | | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 | 44,146 |
| 4. Erosion prevention | | 40,235 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 | 41,961 |
| **III. Total incremental output** | **-** | **366,169** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** | **367,895** |
| | | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **357,719** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** | **359,445** |

| | | |
|---|---|---|
| **Discount rate** | 9% | 6% |
| **Net present value (NPV)** | 1,867,346 | 2,974,508 |
| **Economic Internal rate of return (EIRR)** | 35.6% | |
| **Total discounted costs** | 684,159 | |
| **Total discounted benefits** | 2,551,505 | |
| **Benefit-cost ratio** | 3.73 | |

## Figure 36. Cost benefit calculations for Poipet

| Year | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | |
| River channel reprofiling | 3,310,000 | 662,000 | 662,000 | 662,000 | 662,000 | 662,000 | | | | | | | | | | |
| Flood plain restoration | 50,714 | - | | | | 50,714 | | | | | | | | | | |
| City greening | 252,425 | 50,485 | 50,485 | 50,485 | 50,485 | 50,485 | | | | | | | | | | |
| **I. Total** | **3,613,139** | **712,485** | **712,485** | **712,485.00** | **712,485.00** | **763,199.28** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | |
| Channel maintainance | - | - | - | - | - | - | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 |
| Opportunity cost of land | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 |
| Flood plain restoration | - | - | - | - | - | - | 13,339 | 13,339 | 13,339 | 13,339 | 13,339 | 6,444 | 6,444 | 6,444 | 6,444 | - |
| Urban greening | - | - | 505 | 1,157 | 1,999 | 3,087 | 4,491 | 5,801 | 7,492 | 9,677 | 12,498 | 16,142 | 19,376 | 22,081 | 24,103 | 25,243 |
| **II. Total** | **-** | **12,888** | **13,393** | **14,045** | **14,887** | **15,975** | **96,919** | **98,228** | **99,919** | **102,104** | **104,925** | **101,674** | **104,908** | **107,613** | **109,635** | **104,331** |
| | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | |
| Avoided flood damages (direct) | - | - | - | - | - | - | 1,362,636 | 1,427,509 | 1,495,537 | 1,566,875 | 1,641,688 | 1,720,147 | 1,802,430 | 1,888,727 | 1,979,236 | 2,074,164 |
| Avoided flood damages (indirect) | - | - | - | - | - | - | 1,362,636 | 1,427,509 | 1,495,537 | 1,566,875 | 1,641,688 | 1,720,147 | 1,802,430 | 1,888,727 | 1,979,236 | 2,074,164 |
| Urban trees | | - | 2,394 | 5,761 | 10,453 | 16,947 | 25,893 | 35,114 | 47,619 | 64,577 | 87,575 | 118,762 | 149,686 | 179,114 | 205,291 | 225,748 |
| **III. Total incremental output** | **-** | **-** | **2,394** | **5,761** | **10,453** | **16,947** | **2,751,165** | **2,890,131** | **3,038,692** | **3,198,328** | **3,370,951** | **3,559,056** | **3,754,546** | **3,956,568** | **4,163,763** | **4,374,075** |
| | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **(725,373)** | **(723,483)** | **(720,769)** | **(716,919)** | **(762,227)** | **2,654,247** | **2,791,903** | **2,938,772** | **3,096,224** | **3,266,026** | **3,457,382** | **3,649,638** | **3,848,955** | **4,054,128** | **4,269,744** |

| Year | | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | | |
| River channel reprofiling | 3,310,000 | | | | | | | | | | | | | | | | |
| Flood plain restoration | 50,714 | | | | | | | | | | | | | | | | |
| City greening | 252,425 | | | | | | | | | | | | | | | | |
| **I. Total** | **3,613,139** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| | | | | | | | | | | | | | | | | | |
| **B. Annual costs** | | | | | | | | | | | | | | | | | |
| Channel maintainance | - | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 | 66,200 |
| Opportunity cost of land | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 | 12,888 |
| Flood plain restoration | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Urban greening | - | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 | 25,243 |
| **II. Total** | **-** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** | **104,331** |
| | | | | | | | | | | | | | | | | | |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | | |
| Avoided flood damages (direct) | - | 2,173,729 | 2,278,161 | 2,387,699 | 2,502,597 | 2,623,118 | 2,749,541 | 2,882,157 | 3,021,273 | 3,167,210 | 3,320,305 | 3,480,912 | 3,649,405 | 3,826,171 | 4,011,623 | 4,206,188 | 4,410,320 |
| Avoided flood damages (indirect) | - | 2,173,729 | 2,278,161 | 2,387,699 | 2,502,597 | 2,623,118 | 2,749,541 | 2,882,157 | 3,021,273 | 3,167,210 | 3,320,305 | 3,480,912 | 3,649,405 | 3,826,171 | 4,011,623 | 4,206,188 | 4,410,320 |
| Urban trees | | 237,035 | 248,887 | 261,331 | 274,398 | 288,118 | 302,524 | 317,650 | 333,532 | 350,209 | 367,719 | 386,105 | 405,411 | 425,681 | 446,965 | 469,313 | 492,779 |
| **III. Total incremental output** | **-** | **4,584,493** | **4,805,209** | **5,036,730** | **5,279,592** | **5,534,354** | **5,801,605** | **6,081,964** | **6,376,078** | **6,684,628** | **7,008,329** | **7,347,930** | **7,704,220** | **8,078,024** | **8,470,210** | **8,881,690** | **9,313,418** |
| | | | | | | | | | | | | | | | | | |
| **E. Net benefits (III-I-II)** | | **4,480,163** | **4,700,878** | **4,932,399** | **5,175,261** | **5,430,023** | **5,697,275** | **5,977,633** | **6,271,747** | **6,580,298** | **6,903,998** | **7,243,600** | **7,599,889** | **7,973,694** | **8,365,880** | **8,777,359** | **9,209,088** |

| | | |
|---|---|---|
| **Discount rate** | 9% | 6% |
| **Net present value (NPV)** | 24,608,751 | 25,488,508 |
| **Economic Internal rate of return (EIRR)** | 39.2% | |
| **Total discounted costs** | 3,523,497 | |
| **Total discounted benefits** | 28,132,248 | |
| **Benefit-cost ratio** | 7.98 | |

## Figure 37. Cost benefit calculations for Aranyaprathet

| Year | | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | | |
| Retention and infiltration of rooftop and surface runoff measures | 48,923,654 | 9,784,731 | 9,784,731 | 9,784,731 | 9,784,731 | 9,784,731 | | | | | | | | | | | |
| Riparian buffer strips (and floodplain restoration) | 32,711 | - | 32,711 | - | - | - | | | | | | | | | | | |
| Urban greening (tree planting) | 311,967 | 62,393 | 62,393 | 62,393 | 62,393 | 62,393 | | | | | | | | | | | |
| **I. Total** | **49,268,331** | **9,847,124** | **9,879,835** | **9,847,124** | **9,847,124** | **9,847,124** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| **B. Annual costs** | | | | | | | | | | | | | | | | | |
| Runoff reduction and greening maintainance | - | - | 489,237 | 978,473 | 1,467,710 | 1,956,946 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 |
| Opportunity cost of land | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 |
| Riparian buffer strip (and floodplain restoration) | - | - | - | 9,464 | 9,464 | 9,464 | 9,464 | 9,464 | 4,572 | 4,572 | 4,572 | 4,572 | - | - | - | - | - |
| Tree maintainance | - | - | 624 | 1,430 | 2,471 | 3,815 | 5,551 | 7,169 | 9,259 | 11,959 | 15,446 | 19,949 | 23,946 | 27,289 | 29,788 | 31,197 | 31,197 |
| **II. Total** | **-** | **9,144** | **499,004** | **998,511** | **1,488,788** | **1,979,369** | **2,470,342** | **2,471,960** | **2,469,158** | **2,471,858** | **2,475,344** | **2,479,848** | **2,479,273** | **2,482,616** | **2,485,115** | **2,486,523** | **2,486,523** |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | | |
| Avoided flood damages (direct) | - | - | 477,782 | 981,365 | 1,511,792 | 2,070,148 | 2,657,552 | 2,729,306 | 2,802,997 | 2,878,678 | 2,956,403 | 3,036,226 | 3,118,204 | 3,202,395 | 3,288,860 | 3,377,659 | 3,468,856 |
| Avoided flood damages (indirect) | - | - | 477,782 | 981,365 | 1,511,792 | 2,070,148 | 2,657,552 | 2,729,306 | 2,802,997 | 2,878,678 | 2,956,403 | 3,036,226 | 3,118,204 | 3,202,395 | 3,288,860 | 3,377,659 | 3,468,856 |
| Urban treess | | - | 6,981 | 16,429 | 29,155 | 46,234 | 69,091 | 91,644 | 121,559 | 161,238 | 213,869 | 283,681 | 349,714 | 409,301 | 458,845 | 493,515 | 506,840 |
| Amenity value | | - | 303,792 | 623,990 | 935,985 | 1,247,979 | 1,559,974 | 1,602,094 | 1,645,350 | 1,689,775 | 1,735,398 | 1,782,254 | 1,830,375 | 1,879,795 | 1,930,550 | 1,982,675 | 2,036,207 |
| **III. Total incremental output** | **-** | **-** | **1,266,338** | **2,603,148** | **3,988,724** | **5,434,509** | **6,944,170** | **7,152,350** | **7,372,904** | **7,608,369** | **7,862,073** | **8,138,386** | **8,416,497** | **8,693,887** | **8,967,115** | **9,231,507** | **9,480,758** |
| **E. Net benefits (III-I-II)** | | **(9,856,268)** | **(9,112,501)** | **(8,242,487)** | **(7,347,188)** | **(6,391,985)** | **4,473,828** | **4,680,390** | **4,903,745** | **5,136,511** | **5,386,729** | **5,658,539** | **5,937,224** | **6,211,271** | **6,482,000** | **6,744,984** | **6,994,235** |

| Year | | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Initial Amount (US$) | | | | | | | | | | | | | | | |
| **A. Investment schedule** | | | | | | | | | | | | | | | | |
| Retention and infiltration of rooftop and surface runoff measures | 48,923,654 | | | | | | | | | | | | | | | |
| Riparian buffer strips (and floodplain restoration) | 32,711 | | | | | | | | | | | | | | | |
| Urban greening (tree planting) | 311,967 | | | | | | | | | | | | | | | |
| **I. Total** | **49,268,331** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** |
| **B. Annual costs** | | | | | | | | | | | | | | | | |
| Runoff reduction and greening maintainance | - | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 | 2,446,183 |
| Opportunity cost of land | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 | 9,144 |
| Riparian buffer strip (and floodplain restoration) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Tree maintainance | - | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 | 31,197 |
| **II. Total** | **-** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** | **2,486,523** |
| **C. Benefits** | **Annual Amount** | | | | | | | | | | | | | | | |
| Avoided flood damages (direct) | - | 3,562,515 | 3,658,703 | 3,757,488 | 3,858,940 | 3,963,131 | 4,070,136 | 4,180,030 | 4,292,890 | 4,408,798 | 4,527,836 | 4,650,088 | 4,775,640 | 4,904,582 | 5,037,006 | 5,173,005 |
| Avoided flood damages (indirect) | - | 3,562,515 | 3,658,703 | 3,757,488 | 3,858,940 | 3,963,131 | 4,070,136 | 4,180,030 | 4,292,890 | 4,408,798 | 4,527,836 | 4,650,088 | 4,775,640 | 4,904,582 | 5,037,006 | 5,173,005 |
| Urban treess | | 520,524 | 534,579 | 549,012 | 563,836 | 579,059 | 594,694 | 610,750 | 627,241 | 644,176 | 661,569 | 679,431 | 697,776 | 716,616 | 735,964 | 755,836 |
| Amenity value | | 2,091,184 | 2,147,646 | 2,205,633 | 2,265,185 | 2,326,345 | 2,389,156 | 2,453,663 | 2,519,912 | 2,587,950 | 2,657,825 | 2,729,586 | 2,803,285 | 2,878,973 | 2,956,706 | 3,036,537 |
| **III. Total incremental output** | **-** | **9,736,739** | **9,999,631** | **10,269,621** | **10,546,900** | **10,831,667** | **11,124,122** | **11,424,473** | **11,732,934** | **12,049,723** | **12,375,065** | **12,709,192** | **13,052,340** | **13,404,754** | **13,766,682** | **14,138,382** |
| **E. Net benefits (III-I-II)** | | **7,250,215** | **7,513,107** | **7,783,097** | **8,060,377** | **8,345,143** | **8,637,598** | **8,937,950** | **9,246,410** | **9,563,200** | **9,888,542** | **10,222,669** | **10,565,817** | **10,918,230** | **11,280,159** | **11,651,859** |

| | | |
|---|---|---|
| **Discount rate** | 9% | 6% |
| **Net present value (NPV)** | 9,717,474 | 10,609,687 |
| **Economic Internal rate of return (EIRR)** | 11.3% | |
| **Total discounted costs** | 57,871,229 | |
| **Total discounted benefits** | 67,588,703 | |
| **Benefit-cost ratio** | 1.17 | |

# ANNEX 2: WORKSHOP INFORMATION

**ELD scoping workshop, Centara Grand at Central Plaza Ladprao Bangkok, Thailand, 06 December 2022** – 39 participants

| | |
|---|---|
| Thai National Mekong Committee (TNMC) | 2 |
| Office of Natural Water Resources (ONWR) | 7 |
| Fiscal Policy Research Institute Foundation | 1 |
| Land Development | 2 |
| NESDC | 1 |
| King Mongkut's University of Technology North Bangkok | 1 |
| MONRE | 1 |
| Ta Phraya Sub-district Administrative Organization | 1 |
| ONEP | 1 |
| Ta Phraya Sub-district Administrative Organization | 1 |
| Department of Public Works and Twon & Country Planning | 2 |
| Kasetsart University | 1 |
| DDPM – Sa Kaeo | 1 |
| Fiscal Policy Research Institute Foundation | 1 |
| DOA | 1 |
| MRC-GIZ | 4 |
| ELD | 2 |
| ICEM | 9 |

**ELD scoping workshop, Hyatt Regency Phnom Penh, Phnom Penh, Cambodia, 12 January 2023** – 23 participants

| | |
|---|---|
| Cambodian National Mekong Committee (CNMC) | 6 |
| Ministry of Agriculture, Forestry and Fisheries | 2 |
| Ministry of Land Management Urban Planning and Construction | 1 |
| Cambodia Development Resource Institute | 1 |
| Ministry of Environment | 1 |
| National Committee for Disaster Management | 1 |
| Institute of Technology of Cambodia | 1 |
| Royal University of Phnom Penh | 1 |
| Royal University of Agriculture | 2 |
| Institute of Technology of Cambodia | 1 |

| | |
|---|---|
| MRC-GIZ | 3 |
| ELD | 2 |
| ICEM | 1 |

**ELD validation workshop, Hyatt Regency, Phnom Penh, Cambodia, 25 May 2023** – 27 participants

| | |
|---|---|
| Cambodia National Mekong Committee (CNMC) | 3 |
| Ministry of Planning | 1 |
| Ministry of Rural Development | 1 |
| Forestry Administration | 1 |
| MEF | 1 |
| MoE | 2 |
| MAFF | 1 |
| ITC | 1 |
| Ministry of Land Management, Urban Planning and Construction | 1 |
| CDRI | 1 |
| RUPP | 1 |
| Tonle Sap Authority | 1 |
| National Committee for Disaster Management | 1 |
| ICEM | 6 |
| MRC-GIZ | 5 |

**ELD validation workshop, Grande Centre Point Ratchadamri, Bangkok, Thailand, 30 May 2023** – 37 participants

| | |
|---|---|
| Thai National Mekong Committee (TNMC) | 2 |
| Office of Natural Water Resources (ONWR) | 11 |
| Department of Public Works and Town & Country Planning | 1 |
| Land Develop Department | 1 |
| Office Of Natural Resources and Environmental Policy and Planning | 1 |
| Office of the National Economics and Social Development Council | 2 |
| Department of Agriculture | 1 |
| Department of Disaster Prevention and Mitigation | 2 |
| Provincial Office of Natural Resources and Environment Sa Kaeo | 1 |
| Sakaeo Land Development | 1 |
| Sakaeo Provincial Irrigation Office | 1 |
| Faculty of Economics, Kasetsart University | 1 |

| | |
|---|---|
| King Mongkut's University of Technology North Bangkok | 1 |
| Faculty of Economics at Sriracha Kasetsart University | 1 |
| Fiscal Policy Research Institute Foundation | 1 |
| MRC-GIZ | 3 |
| ICEM | 6 |

**ELD validation workshop, Phnom Penh, Kompong Cham Province, Cambodia, 11 August 2023** – 24 participants

| | |
|---|---|
| Cambodia National Mekong Committee (CNMC) | 12 |
| MLMUPC | 1 |
| Ministry of Environment | 1 |
| NCDM | 1 |
| MAFF | 1 |
| Ministry of Planning | 1 |
| Ministry of Rural Development | 1 |
| ITC | 1 |
| RUPP | 1 |
| CDRI | 1 |
| MRC-GIZ | 3 |
| ICEM | 1 |

**ELD validation workshop, Centara Grand at Central Plaza, Bangkok, Thailand 15 August 2023** – 32 participants

| | |
|---|---|
| Thai National Mekong Committee (TNMC) | 3 |
| Office of Natural Water Resources (ONWR) | 13 |
| Kasetsart University | 1 |
| King Mongkut's University of Technology North Bangkok | 1 |
| Office of the National Economic and Social Development Council | 2 |
| Land Development Department | 3 |
| Office of Natural Resources and Environmental Policy and Planning | 1 |
| Royal Irrigation Department | 1 |
| Department of Public Works and Town & Country Planning | 2 |
| Department of Disaster Prevention and Mitigation | 2 |
| MRC-GIZ | 2 |
| ICEM | 1 |

# ANNEX 3: HYDROLOGICAL MODELLING OUTPUTS

**Ang Trapeang Thmor reservoir**

The NbS measures considered as part of the Talsim-NG hydrologic modelling for ATT, comprised:

- Area (Ha) of Sreng natural channel buffer and wetland corridor;
- Area (Ha) of new irrigation/fish ponds;
- Area (Ha) of restored drainage channels;
- Area (Ha) of agricultural field edge buffer network;
- Area (Ha) of restored flooded forest and Plong grassland; and
- Area (Ha) of rehabilitation and reforestation areas.

All formulas were taken from SWAT documentation and Meyer (1995). The SWAT formulas stem from regression models based on field observations. The uncertainty is high, in particular the formulas for nutrients. The advantage Meyer formula brings is that soil texture is considered with fractions of sand, silt and clay. Therefore, Meyer formula was given priority.

Land use factors (c and p) were reduced to reflect the changes from shrubs, upland crops to mixed open forest/shrubs and grassland/open forest/upland crops in the five grid cells. The c and p factors are parameters of the Modified Universal Soil Loss Equation (MUSLE) approach. MUSLE results are considered representative for all NbS measures and cover the sediment reduction potential of all NbS in the grid cells. The assumption is that the cumulative effect of all NbS measures cannot exceed the soil loss reduction calculated with MUSLE.

17 cells reflect the NbS measures of which 8 with significant land cover and management changes. The remaining 9 had already good land cover and management conditions.

The results are approximations and should be treated with caution. It is not guaranteed that effects as indicated with the calculations will occur in practice.

**Figure 38: NbS measures and model grid cells**

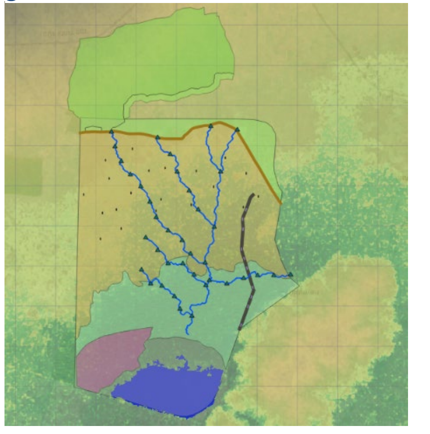
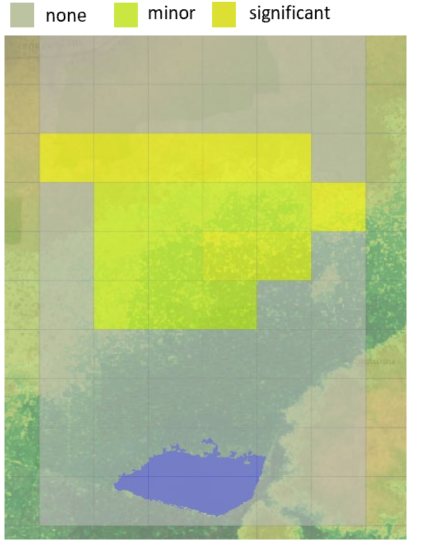


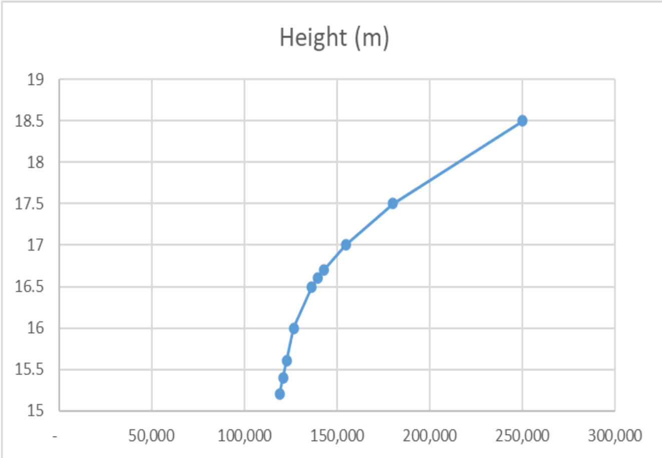
**Figure 39: Land cover change**



Sedimentation and reservoir volume

The characteristic of the ATT reservoir indicates that sediment is mainly deposited as illustrated in Figure 40. This was derived by applying a rule of thumb function that assesses sediment deposition based on the bathymetry. Sediment will enter the reservoir through overland flow and through the relic canals once re-established. The delta area (Plong wetland) is where the bulk load of sediment will be deposited. 17.5 m is the maximum, reaching 180 million m³.

It should be noted that the high fraction of clay and silt reduces the sediment reduction potential of the proposed NbS. Maintenance of buffer strips is necessary due to the high sediment load.



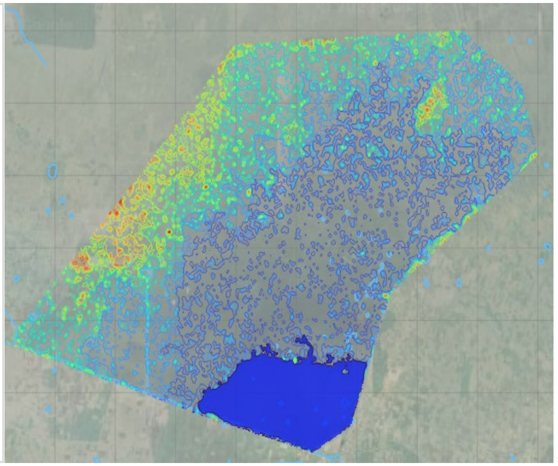
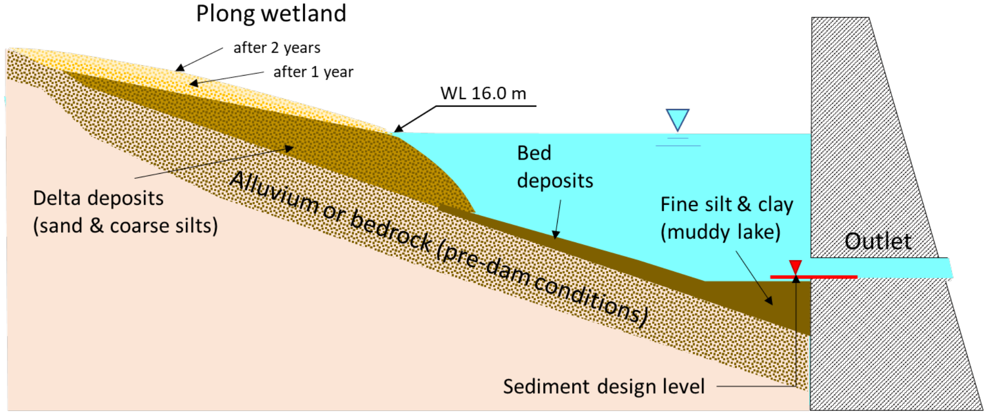



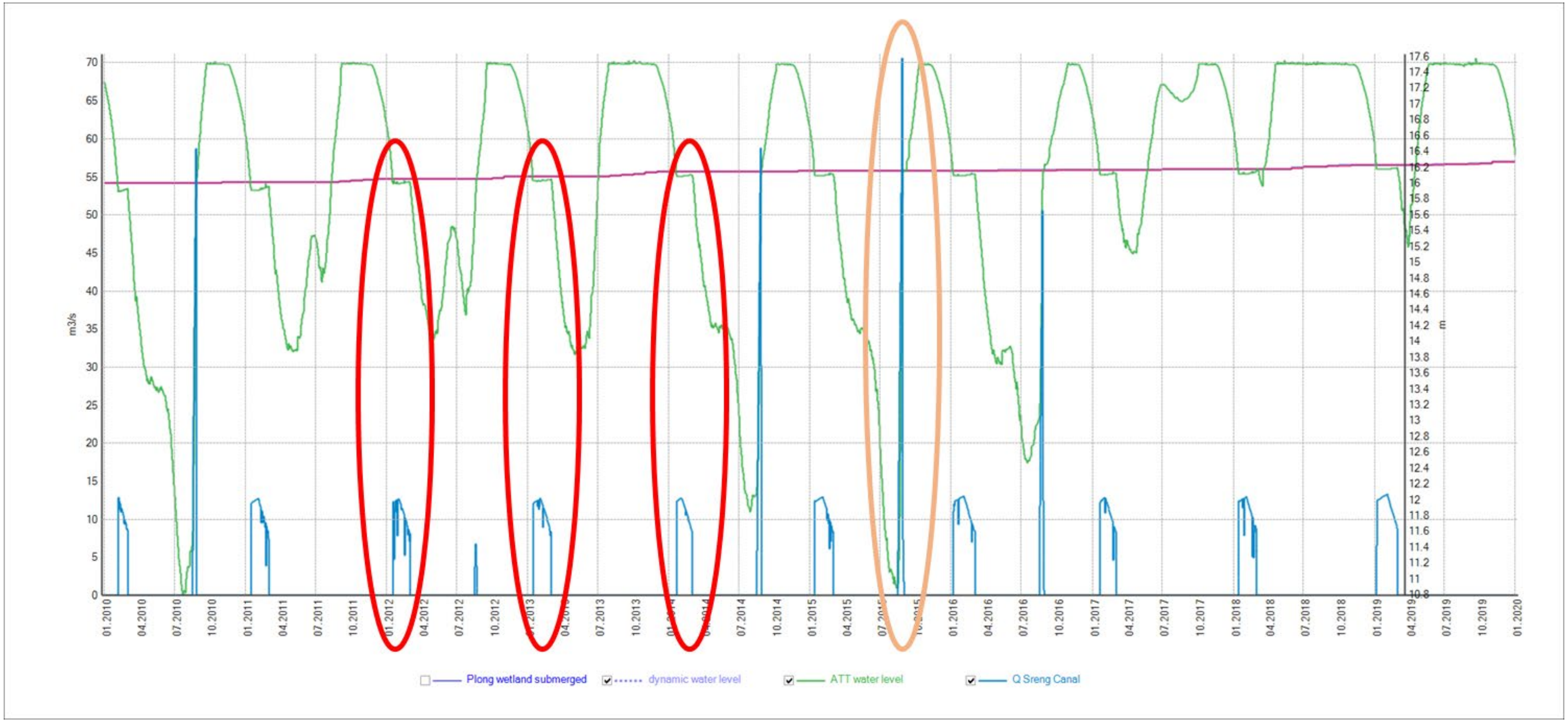
**Figure 41: ATT model output and level-area-volume curve**

**Figure 40: sediment characteristics at ATT**




The Plong wetland starts at a level of 16.0m according to the DEM (30x30m). In order to be maintained and functioning, the wetland requires to be submerged every year beginning in September until end of February. The simulation runs consider a rising water level depending on sediment load in order to maintain the Plong wetland. The sediment entering the reservoir will rise the water level that is required for inundating the wetland and therefore, any measure aiming at reducing sediment is beneficial for all other purposes of the reservoir. Measures in the grass land or areas already indicated as wetland have a lower potential compared to the agricultural areas. Sedimentation occurs to a significant proportion on the grassland/wetland.

**Figure 42: water level and storage dynamics**




Example of maintaining the target water level until end of February

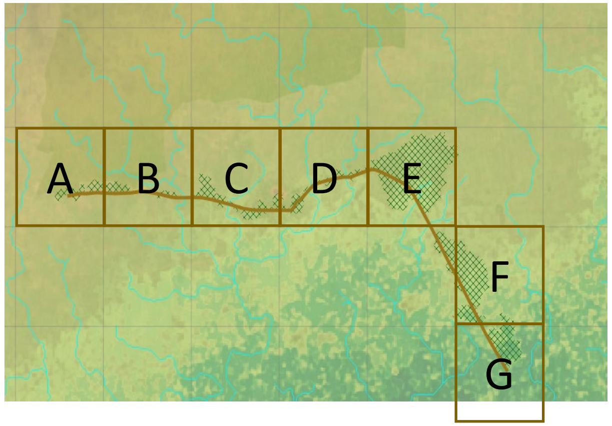
Example of reaching the target water level in September

Buffer strip approach

The grid cells size applied for the modelling was 30x30m. The direct catchments of buffer strips were derived from this 30x30m DEM. Drainage routes from upstream were not considered as direct catchment of a buffer strip since no buffer strip can be implemented in drainage routes. This means that the buffer strips calculation considers only the retention effect of a buffer strip but excludes any impact on sediment coming from the drainage routes.

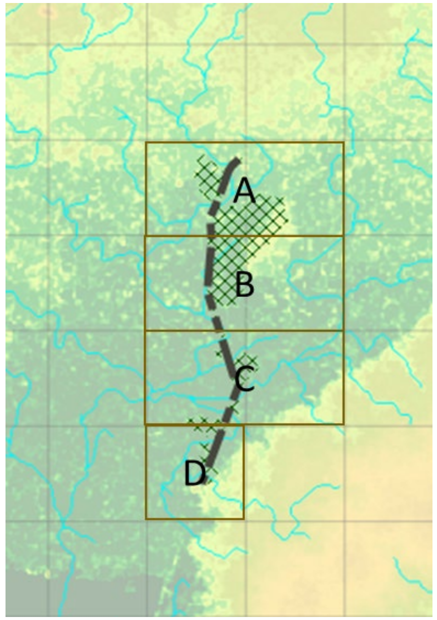
The sediment formulas for the Sreng buffer strips followed the SWAT documentation and Meyer (1995). The Meyer formula resulted in less sediment reduction potential and was applied as a conservative approach. The potential for sediment reduction ranged from 69% for cell A to 12% for cell D. The direct catchment of the buffer strip covers an area of 464 ha. Using the direct catchments only, the benefit sums up to 1000 tons/yr with a maximum of 430 within F and a minimum of 1 in within G. The highest reduction potential per unit of area can be found in cell B, F and A. A reduction of discharge from Sreng Canal of approx. 20,000 $m^3$ per year is possible when applying NbS measures aiming at reducing soil loss/erosion.

**Figure 43: modelled cells for Sreng canal buffer**




For the road buffer, the potential for sediment reduction ranged from 66% for cell D to 30% for cell C. The direct catchment of the buffer strip covers an area of 355 ha. Using the direct catchments only, the benefit sums up to 1406 tons/yr with a maximum of 1400 within A and a minimum of 9 in within C. The highest reduction potential per unit of area can be found in cell A, all others are low. The road buffer strip has a high potential if drainage routes are also considered.

**Figure 44: modelled cells for road buffer**



## Sompoi reservoir

The NbS measures considered as part of the Talsim-NG hydrologic modelling for Sompoi, comprised:

- Area (Ha) of drainage channel rehabilitation and riparian buffers;
- Check dams and leaky weirs;
- Area (Ha) of new irrigation ponds;
- Area (Ha) of agricultural field edge buffer network;
- Area (Ha) of forest rehabilitation;
- Area (Ha) of reforestation sites;
- Lalu vegetated edge buffer; and
- Area (Ha) of road drainage and buffer.

The Sompoi modelling applied a similar approach as for ATT, using SWAT documentation and Meyer (1995) and applying similar land use factors and MUSLE approach. Land use factors (c and p) were reduced to reflect the changes from shrubs, upland crops to mixed open forest/shrubs and grassland/open forest/upland crops in the five grid cells.

Sedimentation and reservoir volume

The Sompoi Reservoir is of type Lake indicating that the sediment settles as a delta. This was derived by applying a rule of thumb function that assesses sediment deposition based on the bathymetry. Since the reservoir is extremely flat and the dominant soil seems to be silt with fine particles, the sediment will settle rather homogeneously as it can be seen on photos of the reservoir. For simplification, sediment is assumed to settle from bottom to top increasing the dead storage gradually.

**Figure 45: Sompoi NbS model approach**

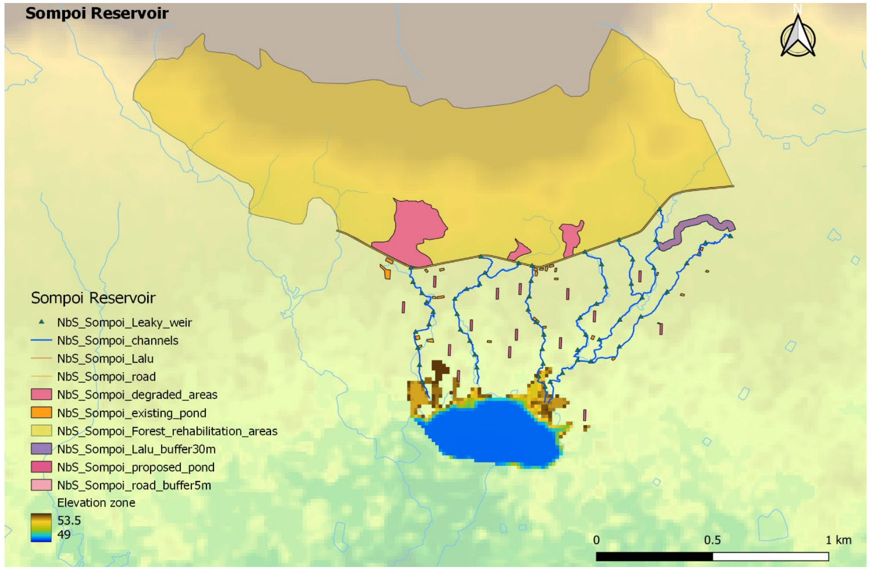
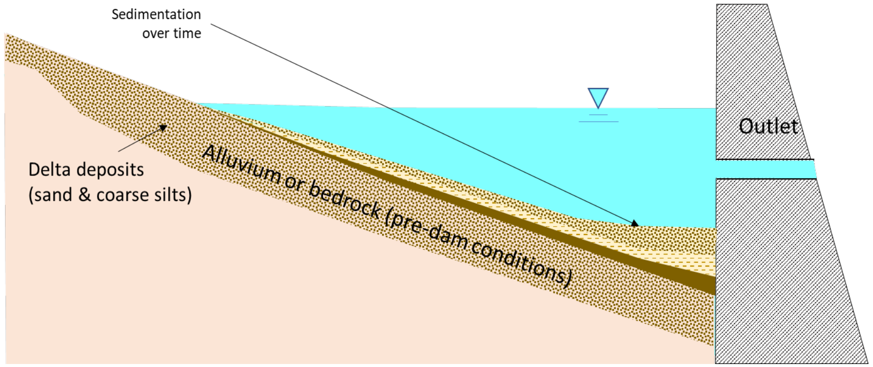


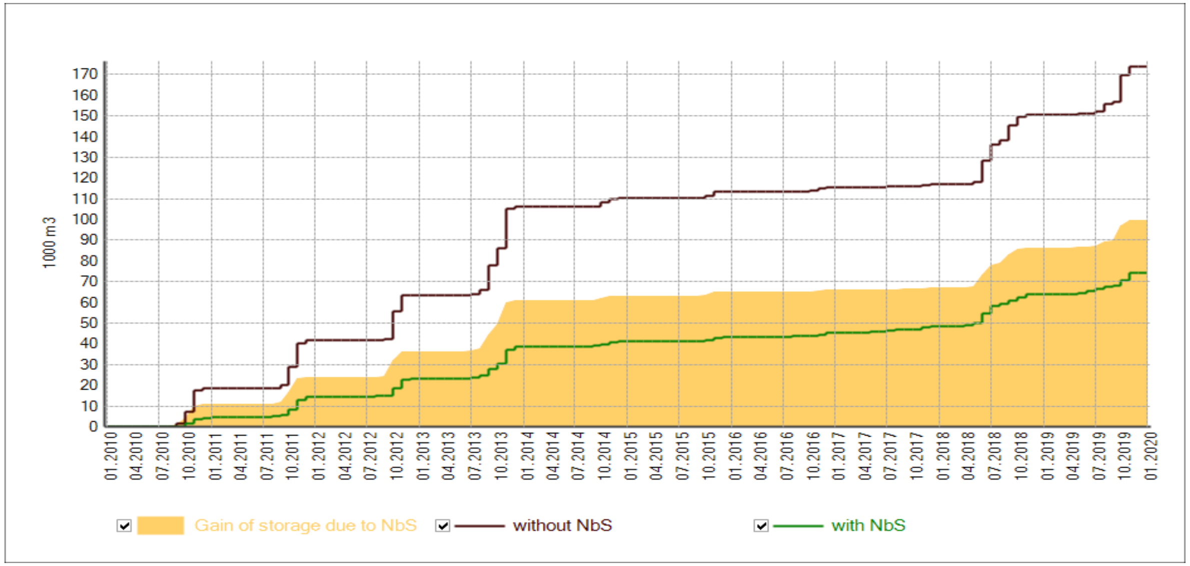

**Figure 46: sediment characteristics at Sompoi**



The Sompoi reservoir is already heavily impacted by sedimentation. The storage volume at the maximum operating level is 1,060 MCM. The volume derived from the 30x30m DEM shows less storage volume – in particular sedimentation at the fringe of the reservoir has reduced the storage volume. The delta of sediment has almost reached the outlet.

A loss of storage volume accumulates over time. A 10 years simulation period shows the sediment settling in the reservoir assuming 100% trap efficiency. A storage volume of > 100,000 m³ in 10 years can be saved with NbS measures as proposed. The absolute benefit of NbS is higher in wet years when more soil loss due to erosion is expected. The positive effects of NbS develop over time when vegetation is applied.

**Figure 47: modelled temporal change in Sompoi reservoir storage volume without NbS (BAU scenario) and with NbS (NbS scenario)**




<u>Buffer strip approach</u>

The sediment formulas for buffer strips followed the SWAT documentation and Meyer (1995). The potential for sediment reduction was 74% for cell A and 73% for cell B. The direct catchment of the buffer strip covers an area of 54 ha. Using the direct catchments only, the benefit sums up to 327 tons/yr with 117 in cell A and 210 in cell B. All NbS measures in the cells C and D were considered in the MUSLE calculation with improved land cover and land management. The MUSLE calculation for cells A-D results in a total reduction of 14,900 tons/yr if all is implemented and vegetation is fully developed. The 14,900 tons/yr can be transformed in m³ with the density of the sediment. With an assumption of 30% sand, 40% silt and 30% clay, the density amounts to approx. 1.5 ton/ m³ of sediment, which brings roughly 10,000 m³ saving of storage loss per year. The location of the road buffer strip results in a high sediment reduction and should be given priority. The drainage routes from upstream must also be considered with sediment management measures.

**Table 31: Sompoi buffer strip sediment reduction efficiency**

| Unit | Land cover | Drainage | Runoff | Soil loss | Effect of sediment redution |
|---|---|---|---|---|---|
| **A** | Shrubs/ open forest | good | high | high | high |
| **B** | Shrubs/ open forest | good | high | high | high |
| **C** | Upland crop | Good | high | high | medium to high |
| **D** | Upland crop | good | high | high | medium to high |

**Figure 48: Sompoi buffer strip model cells**

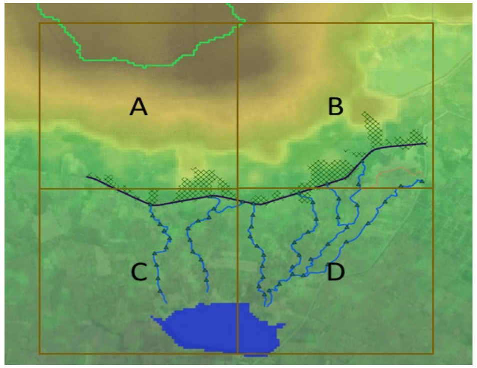
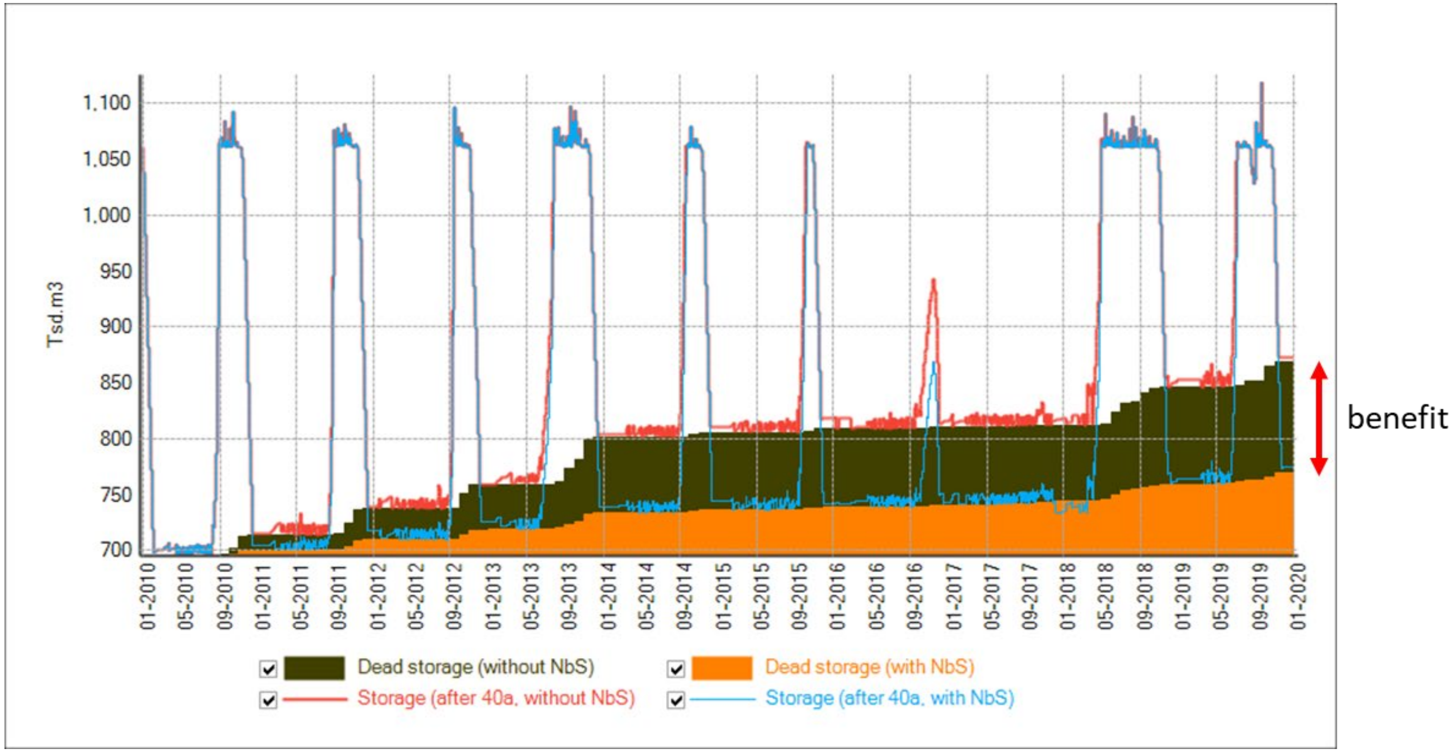


**Figure 49: Sompoi storage change without NbS (BAU scenario) and with NbS (NbS scenario)**



## Poipet

Hydraulic modelling has been undertaken for Poipet based on GIS inputs, to generate flood damage based on a stage-damage curve (using Hec-Ras). This was undertaken for both the BAU and NbS scenarios. Damage is weighted with annual exceedance probability (AEP) of the flood events (with 2010 as a reference). In total, five different inundation maps were created. Land use types were distinguished to produce individual stage-damage curves for each land use type. The list of land use types in and around Poipet is presented in the graphs. Not all land use types were affected; largely built up, paddy crops, open forest and orchard plantations.

The results reflect return periods up to 10 years – data above this return period was not available. With the channel reconstructed as a natural, widened river bed, there is only little damage left up to a return period of 10 years.

**Table 32: Damage values for BAU and NbS scenarios**

| Code | Label | BAU damage (EUR) | NbS damage (EUR) |
|---|---|---|---|
| 10 | Water | - | - |
| 20 | Closed forest | - | - |
| 21 | Open forest | - | - |
| 22 | Flooded forest | - | - |
| 30 | Orchard plantation | 5,839 | 788 |
| 31 | Rubber/Eucalyptus plantations | 691 | 547 |
| 40 | Shrubs | - | - |
| 50 | Wetlands | - | - |
| 60 | Paddy crops | 52,256 | 6,957 |
| 61 | Upland crops | 14,415 | 1,565 |
| 70 | Built-up | 373,770 | 49,336 |
| 80 | Grass/barren (non-veg) | - | - |
| | **Total** | **446,971** | **59,192** |

**Figure 50: Damage functions per land use type in Poipet. BAU scenario without interventions (top) and NbS scenario with interventions (bottom)**

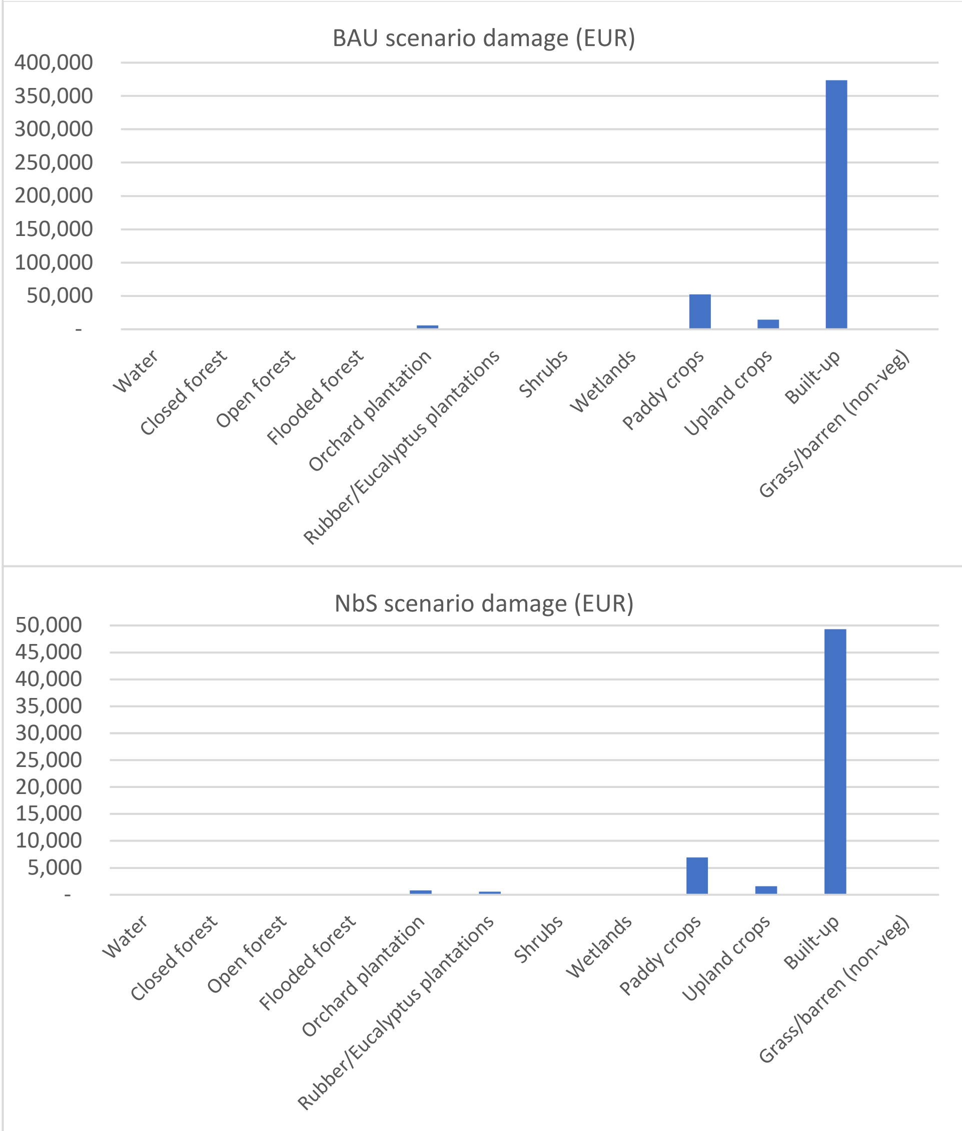



**Figure 51: Modelled inundation for BAU (left) and NbS (right) scenarios**


**Figure 52: hydrological model extent and cross section calculation locations**

**Aranyaprathet**

The NbS measures considered as part of the Talsim-NG hydrologic modelling for Aranyaprathet, comprised:

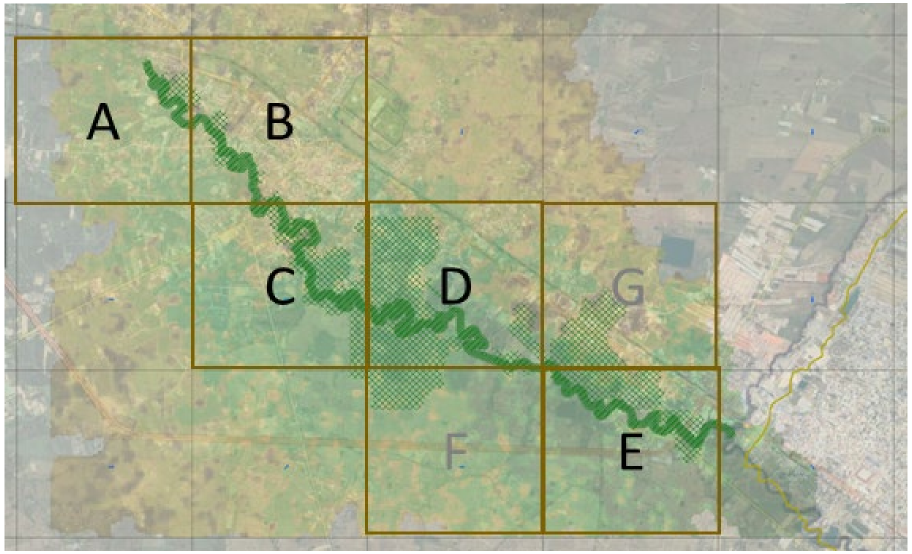
- Retention and infiltration of rooftop runoff measures (including the development of rain gardens and green roofs) and surface runoff measures (including the development of bioswales and infiltration trenches for road drainage – variable being the length of the proposed trenches and swales);
- Area (ha) of riparian buffer strips (the river buffer strip was considered with detailed approach using Meyer and SWAT documentation); and
- Urban greening (with a focus on tree planting – variable being the portion of greening distributed over the built-up area).

All formulas are taken from SWAT documentation and Meyer (1995). The SWAT formulas stem from regression models based on field observations. The uncertainty is high, in particular the formulas for nutrients. The advantage Meyer formula brings is that soil texture is considered with fractions of sand, silt and clay. Therefore, Meyer formula was given priority. Therefore, the results are approximations and should be treated with caution. It is not guaranteed that effects as indicated with the calculations will occur in practice. A second limitation is the DEM that was used to calculated direct catchment of the buffer strips.

<u>Riparian buffer strip calculation approach</u>

The sediment formulas for buffer strips following the SWAT documentation and Meyer* (1995) were used. Meyer formula resulted in less sediment reduction potential and was applied as a conservative approach. The catchment area of the buffer strip was obtained from the 30x30m DEM (the original SRTM30). Only sediment from the catchment area can be retained by the buffer strip. Drainage routes cannot be controlled by buffer strips and were not considered. The direct catchments of buffer strips were derived from this 30x30m DEM. Drainage routes from upstream were not considered as direct catchment of a buffer strip since no buffer strip can be implemented in drainage routes. This means that the buffer strips calculation considers only the retention effect of a buffer strip but excludes any impact on sediment coming from the drainage routes.

**Figure 53: Aranyaprathet riparian buffer strip model cells**




Cells B, C and D shown in Figure 53 are dominated by urban areas, while A and E have agriculture with a portion of > 50%. F and G contribute to D and G respectively. The potential for sediment reduction ranged from 32% for cell E to 46% for cell B. The direct catchment of the buffer strip covers an area of 469 ha. Using the direct catchments only, the benefit sums up to approx. 870 tons/yr with a maximum of 530 within E and a minimum of 23 within D. The highest reduction potential per unit of area can be found in cell A and E. Therefore, in summary, a well-maintained buffer strip along the river passing Aranyaprathet has a potential of approx. 870 tons/yr reduction in sediment load.

**Figure 54: river buffer strip characterisation of units A to G**

| Cell | Land cover | Drainage | Runoff | Soil loss | Effect of sediment redution |
|---|---|---|---|---|---|
| A | Agriculture + built up | good | medium | very high | high |
| B | Built up | good | medium | high | high |
| C | Built up + agriculture | good | medium | high | high |
| D | Built up + agriculture | good | medium | low | low |
| E | Agriculture + built up | medium | high | very high | high |
| F | Agriculture + minor built up | medium | medium | very high | high |
| G | Built up + agriculture | good | low | medium | medium |

Retention and infiltration of rooftop and surface runoff and urban greening calculation approaches

Improved measures to retain and infiltrate rooftop runoff (green roofs and rain gardens) and increases in the area of urban greening measures (vegetation enhancement in parks and open spaces) were modelling to assess impacts on runoff and peak flow reductions. The urban greening assumption is a homogeneous distribution over the entire built-up area – no spatially explicit locations for greening were identified for the modelling.

Separate modelling was undertaken for the retention and infiltration of surface runoff via swales and infiltration trenches along roads. These interventions have a potential to reduce runoff volume by 4% for storm events > 60 minutes up to 30% for storm events <= 15 minutes (high confidence). This is dependent on how many trenches and swales will be implemented. A flood peak reduction is very unlikely (high confidence). Urban greening has the potential to reduce runoff peaks and volume, depending on the area of greening. 1% of the built-up area brings a reduction of <1%, 15% of the built-up area achieves up to 7% reduction.

Infiltration trenches and swales requires space along roads. Due consideration must be given to water quality aspects when infiltrating runoff to the underground. Urban greening is cheap and does not imply infrastructure. The same applies for the buffer strip.

**Figure 55: Greening measures modelled with GIS land use map**

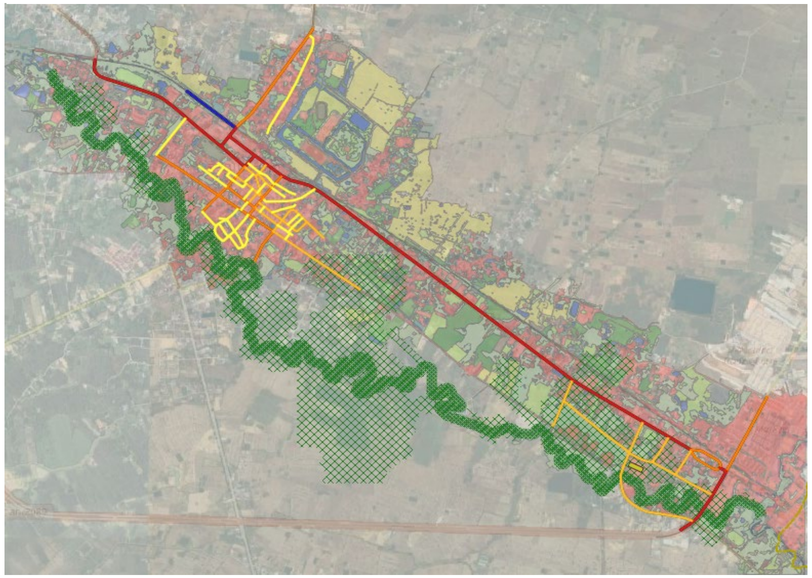


**Figure 56: Model results for the retention and infiltration of rooftop runoff and urban greening – peak flow reduction based on vegetation improvements (green roofs, rain gardens, parks)**

| Return | Rainfall | Peak reduction in % with vegetation improvement | | | | |
|---|---|---|---|---|---|---|
| period | duration | urban green portion in % of total built up area | | | | |
| [a] | [min] | 1% | 3% | 5% | 8% | 15% |
| 10 | 15 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 10 | 60 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 10 | 120 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 10 | 360 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 10 | 720 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 10 | 1440 | 0.4% | 1.1% | 2.3% | 3.7% | 7.0% |
| 20 | 15 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 20 | 60 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 20 | 120 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 20 | 360 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 20 | 720 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 20 | 1440 | 0.3% | 1.3% | 2.1% | 3.4% | 6.3% |
| 50 | 15 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 50 | 60 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 50 | 120 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 50 | 360 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 50 | 720 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 50 | 1440 | 0.3% | 1.1% | 1.8% | 2.9% | 5.4% |
| 100 | 15 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |
| 100 | 60 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |
| 100 | 120 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |
| 100 | 360 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |
| 100 | 720 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |
| 100 | 1440 | 0.3% | 1.0% | 1.6% | 2.6% | 4.9% |

**Figure 57: Model results for the retention and infiltration of surface runoff (road drainage) – peak flow reduction based on vegetation improvements (infiltration trenches and swales)**

| Return | Rainfall | Runoff reduction in % with swales and infiltration trenches along streets | | | | |
|---|---|---|---|---|---|---|
| period | duration | length of swales and infiltration trenches in % of total length of roads | | | | |
| [a] | [min] | 50% | 40% | 30% | 20% | 10% |
| 10 | 15 | 32% | 25% | 19% | 13% | 6% |
| 10 | 60 | 32% | 25% | 19% | 13% | 6% |
| 10 | 120 | 32% | 25% | 19% | 13% | 6% |
| 10 | 360 | 32% | 25% | 19% | 13% | 6% |
| 20 | 15 | 27% | 22% | 16% | 11% | 5% |
| 20 | 60 | 27% | 22% | 16% | 11% | 5% |
| 20 | 120 | 27% | 22% | 16% | 11% | 5% |
| 20 | 360 | 27% | 22% | 16% | 11% | 5% |
| 50 | 15 | 23% | 18% | 14% | 9% | 5% |
| 50 | 60 | 23% | 18% | 14% | 9% | 5% |
| 50 | 120 | 23% | 18% | 14% | 9% | 5% |
| 50 | 360 | 23% | 18% | 14% | 9% | 5% |
| 100 | 15 | 20% | 16% | 12% | 8% | 4% |
| 100 | 60 | 20% | 16% | 12% | 8% | 4% |
| 100 | 120 | 20% | 16% | 12% | 8% | 4% |
| 100 | 360 | 20% | 16% | 12% | 8% | 4% |

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