Cost-Benefit Analysis of Landscape Restoration Measures in Sangker River Basin, Cambodia

Investing in Climate Change Adaptation through Agroecological Landscape Restoration: A Nature-Based Solution for Climate Resilience

May 2024

Aerial view of pilot farm in Takhes Meanchey. Drone photo taken in the 3rd field mission to pilot sites in Cambodia (photo by Project Team).

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Deliverable summaries

TA-6539 Investing in Climate Change Adaptation through Agroecological Landscape Restoration: A Nature-based Solution for Climate Resilience led to the preparation of the following knowledge products:

- KP1 (1): Landscape Restoration Country Profile: Philippines
- KP1 (2): Landscape Restoration Country Profile: Cambodia
- KP3: Business Models to Encourage Private Sector Participation in Sustainable Land and Forest Landscape Management
- KP4 (1): Climate Change Risk and Adaptation Options Assessment – Sangker River Basin, Cambodia
- KP4 (2): Climate Change Risk and Adaptation Options Assessment – Manupali Watershed, Mindanao River Basin, the Philippines
- KP5: Good practices manual on biodiverse forest and landscape restoration
- KP6: Community-based Climate Vulnerability Assessment and Adaptation Planning for Resilient Agroecosystems
- KP 7: Applying Advanced Technologies in Support of Landscape Restoration and Climate Change Adaptation
- KP8 (1): User Manual: Sangker River Basin Decision Support System
- KP8 (2): User Manual: Mindanao/Manupali River Basin Decision Support System
- KP8 (3): Admin Manual: Sangker River Basin Decision Support System
- KP8 (4): Admin Manual: Mindanao/Manupali River Basin Decision Support System
- KP9 (1): Restoration plans for demonstration areas in Cambodia and the Philippines
- KP9 (2): Gender and Social Inclusion in the Mindanao River Basin, the Philippines, and the Sangker River Basin, Cambodia
- KP9(3): Cost-Benefit Analysis of Landscape Restoration Measures in Sangker River Basin, Cambodia
- KP9(4): Cost-Benefit Analysis of Landscape Restoration Measures in Manupali Watershed, Philippines
- KP 10: Integrating the principles of ecological agriculture into upland farming systems of Manupali Watershed, the Philippines

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Photo credit

Front page: **Aerial view of pilot farm in Takhes Meanchey**. Drone photo taken in the 3rd field mission to pilot sites in Cambodia (photo by Project Team).

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Abbreviations

ADB	Asian Development Bank
BCR	Benefit-cost ratio
CBA	Cost-benefit analysis
FS	Future scenario
GIS	Geographic information system
ICEM	International Centre for Environmental Management
ICRAF	International Centre for Research in Agroforestry
IRR	Internal rate of return
KP	Knowledge product
MOE	Ministry of Environment
MP	Market price for carbon credits
MUA	Samlout multiple use area
NbS	Nature-based solutions
NPV	Net present value
NTFP	Non-timber forest products
O&M	Operation and Maintenance
PES	Payment for ecosystem services
RCP	Representative concentration pathway
SVC	Social value of carbon
SWAT	Soil and water assessment tool
USD	United States Dollar

Weights and Measures

C	carbon
CO_2e	Carbon dioxide equivalent
ha	hectare
km	kilometre
km^2	Square kilometre
m	metre
T	ton

1 Introduction

The Asian Development Bank (ADB) project Investing in Climate Change Adaptation through Agroecological Landscape Restoration – 1, Climate Change Risk and Adaptation/Restoration Option Assessment aims to assist Cambodia and the Philippines to develop, evaluate, and promote innovative approaches to scale up climate change adaptation interventions through agroecological landscape restoration; and to strengthen the capacity of communities to restore and manage their climate-resilient landscapes for food and nutrition security through agroecology. The project is contributing to the implementation of landscape restoration measures within target watersheds.

In Cambodia, the project is led by the Ministry of Environment (MOE) with technical support from the International Centre for Environmental Management (ICEM) and the International Centre for Research in Agroforestry (ICRAF). Following detailed assessments, MOE identified the Sangker River basin as a suitable target river basin to demonstrate the landscape restoration planning process and tools and implement restoration plans for specific community forests working with local government and communities. The emphasis is on forest restoration, agroforestry, and agro-ecology as part of building climate change resilience, biodiversity gains, and livelihood enhancement.

In the Sangker River Basin, the project worked with local communities to demonstrate agroforestry techniques and rejuvenate four Community Forests in the upper headlands of the River Basin. Communities worked with the project team to develop bespoke restoration plans and implement them.

Building on experiences at the demonstration sites, analysis of the River Basin's hydrology, and the results of consultations with the local community, the project team outlined a strategy to restore the remainder of the River Basin.

The strategy proposed rolling out the approach deployed at the four demonstration sites to the remaining Community Forests in the River Basin, introducing agroforestry and conservation agriculture techniques to croplands in the Upper River Basin, and restoring key drainage corridors.

The following analysis provides a high-level cost-benefit analysis of the approach, estimating a range of benefits.

2 Sangker River Basin

The Sangker River Basin is located in Battambang Province , northwest of Cambodia. The basin contains fifty-five sub-basins with a total drainage area of 6,051 km^2. The Stung Sangker River flows through the basin and is the third largest tributary in the Tonle Sap Basin River system. The 250 km river flows through six districts and twenty-seven communes before draining into the Tonle Sap Lake. The lower basin includes part of Cambodia's 'rice bowl,' an important food-producing area, and Battambang itself, the country's second-largest city.

The basin consists of a flat lowland region including internationally important wetlands immediately upstream of the Tonle Sap Lake and a highland region towards the south and west of the basin, where elevations extend to around 1,400m. The flat lower basin has long been cultivated. However, the steeper hills of the upper basin have been cleared relatively recently.

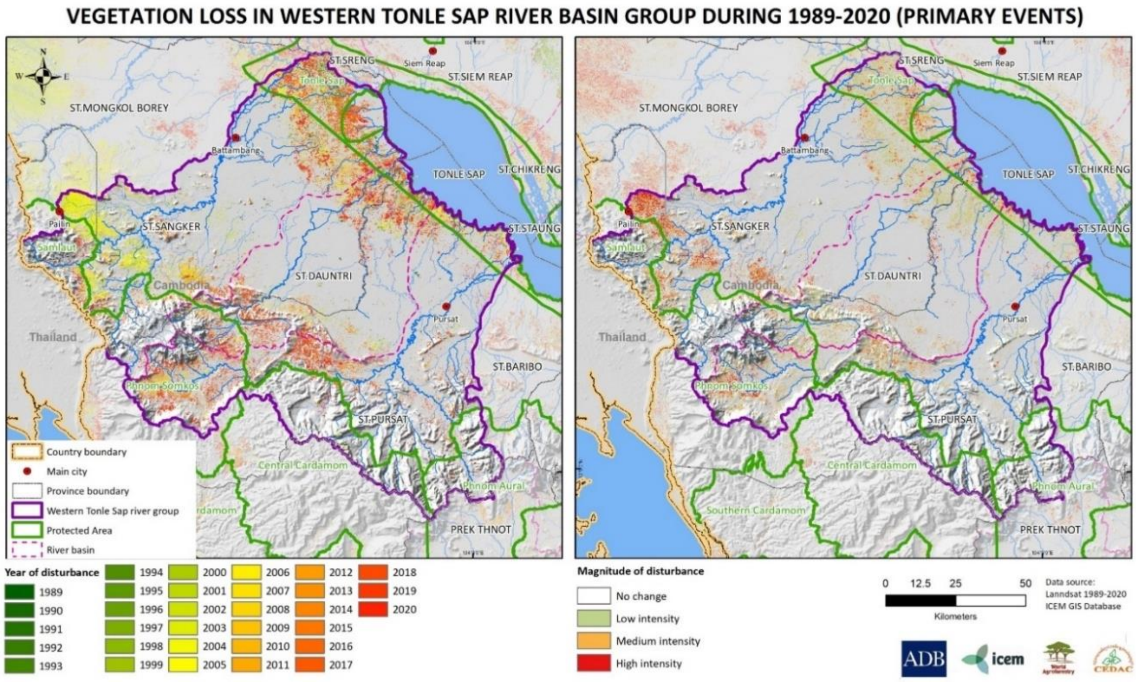
Since the mid 1990's, displaced people have begun cropping in the uplands, finding that soil fertility was high in recently cleared rainforests.[1] Many smallholders began planting maize before finding that the resulting drop in soil fertility, nutrient deficiencies and a falling maize price made converting land to cassava more profitable.

[1] Montgomery, Stephanie & Martin, Robert & Guppy, Chris & Wright, Graeme & Tighe, Matthew. 2017. Farmer knowledge and perception of production constraints in Northwest Cambodia. Journal of Rural Studies. 56. 12-20. 10.1016/j.jrurstud.2017.09.003.

From around 2007 onwards, cassava emerged as the favoured crop, with increased demand in Thailand, Vietnam, and China.

The deforestation rate in Sangker River Basin is estimated to range from 0.14% to 1.76% per annum. Forest loss is equivalent to observed increases in agricultural land. Forest cover remained constant from 1976 to 1997, although large areas of dense forest became degraded. Since 1998, and particularly since 2010, deforested areas have increased, typically making way for agricultural land such as paddy rice fields, field crops, horticulture, rubber, and oil palm. Overall forest cover (Evergreen, Deciduous, and Mixed Forest) declined from 44% in 2002 to 29% in 2017, Orchards and Plantations from 28% to 18%, while agriculture and cropland grew from 29% to 43%. This trend is observed throughout the Sangker basin (Figure 1).

Figure 1: Vegetation loss in western Tonle Sap River basin group from 1989 to 2020



3 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.

An intervention's total economic benefit includes the core benefits the project is designed to address and other co-benefits. In many cases, particularly with Nature Based Solutions (NbS) measures the combination of co-benefits is often larger than the core benefit of the project.

The costs of an intervention include the direct investment, maintenance and operational costs, and also opportunity costs. Opportunity costs represent the benefits foregone if resources were used differently. In many environmental and restoration projects such as this one the opportunity cost of alternative uses to land that is being conserved or restored can be substantial.

4 Scope of Analysis

The analysis assesses the potential impact of implementing the recommendations for a river basin-wide restoration strategy outlined in a *Climate Change Risk and Adaptation Options Assessment* produced for the project. The report outlined an approach to landscape restoration in the river basin that would mitigate the impacts of climate change.

In summary, the recommendations are to:

- Roll out the restoration activities at the pilot sites in four Community Forests to the remaining Community Forests located in the interfluve between the Stung Sangker and Stung Chaml Any Kuoy Rivers.
- Restore drainage corridors, particularly in the upper River Basin.
- Establish a buffer zone around the borders of the Samlout Multiple Use Area (MUA).
- Introduce agroforestry and conservation farming combinations to cropland in the upper Sangker River Basin.

The recommendations are expected to bring about several benefits, including:

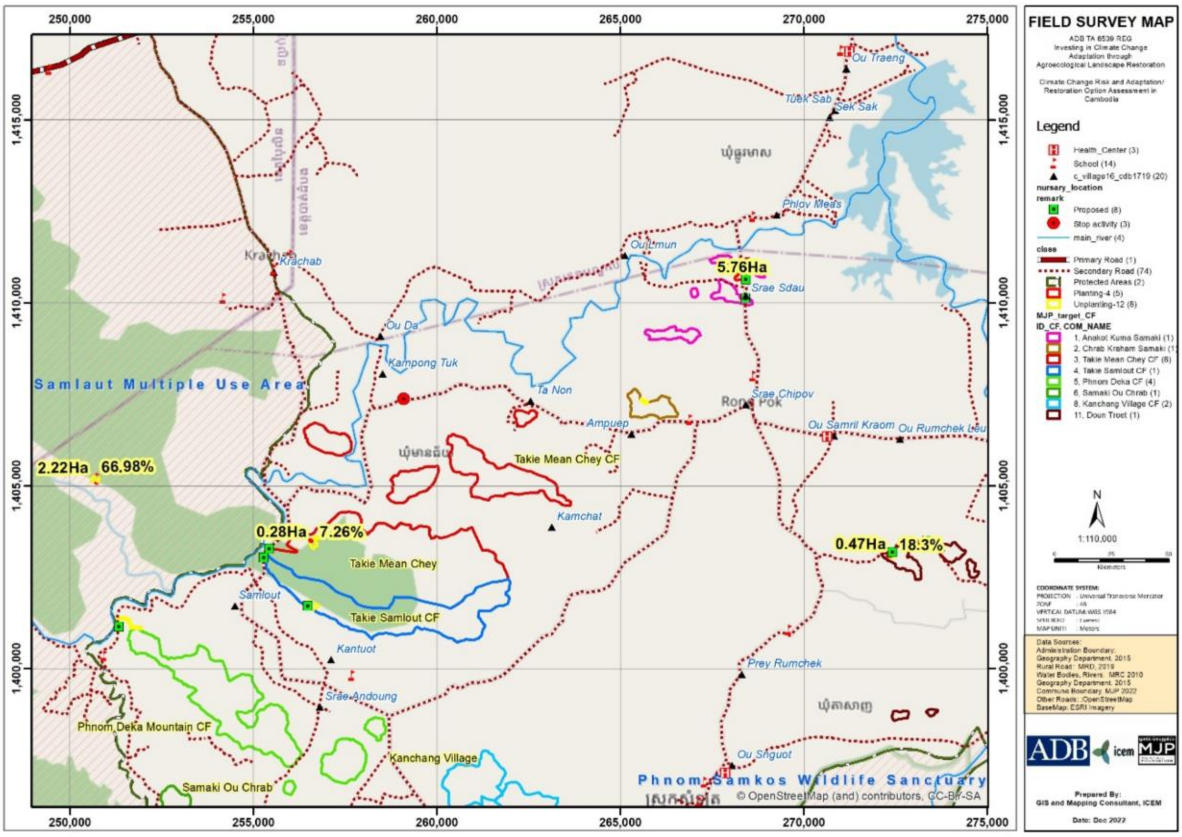
- Net increases in biodiversity in the Community Forest areas and in croplands converted to agroforestry/ conservation farming.
- Increased yields to farmers implementing conservation farming techniques or turning some of their land into agroforestry. Increased yields arise from increased soil fertility, diversification of crops (leading to increase resilience and more consistent incomes) and intercropping (leading to increased productivity), and increased resistance to pests.
- An increase in the provision of non-timber forest products (NTFPs) in community forests.
- Reduced erosion, particularly in croplands composed primarily of cassava fields. Reduced erosion will slow the removal of nutrients from topsoils.
- Reduced sedimentation loads in rivers, drainage corridors, the Treng reservoir, and the Tonle Sap Lake.
- Increased sequestration of carbon in community forests.
- Reduced incidence of flooding, particularly in the River Basin's lowlands and urban areas, resulting in lower building and crop damage.

To estimate the value of the impacts, the analysis draws upon experience to date in the demonstration sites, literature on the impacts of conservation farming, and the Soil and Water Assessment Tool (SWAT) model produced as part of the project.

4.1 Demonstration Sites

At the landscape level, the project is primarily concerned with establishing pilot sites in the Upper Sangker River basin. Eleven community forests were initially identified as potentially suitable for restoration work based on the degree of degradation and commitment of the respective community forest management groups to restoration. Four sites were selected as pilots: O'Slev within the Samlout MUA and Anakot Koma Samaky, Takhes Meanchey and Dontret Community Forest areas in the Samlout buffer between the Stung Sangker and the Stung Chaml Any Kuoy (Figure 2).

Figure 2: Pilot community forests in the upper Sangker basin



Each pilot site was between two and eleven hectares, a small proportion of the total area of each of the community forests. Restoration of the sites generally sought to increase forest canopy cover, restore species composition, reduce runoff and soil erosion, increase carbon sequestration, and enhance biodiversity by reintroducing native species and providing alternatives to monocultures, such as cassava[2].

4.2 Hydrology Modeling

Ecosystems, agriculture, and agroforestry rely on river basins for their hydrological needs. However, agricultural and urban developments can significantly affect hydrology and sediment transport processes. Changes in land use and land cover can change the timing and volumes of runoff, which, in turn, can change water availability in the dry season and increase the likelihood of flooding in the wet season.

Furthermore, increases in flooding and the removal of native vegetation may exacerbate erosion, potentially leading to the loss of topsoil and damaging crops and arable land adjacent to waterways.

Climate change can also alter the timing and volumes of runoff, affecting the capacity of river basins to sustain functioning agricultural systems and ecosystems. Durations and the timing of dry periods may change, potentially leading to more severe droughts. Changes in the transitions between the wet and dry seasons may affect the timing of planting and harvesting crops.

SWAT models provide valuable insights into hydrologic and sediment processes and the impact of climate change and landscape change. SWAT models have been used for over 40 years to study rainfall-runoff and erosion processes[3], including studies in Cambodia, the Mekong River basin, and the

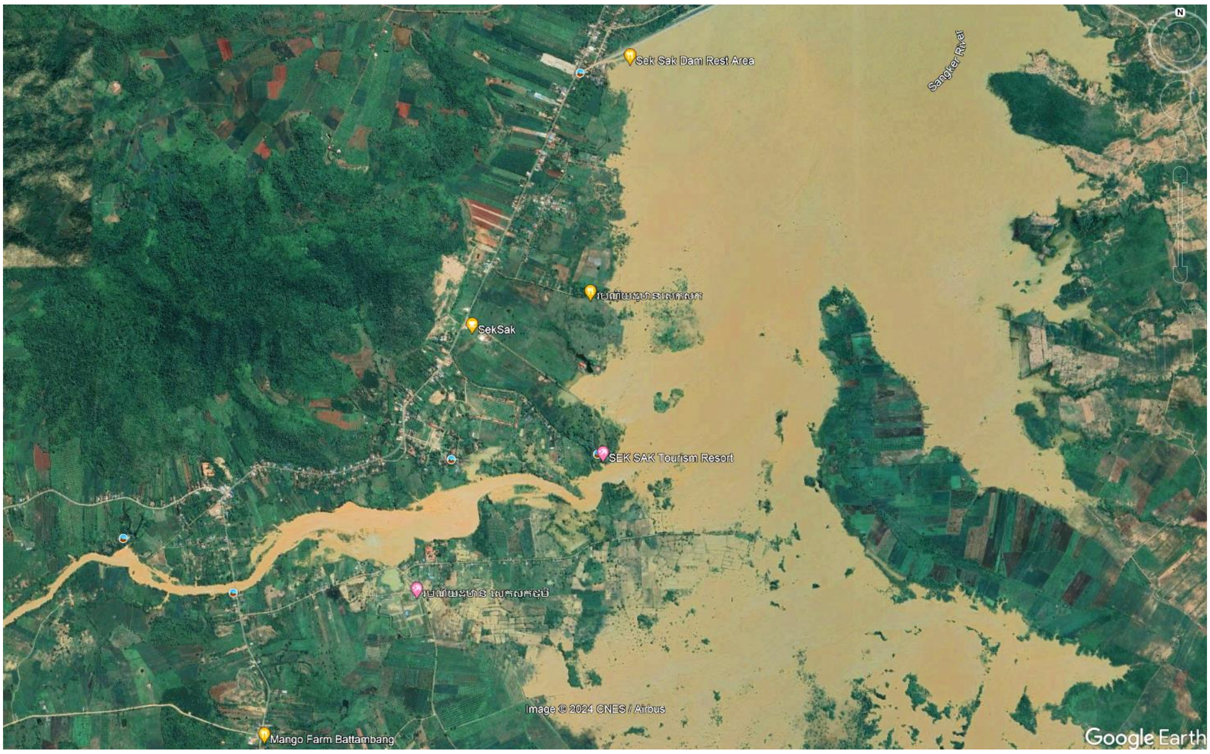
[2] The restoration plans for each site can be found in a companion report.
[3] Arnold et al. 2012. *SWAT: Model use, calibration, and validation.* Transactions of the ASABE Vol. 55(4): 1491-1508.

Sangker basin. This analysis draws heavily on the SWAT hydrology modeling completed as part of the project.

The modeling assessed the impact of climate change on rainfall and water and sediment flows (typically due to the erosion of unprotected topsoils) in the Sangker River Basin. The analysis established a baseline and developed three scenarios, each varying in terms of the impact of climate change and the efforts to mitigate its effects.

Baseline analysis revealed that changes in land use have already had noticeable effects on the basin's hydrology (the distribution and movement of water). Average annual water flows have decreased since 2000 as agricultural land replaced forested land, reducing water availability in downstream areas. Analysis of wet season flows revealed an increased tendency for flash floods and the more rapid occurrence of flood events leading to increased sediment load in the Sangker River (Figure 3). By contrast, the dry season is experiencing more extended periods of rain-free days.

Figure 3: Sediment transport from the upper Sangker River basin into the Treng Reservoir in 2024



Three scenarios then explored the future impact of climate change on the river basin and the potential impacts of reforesting degraded land and implementing conservation measures in lowland agricultural areas.

Future Scenario 1 (FS1) adjusts the baseline rainfall in line with the Representative Concentration Pathway (RCP) 8.5, in which carbon emissions are assumed to rise at a high rate throughout the century. The scenario assesses the impact of the changes to rainfall patterns on the hydrology and sediment in the river basin. Under the scenario, monthly rainfall increases in the highest flow months of September and October and is lower for all other months. The most significant increase is observed in October, with an increase in average monthly flows of 15%. The increase will likely cause flood damage to the basin's infrastructure, crops, and property. By contrast, the decrease in flows in the dry season could potentially lead to drought and water supply issues for agriculture, human well-being, and ecosystems. In the scenario, sediment loads increase by 14% compared to the baseline scenario, with a 12% increase in loads entering the Treng reservoir and an increase in flows in lowland and upstream areas. Flows into the Treng reservoir may affect the reservoir's serviceability, and the increase in flows in the upland and lowland areas is also of concern.

Future Scenario 2 also adjusted the baseline rainfall in line with the Representative Concentration Pathway (RCP) 8.5 and assessed the mitigating impact of converting 30% of agricultural land in upstream areas to agroforestry. The analysis demonstrates that agroforestry will reduce the average river discharges compared to the baseline scenario and Future Scenario 1. However, while sediment loads are lower than in FS1, they are 11% higher than the baseline scenario at the Treng reservoir and 12% higher at the Sangker River outlet, implying that further measures will be needed to prevent increases in sediment loads from occurring in downstream waterways.

The SWAT model also tested a *Future Scenario 3,* which extended FS2 by implementing contour farming on the remaining agricultural areas across the River Basin not converted to agroforestry. The cost-benefit analysis (CBA) will only use the results for FS2 and FS1, which most closely match the recommendations in KP4.

4.3 Protecting Existing Forests

Although not included in the hydrology model, it is likely that without intervention, smallholders will continue to encroach on forest land, particularly as soil fertility falls, the impacts of climate change are felt, and, potentially, in response to market signals. Indeed, during the project, one demonstration site - O'Slev within the Samlout MUA - was illegally converted from forest to agricultural land, despite appeals from the project team to the Palin Governor.

Since 2001, the Sangker River basin has experienced a significant reduction in native deciduous, orchard, and mixed forest (Table 1). The total forest area lost almost (82,979) hectares, which almost exactly matches the additional cropland in the basin (82,394 hectares).

Table 1: Impact of Deforestation in the Sangker River Basin

Land Use	2001	2017	% Change
Native deciduous forest	44,154	20,941	-53%
Orchard or plantation forest	167,738	109,161	-35%
Native evergreen broadleaf	51,277	50,732	-1%
Mixed native and plantation forest	885	241	-73%
Cropland	137,669	220,064	60%
Rice	35,606	39,758	12%

Source: Servir-Mekong, ICEM GIS Database 2022

Between 2000 and 2017, the average rate of forest loss was 1.8% per year, totalling over 41,000 hectares. However, the rate includes dramatic forest loss between 2000 and 2002, in which 17,528 hectares or one-third of deciduous forest was destroyed. Between 2003 and 2017, the annual average loss was 1.6%, falling to 0.15% in the shorter period from 2013 to 2017.

The CBA will assume a 0.1% annual reduction in forest cover in the upper Sangker over the thirty-year appraisal period. It should be noted that discussions with stakeholders in the Sangker River basin suggested that the deforestation rate remains relatively high in protected areas. As such 0.1% may be an underestimate.

A further loss of forest, particularly to cropland, will bring with it greater soil loss, sedimentation, and potential flooding. However, further forest loss was not factored into the hydrology modeling. The CBA analysis will include an assessment of the impact of forest loss on farmers (increased incomes), carbon emissions (emitted carbon and foregone sequestration), and foregone forest provisions but will not assess the impact on flooding, erosion, or sequestration.

4.4 Climate Change Assessment

Drawing on regional analysis, the hydrology model, and consultation with stakeholders and experts, the team assessed the climate change risks to the Sangker River basin. Several trends and risks were identified, presenting costs to the environment, businesses, farms, and communities (Table 2).

Table 2: Potential climate change impacts on the Sangker River basin

Risk/ Trend	Potential Impact	Costs incurred
Shift in the rainfall pattern, resulting in increased rainfall towards the end of the wet season.	Elevated risk of flooding	Crop, infrastructure, and building damage
Rising temperatures and decline in dry season rainfall	Greater frequency and intensity droughts	Crop damage, water shortages,
Reduced river flows resulting from diminished upstream storage	Reduced water supply for consumption and irrigation	Crop damage, Costs of ensuring additional water supply
Escalating runoff and an augmented risk of flash flooding and soil erosion	Soil erosion, sedimentation, flooding.	Reduced crop yields, crop damage, infrastructure and building damage, greater use of agricultural chemicals
Agricultural expansion into hilly areas causing deforestation and forest degradation	Reduced water retention, amplified runoff, soil erosion, sediment transfer, increase in the risk of floods and drought	Crop, infrastructure and building damage, reduced yields, water shortages, loss of biodiversity, Carbon release, reduction in carbon sequestration, reduction in NFTPs, reduced attractiveness for tourism.

Source: ICEM Project Analysis

The risk assessment identified the Upper Sangker basin as the primary source of the risks and, therefore, the focus of landscape restoration measures.

5 Scenarios

The CBA analysis models two scenarios. The first, Future Scenario 1 (FS1), draws on the SWAT analysis of the impact of climate change on the Sangker River Basin. The second, Future Scenario 2 (FS2), models the restoration of Community Forests, the conversion of cropland to conservation farming, the restoration of drainage corridors, the creation of a buffer along the edge of the Samlout MUA, and a halt to deforestation in the River Basin.

5.1 Future Scenario 1 – Business as Usual

Under Future Scenario 1[4], heavier and changing rainfall patterns, exacerbated by poor land management techniques, see an increase in erosion (sediment yield) rates and the accumulation of sediment in the Treng reservoir, Tonle Sap Lake, and other water courses.

The impacts can be quantified as reduced agricultural yields (from the loss of topsoils, and so reduced fertility), and the cost of sediment removal from water bodies. An increase in water flows, particularly

[4] The analysis will adopt the same nomenclature as the hydrology model produced by the report. Hence, the Business as Usual scenario – what is expected to occur in the Sangker River Basin in the absence of the proposed interventions – will be termed Future Scenario 1, or FS1.

maximum flows in the wet season, also increases the probability of flooding in the lower reaches of the river basin and urban areas, including Battambang.

FS1 also assumes - in line with the 2019 study and trends up to 2017 - a (conservative) 0.1% reduction in forest land per annum. Such deforestation would impose additional costs on the environment, businesses, and communities, including the release of carbon into the atmosphere, additional soil loss, sedimentation, and water flows. However, as the hydrology model did not model the impact on hydrology of continued forest loss, the impacts of erosion, sedimentation, and changes to the water supply that would result from deforestation have not been estimated. However, the impacts on carbon sequestration are included.

FS1, therefore, provides an estimate of the increase in sediment yields and sediment load, as well as the potential impact of more intense flooding that will result as the effects of climate change are felt. These are, however, likely to be underestimates, as the continued deforestation assumed in FS1 will further increase the rate of soil loss, sedimentation of water assets, and the risk of flooding.

5.2 Future Scenario 2

Future Scenario 2 assumes that Community Forests and drainage corridors are restored, cropland in the upper Sangker is converted to agroforestry and conservation farming, buffer zones are established along drainage corridors and along the border of the Samlout MUA, and the deforestation is halted.

5.2.1 Future Scenario 2 - 12 Community Forests

There are 33 community forests in the upper Sangker basin. The communally owned and managed forests are comprised of relatively recently degraded forest and agricultural encroachment.

The community forests are particularly important, as most contain remnant forested hills that form the headwaters of micro-watersheds, appearing like forested islands in a sea of cultivated land. Reforestation of these 'islands' would support biodiversity conservation and provide improved ecosystem services and soil and water conservation benefiting the local population and agricultural land downstream.

Central to the proposed strategy is the restoration of the twelve community forests located in the interfluves of the Stung Sangker and Stung Chaml Any Kuoy Rivers. The approach adopted will mirror that taken in the four demonstration sites. Restoration plans will be developed in cooperation with local communities and will focus on returning forests to a natural state, securing and protecting drainage corridors across the agricultural landscape, introducing nature-based solutions (NbS) to combat soil erosion and retain water, and developing non-timber forest products to generate additional income for local communities. Restoring the sites is derived from the costs identified for implementing the restoration plans at the four demonstration sites.

The benefits of rejuvenating the twelve demonstration sites are primarily carbon sequestration, erosion control, and reductions in downstream sedimentation. Further benefits include increased incomes from conservation agriculture activities such as beekeeping.

Perhaps the most significant benefit is the net contribution to biodiversity in the area. Restoring the community forests will create a network of "stepping stones", enabling animals, insects, birds, and plants to expand their habitable areas, bringing with them a range of potential benefits. However, in the absence of willingness-to-pay surveys or ecological surveys assessing the contribution of species and combinations of species to the production of measurable ecosystem services, accurate monetization of biodiversity benefits is difficult.

5.2.2 Conversion to Conservation Agriculture/ Agroforestry

The SWAT model assumed that in FS2, 30% of agricultural land in the upper River Basin would be converted to agroforestry, and the remainder would be modeled in FS3. This analysis assumes that

30% of cropland is converted to agroforestry in Year 3, and the remainder (70%) of upland cropland is converted in Year 6. It does not assume any changes to lowland cropland.

5.2.2.1 Establishment Costs

The analysis draws on the costs of a 2013 project that intercropped Taro with several varieties of fruit trees to estimate the per-hectare costs of establishing conservation agriculture.[5] The total cost of planting and additional preparation was USD 904 (in 2023 USD).

An essential part of rolling out conservation agriculture techniques across remaining cropland will be training smallholder farmers. The analysis assumes that farmers will receive two training sessions in the first year; each for 35 people and costing USD 500 (figures derived from training undertaken at the project demonstration sites). The average farm size in Samlout is 20 hectares. Assuming one person per farm receives training, the total cost of training farmers representing 30% of cropland will be USD 26,084, and USD 86,947 for all farmers. For the analysis, a per-hectare cost of USD 1.43 is assumed.

5.2.2.2 Yields

The project proposes that farmers intercrop existing crops with fruit trees. The practice is expected to have several benefits, including water and soil retention and more stable incomes.

Upland farmers produce several crops, including rice, maize, and cassava. Although the analysis can only be indicative, as the actual identification of the land to be converted to agroforestry will take place after consultation and study, it is likely that the majority of cropland converted to agroforestry and conservation agriculture is cassava. Cassava covers a sizeable proportion of the upper reaches of the Sangker River basin. Peuo (2021) estimated that 50,000 hectares of the upper Sangker River basin were devoted to cassava, close to the estimated total cropland area of 60,841 hectares.[6]

Table 3: Land use in the upper Sangker River basin

Land Use	Area in Upper Sangker River Basin (Ha)
Surface water	811
Flooded forest	-
Deciduous forest	18,935
Orchard or plantation forest	78,926
Evergreen Broadleaf	49,739
Mixed forest	221
Urban and built-up	300
Cropland	**60,841**
Rice	-
Barren	86
Wetland	8
Grassland	46
Shrubland	11,194
Aquaculture	22

Source: ICEM GIS Database 2023

[5] The USAID project took place between 2013 and 2015. The costs are derived from and unpublished project report, and can be made available on request.

[6] Peuo, V. 2021. Analysis of the cassava yield variation at Cambodia- Thailand border. Asian Journal of agricultural and Environmental Safety. Vol 2020. Issue 1. Accessed here: https://www.researchgate.net/publication/353804026_Analysis_of_the_cassava_yield_variation_at_Cambodia-_Thailand_border

Cassava production in the upper Sangker watershed provides income to many households within the river basin. However, cassava production can be detrimental to the soil, resulting in erosion and a reduction in soil nutrients.[7]

As outlined in *Climate Change Risk and Adaptation Options Assessment* and modeled in the Sangker River basin hydrology model, the river basin restoration strategy proposes integrating agroforestry techniques in 30% of cropland within the upper Sangker River basin.

In practice, this will involve various techniques, including intercropping, grass strips, and conservation tillage. This cost-benefit analysis assumes that a proportion of the land currently dedicated to cassava plantations will be replaced with the intercropping of fruit trees and other crops.

Peuo (2021) studied cassava farming in the upper Sangker, finding that:[8]

- Average cassava yields are 24.16 tons per hectare, although this disguises a wide variation in yields.
- Total revenues are 1,486.58 USD per hectare.
- The average price of cassava is 61.53 USD per ton.
- Labour costs are 21.16% of total revenues.
- The total cost of production is 1,058.19 usd per year, and total profits are 428.4 USD.

No studies have examined the impact of conservation farming on yields in Cambodia, although the impacts are widely assumed to be beneficial.[9] However, available studies from elsewhere estimate that yields rise by as much as 30% and that labor costs can fall by as much as 65%.[10] Initial total yields are also likely to fall as new cropping patterns and techniques are implemented. Available evidence suggests reduced yields for between one and three years.

This analysis will assume that farmers' profits increase by 30% (up to USD 557.13) after three years and that, representing initial reductions in yield, profits are zero for three years, imposing a cost of USD 428 per hectare per year on farmers.

Potential additional benefits would arise if yields fall in the FS1 scenario as a result of erosion, and resultant nutrient loss. The SWAT model estimates an average annual sediment yield of 7.43 tons per hectare in the upper Sangker. This is consistent with other studies of cassava cropping in the region.[11] Studies of erosion in cassava farms suggest soil loss of 60 tons or even 200 tons per hectare on sloping land is possible.[12]

However, there is no convincing evidence that yields will fall significantly or rapidly in the FS1 scenario. Soil depth is close to four meters, suggesting that at even 60 tons per hectare per year, top soils will remain largely intact for some years. Moreover, cassava is a hardy crop, able to maintain yields in poor soil. Nevertheless, there is likely to be some nutrient loss resulting from erosion. The analysis is also effectively assuming homogeneity of the upland farms. However, yields vary substantially, as will the impact of erosion on soil fertility, so it is likely that some farmers will need to compensate for nutrient

[7] Nut, N et al. 2021. Land Use and Land Cover Changes and Its Impact on Soil Erosion in Stung Sangkae Catchment of Cambodia. Sustainability 2021, 13(16), 9276; https://doi.org/10.3390/su13169276.

[8] Peuo, V. et al. 2021. Economic analysis of cassava production in Cambodia. International Journal of Agricultural Technology 2021 Vol. 17(1):277-290.

[9] See, for example, Delaquis, Erik; De Haan, Stefan; Wyckhuys, Kris A.G.. 2017. On-farm diversity offsets environmental pressures in tropical agroecosystems: A synthetic review for cassava-based systems. Agriculture, Ecosystems and Environment. 251: 226-235.

[10] Delaquis, Erik; De Haan, Stefan; Wyckhuys, Kris A.G.. 2017. On-farm diversity offsets environmental pressures in tropical agroecosystems: A synthetic review for cassava-based systems. Agriculture, Ecosystems and Environment. 251: 226-235.,

[11] Trung Thanh Nguyen et al. 2022. Cassava-cowpea intercropping system for controlling soil erosion in the Northern mountainous areas of Vietnam. *Asia-Pacific Journal of Science and Technology*, *27*(5), 11.

[12] Putthacharoen, S. et al. 1997. Nutrient uptake and soil erosion losses in cassava and six other crops in a Psamment in eastern Thailand. Field Crops Research 57 1998 113–126

loss. The analysis assumes, therefore, that in the FS1 scenario, after ten years, farmers add an extra 10 kgs of fertilizer per hectare (farmers currently use approximately 30 kgs of fertilizer per hectare[13]) at an extra USD 10 per hectare[14]. This value is included as a benefit in the analysis.

5.2.3 Drainage Corridors

The upper Sangker contains approximately 1,000 kilometers of drainage corridors. Of these, 664.4 km are within the Samlut MUA and the Phnom Samkos Wildlife Sanctuary. FS1 includes creating a 15-meter buffer zone on either side of the drainage corridors and placing leaky weirs at approximately 600m intervals.

The buffer zones and leaky weirs are assumed to be established in the third year. Establishment costs are USD 805 per hectare, as calculated for Community Forests. Maintenance costs are USD 103 for the first ten years. Annual maintenance costs for the leaky weirs are assumed to be 2% of establishment costs.

5.2.4 Samlout Buffer Zone

Project recommendations, as outlined in the *Climate Change Risk and Adaptation Options Assessment*, include establishing a buffer zone along the border of the Samlout MUA. A buffer zone is a clearly demarcated area, with or without forest cover, lying outside the boundaries of a protected area that is managed to enhance the conservation value of the protected area, and of the buffer zone itself, while providing benefits for the people living around the area[15]The analysis assumes that a 2km buffer zone is established along the MUA border. This is consistent with Cambodian practice. As early as 1999, the Cambodian Prime Minister recommended that buffers extend 2-3 km from the border of protected areas.

The project recommends that agro-forestry and conservation agriculture is practiced in the buffer zone. Intensive industrial and commercial agriculture should be discouraged, and increased attention needs to be paid to agriculture that embraces mixes of annual and perennial crops and reflects the structure and species composition of traditional agricultural systems and the adjoining natural ecosystems. The development and promotion of sustainable agro-forestry is important for protected area buffer zone management.

Table 4 provides current landuse in the proposed 2 km buffer zone. Forest land comprises 633.3 hectares, plantation and orchard over 3,000 hectares, cropland 5,026 hectares and scrubland 988.5 hectares.

Table 4: Land use by area within 2 km Samlout buffer zone

Land Use	Area (ha)
Surface water	77.8
Deciduous forest	565.0
Orchard or plantation forest	3,716.8
Evergreen Broadleaf	61.4
Mixed forest	6.9
Urban and built-up areas	53.4
Cropland	5,025.6
Barren	16.7
Shrubland	988.5
Total Area	10,512.1

Source: ICEM GIS Database 2023

[13] Discussions with stakeholders, and consistent with Vuthy, T. et al. 2014. The Fertilizer Industry In Cambodia: market, challenges and the way forward. Policy Note 6. ReSAKSS Asia.
[14] Discussion with stakeholders.
[15] ICEM, 2003. Cambodia National Report on Protected Areas and Development. Review of Protected Areas and Development in the Lower Mekong River Region, Indooroopilly, Queensland, Australia.

The 5,026 hectares of cropland will be included in the 30% of cropland converted to conservation agriculture. Scrubland will be reforested, providing sequestration and biodiversity benefits. Additional benefits are, in principle, the further discouragement of encroachment into the Samlout Protected Area. This has not been explicitly calculated.

5.2.5 Additional Benefits

In addition to increased yields, the restoration of Community Forests and drainage corridors and the conversion of cropland to agroforestry and conservation farming will reduce sedimentation, increase the amount of carbon removed from the atmosphere, and reduce the likelihood and incidence of extreme flooding.

5.2.5.1 Carbon Sequestration

The value of carbon is derived from the additional carbon sequestration in the restored community forests the avoided deforestation of existing forest land, and the avoided carbon emissions from the encroachment onto forest land.

Annual sequestration is assumed to be 4.71 tons of carbon per hectare of forest, converted to CO_2e at a conversion rate of 3.67.[16]

Estimates of avoided carbon in Cambodia are provided by the World Bank's 2020 study in the Pursat Basin in Cambodia (Table 5).[17]

Table 5: Carbon stocks by forest type

	Evergreen	Semi-evergreen	Deciduous
Lower Limit (t C/ha)	140.3	109.7	73.7
Upper Limit (t C/ha)	183.0	166.7	94.0
Average (t C/ha)	161.7	138.2	83.9
Average (t CO2-e/ha)	593	507	308

Average values are assumed in the analysis.

Two approaches are taken to estimate the monetary value of carbon. The first adopts the current market price (MP) of approximately USD 10 for carbon credits with co-benefits, as the emphasis on community support and biodiversity in the proposal to restore the Community Forests should command a premium[18]. This value more accurately reflects the actual opportunity cost of forest land for Cambodia. The second is the social cost of carbon emissions (SVC). A mid-point of USD 73 between World Bank low (USD 37 per ton) and high (USD 75 per ton) estimates are assumed, although recent studies point to the higher of the two[19].

5.2.5.2 Reduced Sedimentation

The hydrology analysis estimates an increase in sediment loads due to climate change. In FS1 2.64 million tons of sediment are deposited in the Treng Reservoir, compared to 2.37 million tons in the baseline scenario. According to the hydrology modelling, the interventions implemented in FS2 reduce the sediment load deposited across the River Basin by 0.01 million tons (2.63 million tons).

To estimate the value of the benefits of reduced sedimentation in FS2, the analysis estimates the cost of removing additional sediment from the Treng reservoir, which would have to occur in FS1. The ICEM

[16] Griscom, B. et al. 2017. Natural Climate Solutions. Proceedings of the National Academy of Sciences 114(44). Accessed here: https://www.researchgate.net/publication/320536154_Natural_climate_solutions

[17] World Bank. 2020. Valuing the ecosystem services provided by forests in Pursat Basin, Cambodia. World Bank.

[18] Forest Trends' Ecosystem Marketplace. 2023. State of the Voluntary Carbon Markets 2023. Washington DC: Forest Trends Association.

[19] World Bank. 2017. "Guidance Note on Shadow Price of Carbon in Economic Analysis." Washington: World Bank. Available at: http://pubdocs.worldbank.org/en/911381516303509498/2017-Shadow-Price-of-Carbon Guidance-Note-FINAL-CLEARED.pdf

hydrology analysis provides estimates of sediment load for 2025 and 2055. Assuming linear growth, and a removal cost of USD 1.5 per ton, 8,666.7 tons per year of sediment mass would have to be removed in FS1. Sediment mass is converted to wet sediment volume using a conversion rate of 1:13.[20] The estimated benefits of reduced sedimentation are the dredging costs saved in FS2. As the hydrology model does not capture the impacts of continued deforestation on sediment loads, the quantity of sediment deposited in FS1 is likely to be underestimated, and so are the benefits of implementing the interventions in FS2.

5.2.5.3 Flood reduction

In the absence of a flood model, the impact of reduced flooding was calculated by estimating the area of agricultural land in the lower River Basin that would be covered by 1.5m or more of flood water in a 1:100-year event in the RCP 8.5 climate change scenario.

Table 6: Areas of cropland flooded in a 1:100-year event (ha)

	Area covered by 1.5m or more by flood water in a 1:100 event baseline (Current)	Area covered by 1.5m or more by flood water in a 1:100 event for RCP 4.5	Area covered by 1.5m or more by flood water in a 1:100 event for RCP 8.5
Crop	35,084	38,260	38,708
Rice	18,284	24,140	24,264

Source: ICEM analysis

The costs of flooding are assumed to equal lost profits of USD 500 per hectare. The actual cost per hectare is 1% of the total value, representing the 1:100 chance of the flood occurring.[21]

The costs of flooding are assumed to equal the difference between the value of crops lost in the baseline and the RCP 8.5 Climate Change Scenario. Again, a linear increase in the impact of flood events was assumed, with the area affected rising each year. Note that the analysis compares the baseline scenario with the RCP 8.5 scenario (representing FS1).

6 Costs and Benefits Summary

6.1 CBA Results – Summary of Costs

The costs are organized into establishment costs (the initial costs of implementing the intervention), annual operations and maintenance costs, and opportunity costs.

6.1.1 Establishment Costs

The most significant establishment cost is converting cropland to conservation agriculture, at USD 16.5 million. By contrast, the total of restoring community forests is just USD 1.2 million (Table 7).

Table 7: Establishment costs (USD, 2023 prices)

Establishment Costs	Total Cost	NPV (9% discount rate)
Community Forests	1,172,557	1,075,741
Agroforestry/ Conservation Agriculture	16,567,341	15,199,396
Restoration of drainage channels	1,604,544	1,472,059
Reforestation of scrubland in the Samlout buffer zone	796,231	670,171
Total Establishment Costs	20,140,674	15,607,631

[20] 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)

[21] Chhom, V., Tsusaka, T. W., Datta, A., & Ahmad, M. M. 2023. Factors influencing paddy producers' profitability and sale to markets: evidence from Battambang Province, Cambodia. Cogent Food & Agriculture, 9(1). https://doi.org/10.1080/23311932.2023.2193311

6.1.2 Operational Costs

Operational costs are also relatively small, at USD 3.6 million, or USD 122,605 per year. Most costs are borne in the initial ten years of new forest growth. No additional maintenance costs are assumed in converted cropland.

Table 8: Operational costs (USD, 2023 prices)

Annual O&M Costs	Total Cost	NPV (9% discount rate)
Community Forests	1,356,306	903,487
Restoration Drainage Channels	1,855,987	1,236,345
Total O&M Costs	3,212,293	1,652,343

6.1.3 Opportunity Costs

Opportunity costs are potentially quite large. If it is assumed that the remaining forest is deforested at a rate of 0.1% per year, the foregone cost of establishing crops in the cleared land is over USD 1 million, nearly USD 40,000 a year. This cost is borne primarily by smallholders looking to expand their current farms. Similarly, smallholders looking to expand will lose the benefits of establishing farmland in the newly created buffer zones.

Table 9: Opportunity costs (USD, 2023 prices)

Opportunity costs	Total cost	NPV (9% discount rate)
Additional cropland yields (FS2)	1,154,846	398,721
Establishing agroforestry	4,693,347	3,960,082
Establishing Samlout MUA buffer zone	17,378	5,323
Total opportunity costs of establishing drainage corridor buffer zones and halting deforestation.	5,865,571	3,461,953

The income foregone over the initial three years following planting as smallholders convert to agroforestry or implement conservation farming techniques is, on average, around USD 1,542 per farm. The opportunity costs to farmers who are prevented from encroaching on forest land, and farming land either side of drainage corridors are USD 5.8 million.

The estimated opportunity costs may be high, as they assume that yields on new cropland are equal to the current average yield. However, The actual costs may be significantly lower as the additional land is likely to be on steeper slopes.

6.2 Cost-Benefit Results – Summary of Benefits

Table 10 summarises the benefits of implementing the restoration strategy in FS2. The largest benefits stem from avoided deforestation of existing forest land. Avoided carbon loss - the one-time release of carbon into the atmosphere as forest is destroyed - at market rates is dwarfed by the social value of carbon loss. The difference between the Net Present Value at a 9% interest rate (USD 46.5 million) and total benefits (effectively a 0% interest rate) (USD 134 million) reflects the choice of discount rate.

Table 10: Benefits (USD, 2023 prices)

Benefits	Total Benefits	NPV (9% discount rate)
Avoided carbon loss (MP)	18,444,903	6,368,269
Avoided carbon loss (Social value of carbon)	134,647,792	46,488,367
Provisioning from existing forest	1,610,530	345,123
Provisioning from community forests	1,310,203	318,045
Carbon sequestration from preserved existing forest (MP)	7,268,707	1,557,624
Carbon sequestration from preserved existing forest (SVC)	3,069,680	657,807

Benefits	Total Benefits	NPV (9% discount rate)
Carbon sequestration from community forests (MP)	5,913,256	1,435,411
Carbon sequestration from community forests (SVC)	43,166,772	10,478,500
Carbon Sequestration in Buffer Zone (MP)	2,153,487	1,173,650
Carbon Sequestration in Buffer Zone (SVC)	15,720,453	8,567,647
Sediment Reduction	188,500	38,579
Additional Income from agroforestry/ conservation agriculture	179,129,422	40,929,002
Fertilizer savings from agroforestry/ conservation agriculture	9,612,819	1,539,004
Avoided flood damage to crops	1,022,380	218,331
Benefits (MP)	228,691,373	53,923,039
Benefits (SVC)	404,349,862	109,580,405
Benefits (MP): existing forest remains intact	201,367,233	45,652,022
Benefits (SVC): existing forest remains intact	265,021,861	62,089,108

MP = Market Price for carbon credits
SVC = Social Value of Carbon

Restoring community forests will provide USD 1.3 million of provisioning benefits over thirty years, or USD 97,358 per year. Farmers and communities should also benefit from additional income from implementing conservation agriculture and agroforestry. In total, farms may earn an additional USD 5.9 million per year (in 2023 prices), or USD 1,962 per farm. Improvements to soil fertility, estimated as savings on fertilizer costs, represent a further non-trivial benefit to farmers.

Flood damage benefits appear relatively low. However, it should be noted that the estimated value reflects the 1% chance of an extreme flood event

6.3 Cost-benefit Results: Comparison of costs and benefits

Table 11 provides the results of the cost-benefit analysis. The Net Present Value (NPV) of costs in USD 20.7 million. The NPV of benefits assuming carbon is valued at the market price for carbon credits is USD 53.9 million, or USD 109.6 million if the social value of carbon is used.

Table 11: Cost-benefit analysis results, 9% discount rate (USD, 2023)

Indicator	Value
NPV Costs	USD 20,721,927
NPV Benefits (MP)	USD 53,923,039
NPV Benefits (SVC)	USD 109,580,405
NPV (MP)	USD 33,201,112
NPV (SVC)	USD 88,858,478
IRR (MP)	21%
IRR (SVC)	46%
BCR (MP)	2.60
BCR (SVC)	5.29

MP = Market Price for carbon credits
SVC = Social Value of Carbon

Assuming market values for carbon, the benefit-cost ratio (BCR) is 2.6, the IRR is 21%, and the Net Present Value[22] is USD 33 million. Assuming social values for carbon, the BCR is 5.3, IRR 46%, and NPV

[22] The Net Present Value of the intervention is equal to the NPV of costs subtracted from the NPV of benefits.

USD 88.8 million. The results suggest that the benefits of implementing the interventions proposed in FS2 far outweigh the costs.

However, the results are subject to the assumptions made in the analysis. Table 12 captures the costs and benefits of the restoration and conservation farming activities in FS2, but omits the costs and benefits of halting deforestation. As such, it assesses the economic case for rolling out conservation farming, restoring drainage corridors, and establishing a buffer zone on the border of the Samlout MUA. Assuming market values for carbon, the BCR is 2.25, the IRR 18%, and the Net Present Value is USD 25.3 million. Using social values for carbon, the BCR is 3.06, the IRR is 23%, and the NPV is USD 41.8 million.

Table 12: Cost-benefit analysis results. The forest remains untouched in counterfactual.

Indicators	Value
NPV Costs	USD 20,323,206
NPV Benefits (MP)	USD 45,652,022
NPV Benefits (SVC)	USD 62,089,108
NPV (MP)	USD 25,328,816
NPV (SVC)	USD 41,765,902
IRR (MP)	18%
IRR (SVC)	23%
BCR (MP)	2.25
BCR (MVC)	3.06

MP = Market Price for carbon credits
SVC = Social Value of Carbon

The results in Tables 11 and 12 demonstrate that if the benefits of avoided carbon loss and additional sequestration are removed, the proposed interventions should still be economically beneficial to communities both upstream and downstream in the Sangker River Basin. The analysis also demonstrates that the suggested approach is valuable even when using lower market rates to value carbon.

Table 13: Sensitivity analysis assuming market rates for carbon (USD 2023, millions)

	NPV (USD Million)			BCR
Case	0%	9%	12%	(at 9%)
Base Case	199.47	33.20	18.01	2.6
20% increase in establishment and maintenance costs	194.80	29.75	14.86	2.2
10% increase in yields (as opposed to 30%)	80.05	5.92	-0.22	1.3
20% increase in costs and 10% increase in yields (as opposed to 30%)	75.38	2.46	-3.37	1.1

Table 13 reports the sensitivity of the results to other key assumptions. It assumes market rates for carbon and adjusts the discount rate, investment costs, and the magnitude of improved yields for farmers who implement new farming techniques.

The sensitivity analysis suggests that the results are sensitive to the discount rate selected. Higher discount rates put less value on impacts that occur further in the future; initial investments will also carry greater relative weight. At a 9% discount rate, commonly selected in cost-benefit analysis, the NPV is USD 33.2 million, and the BCR 2.6. Reducing the discount rate to 0% - effectively giving future benefits the same weight as those received at the beginning of the project - increases the NPV to USD 199.5 million, and raises the BCR to 7.2. There is a strong case for adopting low discount rates for environmental projects, which, in most cases, tend to take time to realize returns and are typically designed to benefit future generations.

The results also demonstrate particular sensitivity to the assumed increase in yields and, thus, incomes for farmers converting to conservation agriculture. At a 9% discount rate, the NPV falls to just under USD 6 million and the BCR to 1.3. Increasing costs will further lower both the NPV and BCR.

A higher discount rate may be a more accurate representation of many farmers' worldviews. Small-holder farmers tend to be more risk-averse and will tend to put less value on benefits that accrue in the future. The sensitivity analysis, therefore, suggests that care should be taken to ensure that new techniques applied to farming land increase farmers' incomes and that, where possible, farmers' perceived risks are adequately mitigated.

Indeed, several studies point to the additional initial costs to farmers of implementing conservation agriculture techniques as a barrier to their adoption. This study assumes these are approximately USD 900 per hectare, a substantial investment for smallholder farmers. Surveys undertaken as part of this project found that, although many farmers had theoretical access to finance, issues with land tenure and other barriers that particularly affected women suggest that many smallholders would struggle to access the funds required. Initial financial support would be needed for the transition.

The results do not include several additional sources of benefits. That the hydrology analysis did not model the impact of continued deforestation suggests that erosion and deforestation rates assumed in the FS1 scenario are likely underestimates, suggesting that the costs to farmers of nutrient loss, and downstream sedimentation are understated. Biodiversity benefits have not been accounted for. Nor have the potential benefits of ecotourism to local communities; at least one of the demonstration sites intends to explore ecotourism options. The results also do not assess the potential costs of additional sedimentation to electricity production in the two hydroelectricity projects, Battambang I and Battambang II, currently under construction. A 2019 study estimated the net present value of potential power loss from sedimentation caused by forest loss to be USD 44.8 million for Battambang I and USD 28 million for Battambang I.[23] The study also estimated the value of a hypothetical payment for ecosystem services (PES) scheme to conserve sufficient forest area to ensure continued electricity generation at USD 153.68 and USD 433.98 per hectare for Battambang I and II, respectively. It is likely that the activities implemented in FS2 would also limit the build up of sediment in the Watershed, providing further benefits measured either as foregone dredging costs, or the value of power lost in FS1 when compared to FS2.

7 Conclusion and Summary

Restoration of the Sangker River basin's uplands will undoubtedly bring significant benefits to local communities and businesses. These will include reduced erosion, reduced siltation of waterways, and increased incomes as community forests are restored and more efficient agricultural techniques are adopted. A significant portion of benefits will arise from sequestered carbon, and if it is assumed that deforestation halts, avoided carbon emissions from existing forest lands. There may also be significant additional benefits that have not been assessed in this analysis. These include net gains in biodiversity, ecotourism, and the added benefits of preserving existing forests that have not been included in the project's SWAT model.

Communities will most directly benefit from the higher incomes new farming techniques will provide. However, farmers will be wary of making significant investments in what they may justifiably see as risky endeavors. The costs of implementing conservation farming will, therefore, likely require initial financial support for farmers and training in new techniques. As the benefits of implementing the strategy also depend on the additional income farms will generate, additional research is required to establish the most suitable techniques.

[23] Mohit Kaura, Mauricio E. Arias, Joshua A. Benjamin, Chantha Oeurng, Thomas A. Cochrane. 2019. Benefits of forest conservation on riverine sediment and hydropower in the Tonle Sap Basin, Cambodia, Ecosystem Services, Volume 39, https://doi.org/10.1016/j.ecoser.2019.101003.

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Plantation in Takhes Meanchey. Drone photo taken in the 3rd mission to pilot sites in Cambodia (photo by ICEM).

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