VALUING THE ECOSYSTEM SERVICES PROVIDED BY FORESTS IN PURSAT BASIN, CAMBODIA

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WAVES

The team thanks Chloe Hill, Herbert Navasca, and Topi Carlos for editing services.

Cover photo: Aerial shots of a remote waterfall in the Cardamom Mountains
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ACRONYMS AND ABBREVIATIONS

CMTS	Cardamom Mountains-Tonle Sap
ECMWF	European Centre for Medium-Range Weather Forecasts
ERPA	Emission Reduction Payment Agreement
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
ha	Hectares
HEP	Hydroelectric power
HRU	Hydrologic response units
MME	Ministry of Mines and Energy
MoE	Ministry of Environment
MoWRAM	Ministry of Water Resources and Meteorology
MUSLE	Modified universal soil loss equation
NCA	Natural Capital Accounting
NDC	Nationally Determined Contribution
NPASMP	National Protected Areas Strategy and Management Plan
NSE	Nash–Sutcliffe Efficiency
NTFP	Non-timber forest product
PA	Protected area
PPU	Percent prediction uncertainty
REDD+	Reduced Emissions from Deforestation and Forest Degradation
RGC	Royal Government of Cambodia
SEEA EEA	System of Environmental-Economic Accounting Experimental Ecosystem Accounts
SCS	Soil Conservation Service
SME	Small and medium enterprise
SVC	Social value of carbon
SWAT	Soil and Water Assessment Tool
tCO2e	Tons of carbon dioxide equivalent
VCS	Verified Carbon Standard
VSSPNP	Veun Sai-Siem Pang National Park

GLOSSARY OF KEY TERMS

Biodiversity	Biodiversity reflects the number, variety and variability of living organisms and how these change over time from one location to another. It forms the basis of the multiple benefits provided by ecosystems to humans.
Ecosystem services	The benefits to people from ecosystems, such as timber, pollination, water supply, water regulation, climate regulation, recreation, mental health and others.
Foregone benefits (costs)	Benefits (costs) of an action that are not received because an alternative action is undertaken.
Landscape	A heterogeneous land area comprising of a cluster of interacting ecosystems that are repeated in a similar form throughout.
Natural Capital	The stock of renewable and non-renewable natural resources (e.g. plants, animals, air water, soils, minerals) that combine to yield a flow of benefits to people.
Natural Capital Accounting	Natural capital accounting integrates natural resources and economic analysis, providing a broader picture of development progress than standard measures such as GDP. Natural capital accounts are a set of objective data showing how natural resources contribute to the economy and how the economy affects natural resources.
Natural hazard regulation	Hazard regulation or disaster mitigation is the function of ecosystems in modulating the effects of extreme events like droughts, floods and fires and in particular in protecting human well-being from the impacts.
Sediment regulation	Sediment regulation refers to the capacity of ecosystems to regulate the quantity of eroded sediment reaching the stream network and thus delivering key benefits, like maintaining soil and water quality and reservoir functions.
Value	The worth, importance or usefulness of something – and is often categorized as anthropocentric and instrumental. Anthropocentric values reflect human needs and preferences. Instrumental values serve a specific goal, use or need.
Water flow regulation	Water flow regulation is an ecosystem service that can be defined as the ability of watersheds and catchments to capture and store water from rain storms, reducing the direct runoff and flood peaks as well as releasing the water more slowly so that flows are sustained into or through the dry season.

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This report is the output of rich dialogue and exchange with a number of institutions and individuals in the RGC. This work is part of the technical assistance (TA) provided under the Bank's Enhancing Environmental Sustainability and Resilience in Cambodia technical assistance Program. The work was funded by a World Bank multi-donor trust fund, Global Program on Sustainability (GPS) (previously known as Wealth Accounting and Valuation of Ecosystem Services or WAVES) and the former Program on Forest (PROFOR).

A World Bank team carried out this work in cooperation with Cambodia's Ministry of Environment (MoE), Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Economy and Finance (MEF), Ministry of Mines and Energy (MME) and Conservation International.

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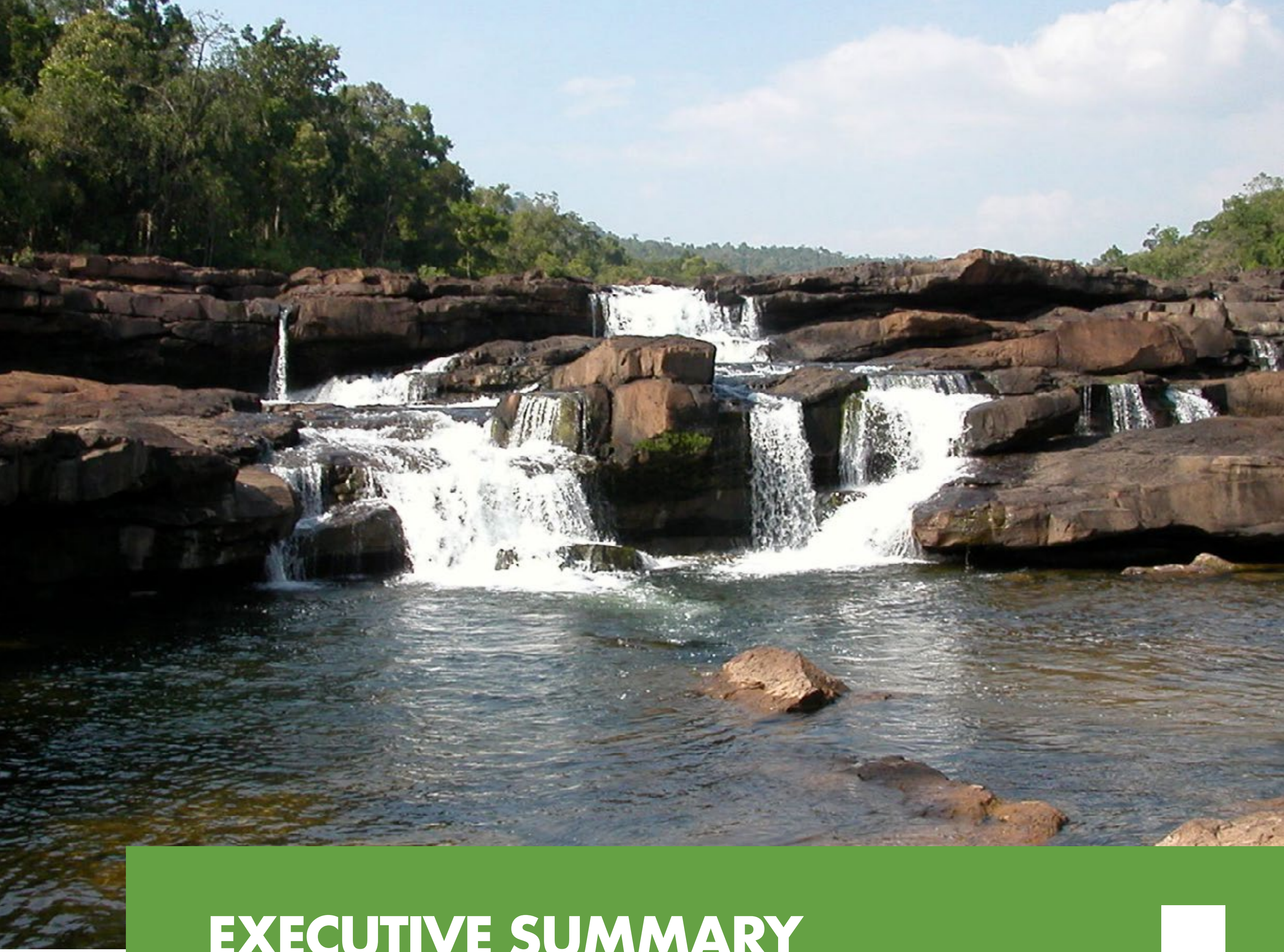


EXECUTIVE SUMMARY

Valuing Ecosystem Services is relevant for Cambodia now

Ecosystem services, such as water flow regulation, erosion reduction and biodiversity conservation that are provided by Cambodia's forests, underpin the country's economy. Agriculture, which depends heavily on water flow regulation, erosion reduction and nutrient retention services all of which are provided by forests, contributed to GDP in 2018 by 22 percent. Tourism and ecotourism, which contributed about 18 percent towards Cambodia's 2018 GDP, is dependent on the country's considerable biodiversity in forest landscapes. Forests also help to sustain hydropower in Cambodia, an essential power source to the garment and other economic sectors.

Waterfall in the Central Cardamoms.
© Conservation International/photo by Jake Brunner

The Royal Government of Cambodia (RGC) has strategically placed the majority of Cambodia's forestlands under the protected areas (PAs) system to better protect forest resources. Cambodia's forests cover about 8.1 million ha (45 percent of the country). Approximately 67 percent of this forest area is under the country's PA system which covers 7.4 million ha (41 percent of Cambodia). Cambodia's forest cover has declined since 2006 because of pressure for land and unsustainable natural resource use. By putting forest resources under the PA system, the RGC, has taken key steps to ensure the reversal of this declining trend in forest cover. Under the PA system, forests will be subject to stricter management that includes no timber harvesting, sustainable harvesting of non-timber forest products (NTFPs), patrolling by rangers and forest communities to prevent illegal activities and forest restoration where needed. Furthermore, the RGC has made a recent significant investment in forest and protected areas management through the World Bank-financed Cambodia Sustainable Landscape and Ecotourism (CSLE) project.

Cambodia's impending water crisis, impacts of climate change and the onset of COVID-19 will put increased attention on forests. Seasonal water scarcity exists in the river basins of the Tonle Sap River Basin Group (18 out of 25 provinces were affected by droughts in 2016, for example, with around 2.5 million people lacking water) and existing reservoir storage capacity (less than 10 percent of total water generated) is insufficient to redistribute water significantly between seasons. Drought and flooding are expected to worsen because of climate change, with an additional 1.5 months of drought and more extensive flooding, particularly in the eastern areas of the country. Forests are a safety net during socioeconomic shocks and are important for linked sectors like ecotourism, as they can help to stimulate jobs and rural economies as well as tourism value chains which have been negatively affected by COVID-19.

The RGC is increasingly recognizing that adequate valuation of ecosystem services is a key input to improved decision-making on protected areas, forest and natural resources more generally; but the lack of data, accepted methodologies and technical capacity have prevented it from using ecosystem valuation for decision making on meaningful scale. There is strong interest among the Ministry of Environment (MoE) and the Ministry of Water Resources and Meteorology (MOWRAM) for integrating ecosystem service values in decision-making as it pertains to forests, protected areas and watershed management. MoE's foremost policy documents on PAs – The Protected Areas Law of 2008 and the National Protected Areas Strategy and Management Plan (NPASMP) 2017-2031 – strongly advocate for the use of ecosystem service values in conservation planning and prioritization of areas in PAs. By utilizing such values, not only are strong protection efforts cultivated but drivers of forest degradation and loss can also be more effectively addressed. However, data and capacity are lacking in Cambodia that are essential for assessing and valuing the benefits provided by ecosystem services and integrating these data and information into decision-making like PA zoning and management planning. Economic analysis has therefore played a limited role in determining how forests are managed and financed in Cambodia.

Meeting the RGC's need for values-driven decision-making on forest and PAs through World Bank analytical support

This analytical work is being undertaken as part of a broader effort of the World Bank to provide guidance to the RGC on managing its natural capital through landscape approaches. By focusing on the Pursat River Basin in the Cardamom Mountains, the case study presented in this report is intended to provide a practical illustration of how the ecosystem services that are provided by a forest can be valued and then compared to the benefits that would otherwise be obtained if the forest was converted to other uses. The study provides evidence of the importance of forests in providing ecosystem services that are important for Cambodia's economy as well as for the country's climate and disaster resilience. The results therefore intend to help the RGC quantify and communicate the value of its natural capital to Cambodia's economy.

The main outputs of the study are:

1. Methodology on how to undertake measurement and valuation of hydrologic ecosystem services that can be repeated in other locations in Cambodia. The work will also provide the underpinnings for tools (e.g. Payment for Ecosystem Services (PES) which will be developed under the Cambodia Sustainable Livelihood and Ecotourism (CSLE) project) as well as investments in forest and PA management also under the CSLE project and natural capital accounting.
2. Quantification of benefits of forest ecosystem services, which provide evidence of the returns on investments that the RGC will gain by strengthening forest ecosystems through use of public resources for forest and protected areas (PAs) management.
3. The causal link between forest conservation/ degradation and regular water flow has been established through the analysis.
4. Recommendations for scaling-up ecosystem services assessment and valuation are provided as a road map within this report and actions proposed for how this work would inform investments for forest and PA management namely conservation, protection and restoration in the Cardamom Mountains.

KEY MESSAGE 1

The economic benefits from intact forests (estimated at US$99 million) are almost five times higher than the gains from cutting them down for small-scale agriculture and charcoal production estimated at US$22 million.

The standing forests in the Pursat River Basin (RB) provide benefits worth at least US$99 million through the provision of ecosystem services like water and sediment flow regulation and tourism. Converting these forests for charcoal production and agriculture would provide benefits worth about US$22 million to only a few individuals, whilst the benefits of maintaining the forests intact, which are worth about US$99 million and which would reach a broader segment of the Cambodian population, would be lost. It is clear, therefore, that Cambodia benefits more from keeping forest ecosystems in the Pursat RB intact than from cutting them down. Considering just agriculture, the findings show that there are more benefits derived from maintaining forests to facilitate water for irrigation (US$28 million) than cutting down the forests for agriculture (US$22 million); see Table ES1.

TABLE ES1: SUMMARY OF ESTIMATED BENEFITS PROVIDED BY FORESTS IN THE PURSAT RIVER BASIN

	Value of benefits	
Beneficiaries	Net Present Value (US$million)	Annual (US$million/yr)
Irrigation	28	1.6
Hydropower (HEP)	18	1.1
Tourism	53	3
Carbon storage	-	2.5

Source: Authors' calculations

Note:

1. Net present value estimates use a 6 percent discount rate. A value of US$5 t/ CO_2e was used for the analysis of carbon. The data and calculations underlying these findings are in Chapters 2, 3, 4 and 5 of the report.
2. The counterfactual approach (if forests were removed) was used to estimate net present value of benefits of forest for irrigation, HEP and tourism.
3. The deforestation scenarios approach was used to estimate annual benefits of forests for irrigation, HEP, carbon storage and tourism.

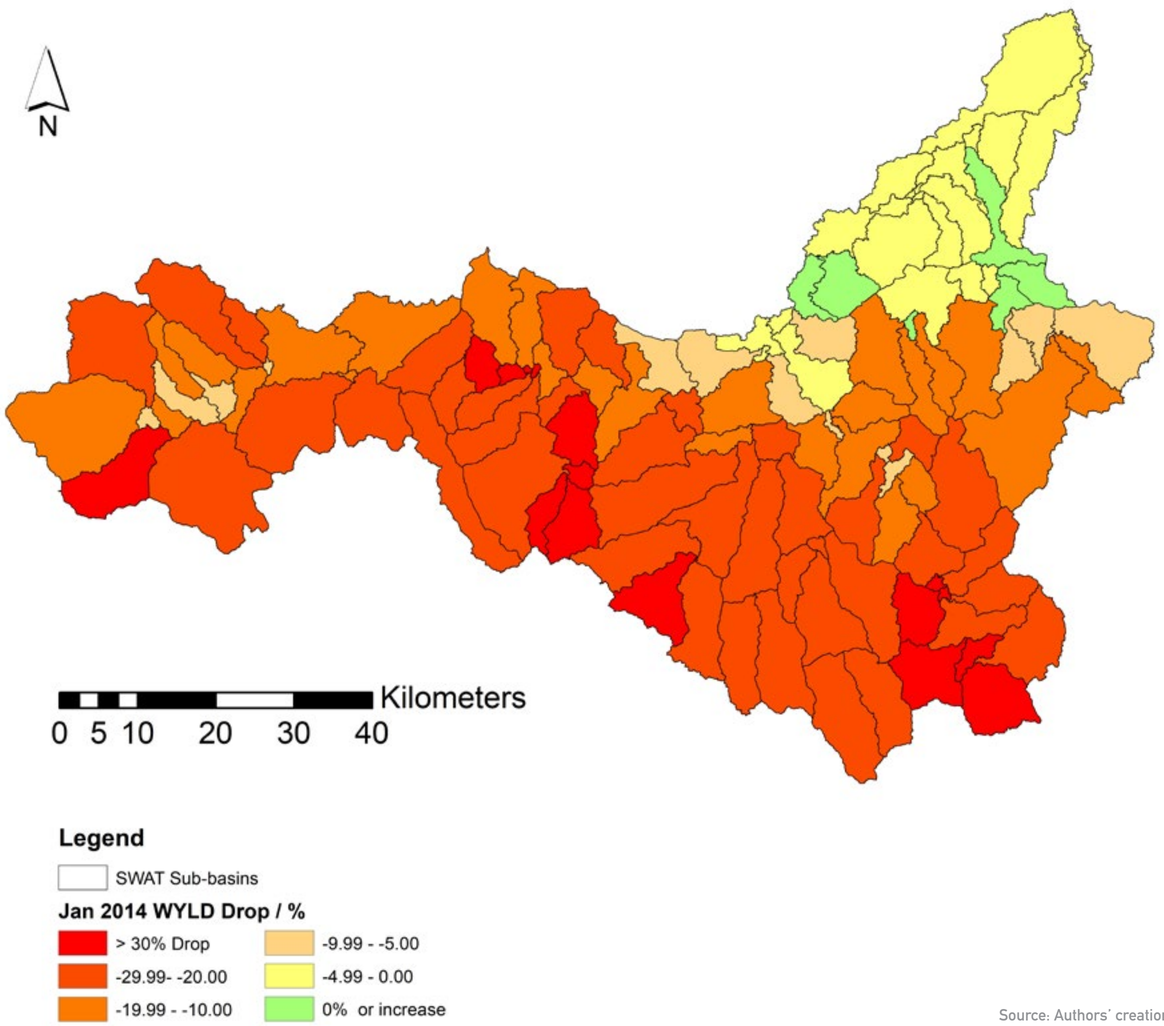
Water flow regulation is one of the key benefits provided by forest ecosystems and understanding its high monetary value creates a strong incentive for investing resources into the sustainable management of the forest ecosystem asset. This study makes the link between upstream forest management, water yield and use of water by downstream users.

Without forests dry season flows would be reduced by 25 percent, which would exacerbate the water deficit already being experienced in drier periods, like February and June; see Figure ES1. With this information, the Ministry of Environment (MoE) can better defend its budget requests and justify its expenditure on PA management for protecting forests in watershed areas like the Pursat Basin.

Results also help to illustrate that investing in protecting forest resources is part of the economic recovery from COVID-19. This will help the RGC to ensure that agricultural growth is not limited by a lack of water and that the ecotourism potential of forest biodiversity is preserved. Importantly, keeping hydropower plants functioning, even during the water crisis, will rely to some extent on the hydrological flows facilitated by forests.

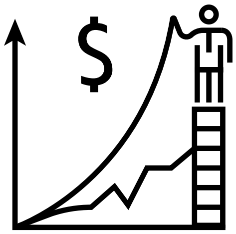
FIGURE ES1: CHANGES IN WATER YIELD IN THE ABSENCE OF FORESTS

THE MAP ILLUSTRATES THE IMPACT ON WATER YIELD IN THE PURSAT RIVER BASIN IF THE FORESTS WERE NOT THERE. THE RED AREAS INDICATE THAT WATER YIELD COULD DECREASE BY MORE THAN 30% IF FOREST WERE NOT THERE. THIS MAP WAS DERIVED FROM THE NO-FOREST COUNTERFACTUAL COMPARED TO CURRENT CONDITIONS.



Source: Authors' creation

KEY MESSAGE 2



Investing in the maintenance of forest is good business. Annual public expenses to maintain the forest in the Pursat Basin are about 20 times lower than the benefits provided by them.

The forests in the Pursat RB provide annual benefits worth an estimated US$8.2 million from tourism, carbon and water and sediment flow regulation. This is about 20 times the US$0.4 million that the RGC spends annually on forest protection in Pursat. This indicates that the return on spending on forest protection is an efficient use of the government's budget.

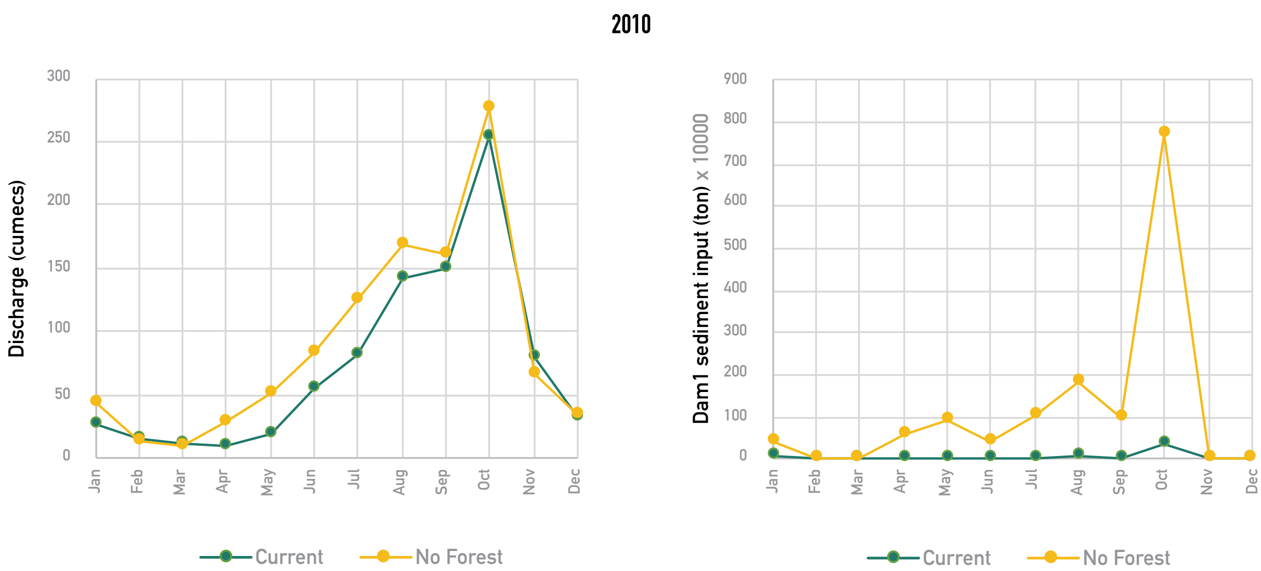
Forest loss or degradation would reduce the benefits that they provide. Such loss and/or degradation would tend to increase peak river flows and erosion, which would lower water availability in the dry season (when water is particularly valuable for irrigation), increase flood risk and increase siltation of reservoirs, thus reducing their useful life. The actual losses would depend on the rate and extent of forest loss.

Upstream deforestation has a high impact on peak river flows and floods. Forests slow the flow of water through a watershed (from rainfall event to the river). In the absence of forests, water would run off faster, resulting in higher flood risk in the wet season and reduced availability in the dry season, as shown in figure ES2 below (left panel).

FIGURE ES2: CHANGES IN WATER AND SEDIMENT FLOWS IN THE ABSENCE OF FORESTS

THE CHART ON THE LEFT SHOWS THE EFFECT OF REMOVING THE FOREST ON RIVER DISCHARGE AND THE CHART ON THE RIGHT SHOWS THE LARGE INCREASE IN SEDIMENT FLOWS THAT ARISE BECAUSE OF REMOVAL OF THE FOREST.

Source: Authors' calculations

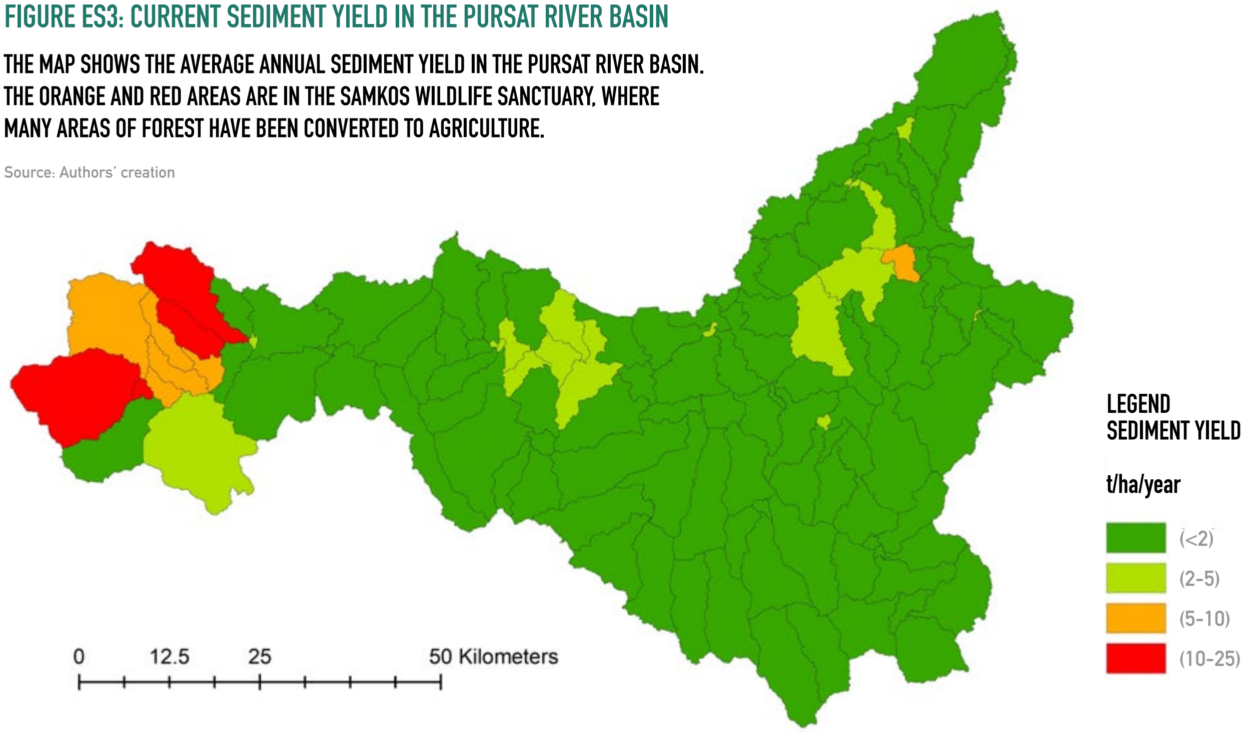


Upstream deforestation has a high impact on sediment output. In the absence of forests, sedimentation would increase 30-fold, as shown in Figure ES2 above (right panel). Under current forest cover conditions, erosion is generally low. The few areas with high erosion rates are in parts of the Samkos Wildlife Sanctuary, where forest conversion has taken place, as shown in Figure ES3 below.

FIGURE ES3: CURRENT SEDIMENT YIELD IN THE PURSAT RIVER BASIN

THE MAP SHOWS THE AVERAGE ANNUAL SEDIMENT YIELD IN THE PURSAT RIVER BASIN. THE ORANGE AND RED AREAS ARE IN THE SAMKOS WILDLIFE SANCTUARY, WHERE MANY AREAS OF FOREST HAVE BEEN CONVERTED TO AGRICULTURE.

Source: Authors' creation



Deforestation would cause reservoir sedimentation, reducing electricity production. In the absence of forests, the reservoir of the hydroelectric power (HEP) station at Dam 1 in the Pursat River Basin would be completely silted up in 65 years, reducing the present value of electricity production by US$18.2 million, as shown in Table ES2. The extensive forest cover in the Pursat Basin protects the reservoir from this fate, but not entirely - even the current and relatively low deforestation rates in the Pursat Basin of 0.25 percent per year (below the national average) would reduce the present value of electricity production by US$0.8 million. Should deforestation accelerate to 1 percent a year, as in the rest of the country, the loss would increase to US$2.8 million. These results demonstrate the benefits from protecting forest resources for HEP.

TABLE ES2: IMPACT OF FOREST LOSS ON HYDROELECTRIC POWER PRODUCTION

	Current deforestation (0.25%/year)	High deforestation (1%/year)	No-forest counterfactual
Change in reservoir capacity (%)	23	61	100 (65 years)
Reduction in value of HEP (US$million)	0.8	2.8	18.2

Note: Present value of reduction in value of HEP computed over 100 years with a discount rate of 6 percent.

These figures provide insight into the values at risk from forest loss. Farmers would be worse off, by only being able to irrigate smaller areas and would also face higher maintenance costs. The population in the lower part of the basin would face increased flood risks. Electricity users would either face shortages of electricity or be forced to switch to other, more expensive sources. And the entire global community would suffer from increased emissions of GHGs.

These benefits of forests are not included in standard national accounts. National policymakers have often not been as concerned with forest loss as they might have been. Conversion of forests to other uses will often appear to be beneficial in national accounts, as crop production will add to them while losses either do not appear at all (carbon, biodiversity), or appear but in ways that seem unrelated to forest loss (irrigation).

KEY MESSAGE 3

Funding for the maintenance of those forests in the long run can be captured from private and international sources.

Although public resources are needed in the short term to finance maintenance of forests, a range of national and international private financing options can be brought to scale to support appropriate forest management. National private financing options include local non-timber forest product (NTFP) enterprises, the Ibis Rice program and companies investing in sustainable plantations like CamAgra and Grandis Timber. International private financing options include conservation trust funds like the Conservation International trust fund[1], private equity financing and private financing for carbon emission payments. This approach is an important emerging trend in conservation and Cambodia has the opportunity to bring this to scale to alleviate public funding sources. With the prospect of more stable and longer-term funding other than reliance on traditional grants, this approach can provide more effective conservation as well as more positive impacts on livelihoods. PES for water and payments for carbon under REDD+ (Reducing Emissions from Deforestation and Degradation) are already being undertaken in Cambodia, but these now need a comprehensive approach to explore those opportunities fully.

With clear beneficiaries of services in the Pursat Basin identified, a PES scheme could be devised to provide payments from the beneficiaries (farmers and hydropower companies) that would help support upland forest conservation. Carbon emission reduction payments under Cambodia's Reducing Emissions from Deforestation and Forest Degradation (REDD+) program could bring in financing from international private sector for the maintenance of upland forest.

PES schemes involve payments to the managers of land or other natural resources in exchange for the provision of specified ecosystem services (or actions anticipated to deliver these services) over-and-above what would otherwise be provided in the absence of payment. Payments are made by the beneficiaries of the services in question, for example, individuals, communities, businesses or governments acting on behalf of various parties.

Source: Smith et al. 2013: 9

Key Recommendations of the Study

The results in this report lead to two sets of recommendations: (i) policy recommendations for the Pursat River Basin (Recommendations 1 and 2) and (ii) recommendations aimed at scaling up the analysis to ultimately cover all of the country (Recommendation 3).

Recommendation 1: Focus forest protection and restoration efforts on upstream watersheds in the Cardamom Mountains Protected Area Landscape to enhance the resilience of water resources.

Cardamom forested lands act to slow down high discharges during wet season and supplement low

1 See more on Conservation International at https://www.conservation.org/projects/cambodias-central-cardamom-protected-forest

flows during dry season. Upstream deforestation in the Sam Kos Wildlife sanctuary, which is linked to improving accessibility by access roads above Dam 1 (see Figure 2.1), possesses a quantifiable risk to the operation of irrigation and hydropower infrastructure downstream. These risks include changes to the pattern of seasonal water yield, higher consumption of water for irrigation in upstream areas during water -stressed months, and increased sediment accumulation in downstream infrastructure. Measures to arrest the rate of deforestation and engage in options for afforestation would be recommended to protect this resource. The results showed that important areas for water yield are overlapping with PAs in the Cardamom Mountains but are also overlapping with an area of the Cardamom Mountains that has experienced high rates of degradation due to agricultural encroachment. Deforestation and forest degradation on the other hand, will reinforce the impact of the climatic trends, magnifying the risk of extreme events like floods in the basin. Protection of upstream forestlands takes on renewed importance in this light.

The RGC has some important decisions to make with regards to prioritizing areas in the PA landscape that require attention, additional resources for management and the implementation of restoration activities. In this context and under this recommendation there are also some strategic actions proposed for the government as well.

Action 1: Prioritize zoning and development of PA management plan in Samkos Wildlife Sanctuary and Biodiversity Conservation Corridors. MoE is already taking a step in this direction through the inclusion of Samkos Wildlife Sanctuary as a priority PA for zoning, PA management planning and boundary demarcation. The PA management planning should assess the best options for reducing forest degradation and conversion and should include a plan for restoration of degraded landscapes. This analysis provides information that MoE can use such as areas of high sediment yield and high-water yield in prioritizing areas within Samkos for interventions.

Action 2: Assess opportunities for agroforestry on existing agricultural lands. Halting forest degradation and conversion is one of the key objectives of MoE's management of PAs. As agriculture is a key driver of forest change in the Cardamoms, it is important that this be addressed in a manner that is pro-poor, recognizing that forest communities need livelihood support. Developing agroforestry is a way of creating additional value on lands that have been converted to agriculture and restoring trees that provide some important forest ecosystem services like sediment regulation. The interventions that are decided from the assessment should also be included in the PA management plan.

Action 3: Develop interventions for reducing the pressure on forest resources from charcoal, including more sustainable charcoal production and environmentally friendly alternatives to wood charcoal. The charcoal industry can be a significant opportunity for Cambodia's rural PA economies if done right. GERES (2015) assessed the industry to be worth about US$177 million per year and the RGC will need to play a key role in leading the organization of this industry in order to reduce its potentially negative impacts on forests. Sourcing wood for charcoal from existing plantations can help to address the wood-supply needs for the charcoal industry and improving the wood to charcoal conversion efficiency could also help to reduce pressure on forests for wood. Four key measures proposed for further action on moving towards more sustainable charcoal production are: (i) formalization of existing small-scale charcoal producers and linking these with private sector plantations who can provide a consistent source of wood through which a certification system for charcoal could be developed; (ii) refining existing charcoal producing techniques and technologies to improve energy efficiency of the firewood conversion into charcoal in a cost-effective way; (iii) developing small-scale woodlots within community use zones and sustainable use zones to meet wood needs for charcoal; (iv) exploring opportunities for more environmentally-friendly options for charcoal like coconut husks. Again, the link to the private sector would be strategic for investments and management of the wood lots.

Recommendation 2: Explore the potential for private financing to support PA management.

Ecosystem service values can help inform government decision-makers, but it will not, by itself, change the incentives facing actors on the ground. In the Pursat RB, these actors receive only a small subset of forest benefits but stand to receive the bulk of the benefits from alternatives such as agriculture.

PES and REDD+ are realistic opportunities in Cambodia for directing private financing to support PA management. There is strong interest of the MoE in establishing PES with ongoing pilots helping to inform development of PES. The success of PES in capturing private payments for conservation has been shown through several international examples including Mexico, Vietnam and Costa Rica. Payments from international private sector under the REDD+ mechanism are already being received in Cambodia and could scale-up. There are already some excellent studies that exist on evaluating carbon resources (stocks), which can be useful when it comes to developing the right benefit-sharing mechanisms and ensuring that these link to an overall revenue system that support protected areas.

The present study contributes to the development of PES in several ways. First, it clearly documents the benefits provided by forests. Second, it identifies several important groups of beneficiaries of these services (irrigated farmers and electricity users) and quantifies the damages that they would face if these services were lost or reduced. Third, the hydrological model developed for the analysis provides tools that would permit PES conservation efforts to the areas where they would be most effective.

To be sure, much more needs to be done. The quantification of benefits provided by this analysis, for example, only provides an upper bound of willingness to pay to avoid damages. For example, the analysis shows that at a deforestation rate of 1 percent a year, the losses suffered by HEP producers would be about US$0.17 million a year. This figure is the maximum amount such producers would be willing to pay for a PES program that stopped all deforestation completely, including both the costs of the payments to participants and the costs of implementation of the program. The corresponding figure on damages that irrigated farmers would suffer from deforestation would add to this amount, and, if an ERPA can be negotiated, carbon payments would increase it even further.

Designing and implementing a PES program to reduce deforestation in the upper Pursat River Basin would require:

1. Using the hydrological model developed for this analysis to identify the critical areas in the upper basin: the areas which, if they were to be deforested, would result in the greatest impact on hydrological flows and sediment loads;
2. Undertaking a threat assessment of these areas, to see how likely they are to be actually deforested, based on factors such as their suitability for agriculture, proximity to roads, etc., and quantifying the potential benefits to local people of converting these areas to other uses;
3. Measuring any benefits that retaining forests could generate for local communities, for example through the sustainable collection of NTFPs and through activities such as ecotourism;
4. Estimating the cost of a PES program to protect these critical areas, based on their size (number of ha to be protected), the size of payments needed to induce forest conservation, based on the net costs to local communities of conserving them (potential benefits from conversion to agriculture minus local benefits from retaining forests), and the likely implementation costs of the program, based primarily on the cost of monitoring, which is affected by the size of plots to be monitored, their dispersion and their accessibility;
5. Determining whether the program, based on these estimates, is feasible (i.e. the total costs are less than total willingness to pay); putting in place arrangements to collect funding from service users (such as irrigated farmers, HEP producers and/or carbon buyers) and make appropriate payments to service providers (upstream communities who refrain from deforesting). The analysis conducted provides a substantial start on this road map, but clearly much more needs to be done.

Lastly, it would be important for any PES or REDD+ scheme to be a part of ongoing plans within the government for strengthening the institutional framework for emissions reduction payments. The national REDD+ strategy and REDD+ nesting framework that is being established currently provides the opportunity to provide payments from reducing carbon emissions through undertaking forest conservation, conservation compatible livelihood activities etc. The kind of analysis undertaken in this study provides a basis for the levels of investment needed to holistically ensure and incentivize more emissions reduction payments. In addition, we recommend the RGC to:

1. Provide oversight and management of REDD+ activities as is being proposed in the REDD+ Regulatory Framework (Prakas), which is being developed.
2. Set up the national system for emissions reduction payments that includes a benefit sharing mechanism that will make clear investments for forest conservation and protected area management, including co-management, etc.
3. Enhance and promote the attractiveness of Cambodia for REDD + payments with clear rules and regulation for the system.
4. Ensure that PES and REDD+ payments are well integrated into the overall financing mechanism for PAs. Revenues from tourism in PAs should also be considered for supporting PA management. Recent work for the Greening Prey Lang project identified a number of fund sources including the Environment and Social Fund, the Forestry Administration National Forest Development Fund, ecotourism revenues and private conservation funds that needed to be managed and used in an integrative way to be efficient and effective.

Recommendation 3: Develop a road map for scaling up assessments of economic benefits provided by forest ecosystems across Cambodia using a Natural Capital Accounting (NCA) approach.

The advantages for Cambodia of a using a NCA approach verses one-off economic valuation studies are: (i) standardizing how ecosystem service values are determined and integrated in regular decision-making of the RGC, for example in determining national budget allocation for MoE for PA management; and (ii) that data and information will be more reliable and less costly if data collection, analysis and access are standardized under an NCA approach. The analysis of the Pursat Basin demonstrates the potential benefits of undertaking NCA both to identify the need for interventions and to help design them and elucidates some key lessons for replication and scaling up. Lessons include the: (i) need for a thorough analysis of the interactions of beneficiaries with ecosystem services; (ii) importance of a robust data collection plan and early commitment on data sharing from relevant ministries.

Moving from a single case study to a comprehensive approach requires a road map that includes:

1. **Conducting a 'scoping' exercise** that identifies (i) policies, decision-making and planning processes for which the implementation of NCA could provide critically important information; and (ii) data availability/needs, institutional framework, financial, technical resources and capacity required for NCA;
2. **Identifying and informing key institutional partners** that should be engaged (i) at the ministry level, such as MoE, Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Rural Development (MRD), Ministry of Agriculture, Forestry and Fisheries (MAFF), Ministry of Interior (MoI), Ministry of Economy and Finance (MEF); (ii) at the provincial level, including Provincial Department(s) of Environment (PDoE); and (iii) NGOs and Development Partners like Conservation International, Flora and Fauna International (FFI) and World Wildlife Fund (WWF) who currently do related work on ecosystem valuation;
3. **Considering a phased approach**, starting with basin-specific accounting-compatible assessments with a small set of key ecosystem services - such as those in the current report - and evolving towards a more encompassing exercise that would in time be extended to the country's national boundaries. A phased approach could initially focus on representative watersheds where there are clear beneficiaries, as in the case of the Pursat Basin. Criteria for prioritizing areas for undertaking ecosystem service accounting-compatible assessments may include: areas that are most at risk from degradation and forest loss; watersheds

important for hydropower and irrigation, water production and sediment regulation. Additional ecosystem services that should be considered include water flow regulation with a particular focus on drought. Estimation of economic benefits of hydrological, carbon and tourism ecosystem services should be prioritized for the following reasons:

a. Cambodia is experiencing a serious water shortage, which is expected to be exacerbated by climate change. It is therefore important that the RGC, through MoE and MOWRAM, strengthen management of important watersheds like the Cardamom Mountains and Kulen Mountains with protection of existing forest resources and restoration of degraded important watershed areas. Analysis of hydrological ecosystem services, as undertaken for this study, will be instructive for prioritizing areas for watershed management.

b. Cambodia has invested significantly in hydropower plants on the Mekong River, as well in the Cardamom Mountains. Ensuring a close to maximum operation capacity of these hydropower plants will be important for energy security in Cambodia especially in the dry season, which means protecting forest watersheds that are upstream of this dam. Valuation of hydrological services can support schemes for hydropower companies to provide finance that can assist with the management of forest resources that provide critical water flow regulation and sediment regulation for the operation of hydropower plants.

c. Carbon storage, as an ecosystem service, is strategic to analyze, as there are well-established methodologies for doing this. The carbon market establishes a price which often accounts for regulating ecosystem services (which have no market and/or are difficult to value) and biodiversity that facilitate carbon storage.

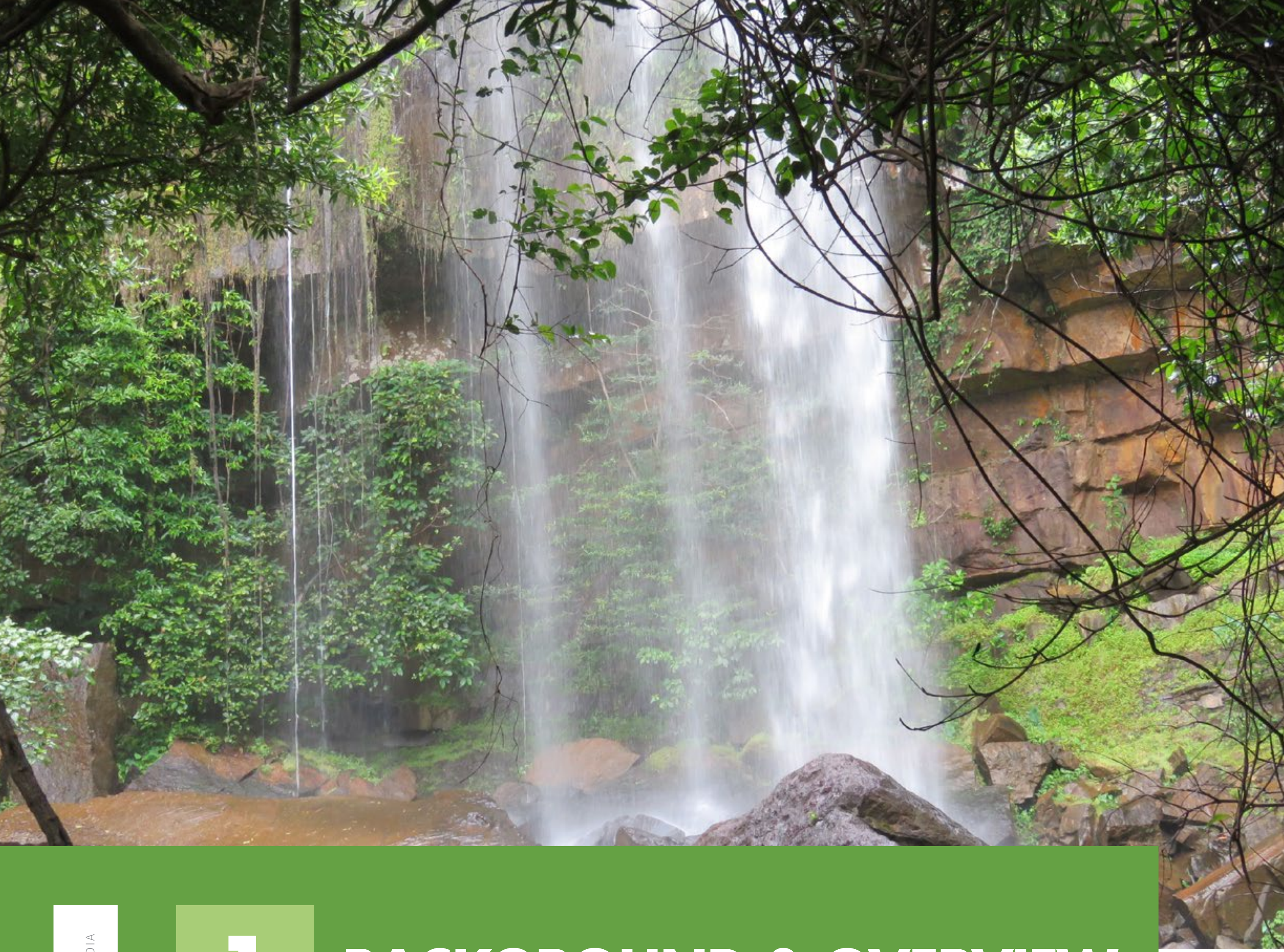
d. Ecotourism development in PAs is a priority of the RGC to boost the overall tourism sector in terms of jobs and value added, provide income for rural and forest communities and generate resources that can help with PA management.

4. We would recommend initial consideration for geographic priorities for undertaking such assessment to include watersheds that feed into the Tonle Sap and Kulen Mt. and Kbal Chay where the government is pursuing pilot PES projects;
5. The scoping and road map would most certainly highlight the need for enhancement on monitoring and generation of data for similar assessments and ultimately for accounting efforts:

   a. As changes in soil erosion and sediment accumulation are significantly affected by forest change and can result in large costs, it is recommended that monitoring of suspended sediment and bed load, at least at the site of the future dams or at the main gauging station be undertaken. Additionally, experimental plots to monitor soil erosion rates could be helpful in verifying soil loss projections.

   b. Rainfall variability in the mountainous region is high. Weather monitoring needs to be strengthened to derive accurate estimates to water resources available. This will become especially important as precipitation patterns continue to shift with a changing climate. A more extensive network of rainfall gauges is needed.

   c. Groundwater often plays an important role, but data on groundwater are even less available than for surface water. Improved groundwater mapping and monitoring is needed to better understand the role that it plays. The first essential step of this should be to map the major aquifers, followed by identifying important recharge areas and travel time. Without this, we risk incomplete protection for water source areas, as we are limiting our source region of the rivers based on visible terrain slope contributing to the river water.
6. The benefits of forest for disaster reduction – flood mitigation and forest fire prevention – would also be important to capture in subsequent analysis. Data on the flood, drought and fire damages would be important for determining the benefits provided by forest in terms of disaster risk reduction;
7. Additional benefits that would be important to capture include: water used for domestic purposes; recreational ecosystem services from ecotourism should be considered for areas where this is significant; non-timber forest products (NTFPs); and charcoal.



1 BACKGROUND & OVERVIEW

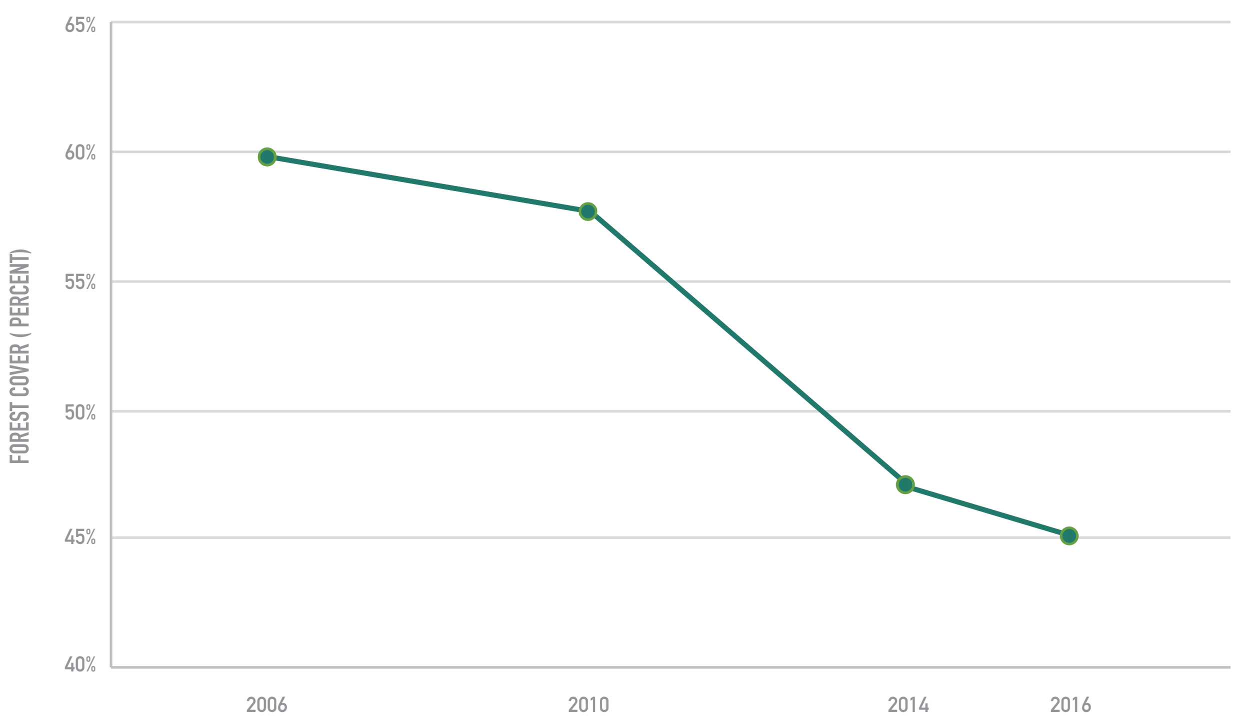
Terrestrial ecosystems such as forests provide important ecosystem services, including freshwater-related services such as sediment regulation, preventing too much soil erosion from filling reservoirs and other irrigation works and reducing their capacity; and water-regulating services affecting the timing of supply - satisfying irrigation water demand, recharging storage tanks and reservoirs, maintaining minimum flows in the river and reducing the likelihood of flooding. Unsustainable land use can drastically alter the ability of these ecosystems to continuously provide these ecosystem services and climate change can exacerbate these effects. Assessing the magnitude of these benefits, both in biophysical and monetary terms, is therefore critically important for decision-making, as it enables a better understanding of changes and trade-offs, leading to more informed and sustainable economic development and planning.

The Chambok water fall at Kirirom National Park

Forests occupy a significant area of Cambodia and the majority of the country's forests and important watersheds are in Protected Areas (PAs). Forests cover about 8.1 million ha (45 percent of the country) with intact forest patches interspersed with secondary forest and areas that have been cleared for agriculture or other activities (MoE 2018). The PA system covers 7.4 million ha (41 percent of Cambodia) and includes about 67 percent of Cambodia's forest area. Many protected areas (PAs) face threats from encroachment for cultivation, charcoal production, illegal timber harvesting and wildlife poaching.

By putting forest resources under the Protected Areas system, the Royal Government of Cambodia (RGC), has made key steps to ensure the reversal of the declining trend on forest cover. Cambodia's forest cover has declined since 2006 because of pressure for land and unsustainable use of natural resources (Figure 1.1). Forest degradation is pervasive and attributed to unsustainable logging practices, salvage logging and fuelwood extraction. Land expansion has been a major factor, with cultivated land for crops increasing by 50 percent between 2002 and 2012, partly at the expense of forests (Forest Trends 2015). In addition, approximately 5.5 million tons of fuelwood are used each year by households and small and medium enterprises (SMEs), with 88 percent of the population still relying on traditional biomass for cooking (GERES 2015). Under the PA system, forests will be subject to stricter management that includes no timber harvesting, sustainable harvesting of non-timber forest products (NTFPs), patrolling by rangers and forest communities to prevent illegal activities and forest restoration where needed.

FIGURE 1.1: FOREST LAND COVER CHANGE IN CAMBODIA, 2006–2018

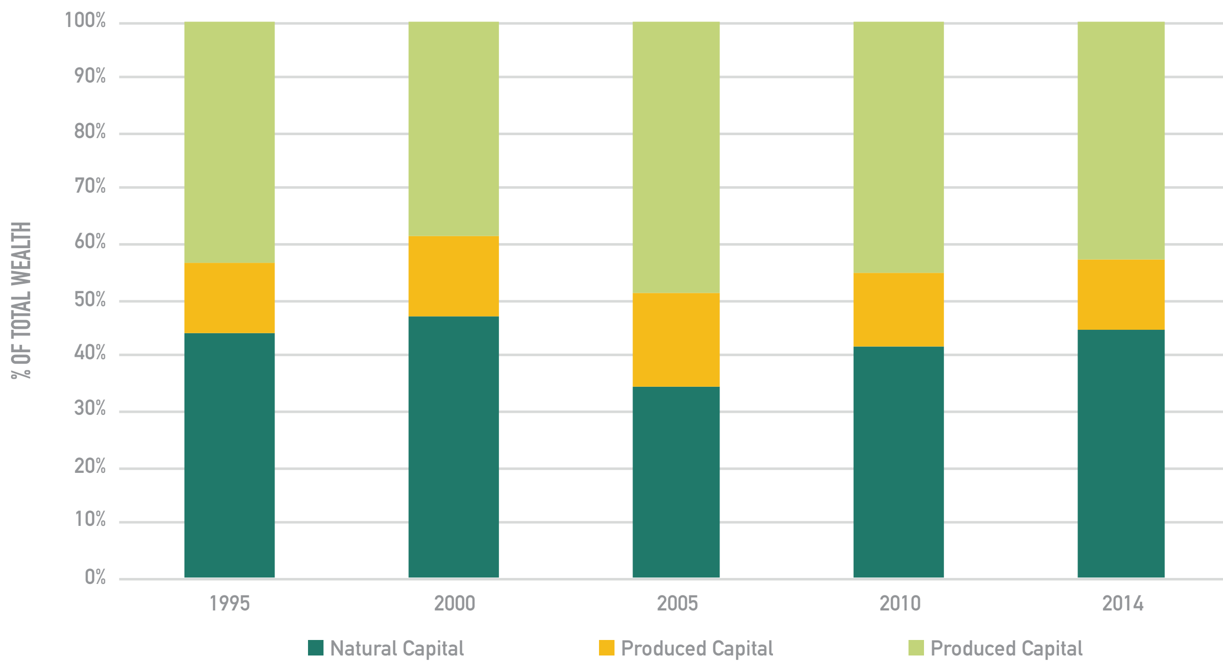


Source: MoE 2018

1.1 How are Forest Ecosystem Services Contributing to Cambodia's Economy?

Natural capital such as forest resources account for about 40 percent of Cambodia's wealth and contributes significantly to its economy; see Figure 1.2. This capital, which includes agriculture, forests and fisheries have contributed to Cambodia's strong economic growth at 7.6 percent from 1994–2019. This demonstrates an increase in gross national per capita from US$300 in 1994 to US$1,623 in 2019 (current prices) and a graduation to lower-middle-income status in 2015. Cambodia's forest ecosystems provide important services like water and sediment flow regulation, biodiversity disaster mitigation that underpin Cambodia's key sectors – agriculture, garments and tourism.

FIGURE 1.2: NATURAL, PRODUCED, AND HUMAN CAPITAL IN CAMBODIA, 1995 – 2014



Terrestrial forests in Cambodia are important habitats for freshwater. All of the headwaters of the country's five major river basins are under forest cover (ADB 2014). Analysis by Bottrill et al. (2015) presented in Figure 1.3 showed that intact forests in the Cardamom Mountains, and in the eastern mountains of Cambodia, are important for regulating water flows and facilitating important water purification processes.

Agriculture, which depends heavily on water flow regulation, erosion regulation and nutrient retention services provided by forests, contributed 22 percent of GDP in 2018.[2] Rice production is the most important contributor to the agricultural economy. Cambodia relies on irrigation for about 16 percent of its total cultivated area, and about 10 percent of its rice crop. Water for irrigation is drawn from surface water sources and, increasingly, groundwater is being used for irrigation, especially in the south of the country. Studies indicate that wet season irrigation has very little impact on rice yields and is more important for dry-season rice. The Ministry of Water Resources and Meteorology (MOWRAM) plans to increase its irrigated area to 872,000 ha (by 2025) from 672,000 in 2015 with surface water structure initiatives like large irrigation canals which underscore the importance of sustaining

2 https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=KH

surface water flows (Raju and Taron 2018).[3] As much as 85-90 percent of household income depends directly on ecosystem services (fisheries, timber, wild food, crops and firewood).[4] Forest products that are collected frequently include timber, bamboo, rattan, other edible plants and wild food such as snails, frogs, eels and crabs for household consumption and sale.

Fisheries are also dependent on forest services. Freshwater mangroves and flooded forests provide habitat support for more than 300 species of fish and crustaceans and thereby help support the fisheries industry. Freshwater fisheries in the Mekong River and Tonle Sap are a vital part of the country's economy, food security and culture. The fisheries sector provides employment to 2 million people, accounting for 75 percent of households' animal protein intake and contributes to about 12 percent of GDP.

Tourism and ecotourism, which contributed to approximately 18 percent of Cambodia's 2018 GDP, is dependent on the country's considerable biodiversity in forest landscapes. Cambodia, which sits within the Indo-Burma biodiversity hotspot, is one of the most biodiverse countries in Southeast Asia. In total, an estimated 53 percent of this biodiversity is contained in the country's protected areas (Bottrill and others 2015). The Cardamom Mountains forest landscape, in particular, has a remarkable diversity of animal species, including elephants, bears, gaur (the world's largest bovine) and freshwater fish and new species are regularly being discovered. The Cardamoms hosts the longest wild elephant track (Koh Kong, southern Cardamom) in the world and has successfully preserved elephants from poaching over the last ten years. The RGC is exploring ecotourism as a driver to strengthen management of its rich natural capital and boost economic prosperity. With a captive tourism market focused on the Angkor temples, the MoE and Cambodia's Ministry of Tourism (MoT) are now developing management policies, regulatory frameworks, strategies and guidelines and making investments to expand ecotourism.

Forest also help to sustain hydropower in Cambodia which provide power to the garment and other industries. The RGC has indicated that investing in hydropower, and sustainable energy is a national priority and have already made significant investments in dams in large hydropower plants in Koh Kong and Kampot provinces. The country's growing energy needs are met in part by hydroelectric power (HEP), where forest systems are important for water flow and sediment regulation in rivers. The RGC estimates that HEP will become an increasingly important part of its energy supply mix in the medium term (from 26 percent in 2013 to about 50 percent by 2020) and have made significant investments already in this (see Table 1.1). However, Cambodia is experiencing increasingly severe droughts which affect the performance of the hydropower plants. A reduction of 75 percent of rated capacity of hydropower plant occurs during the dry season and this will be exacerbated under climate change (RGC 2014).

TABLE1.1: LARGE HYDROPOWER DAMS IN CAMBODIA

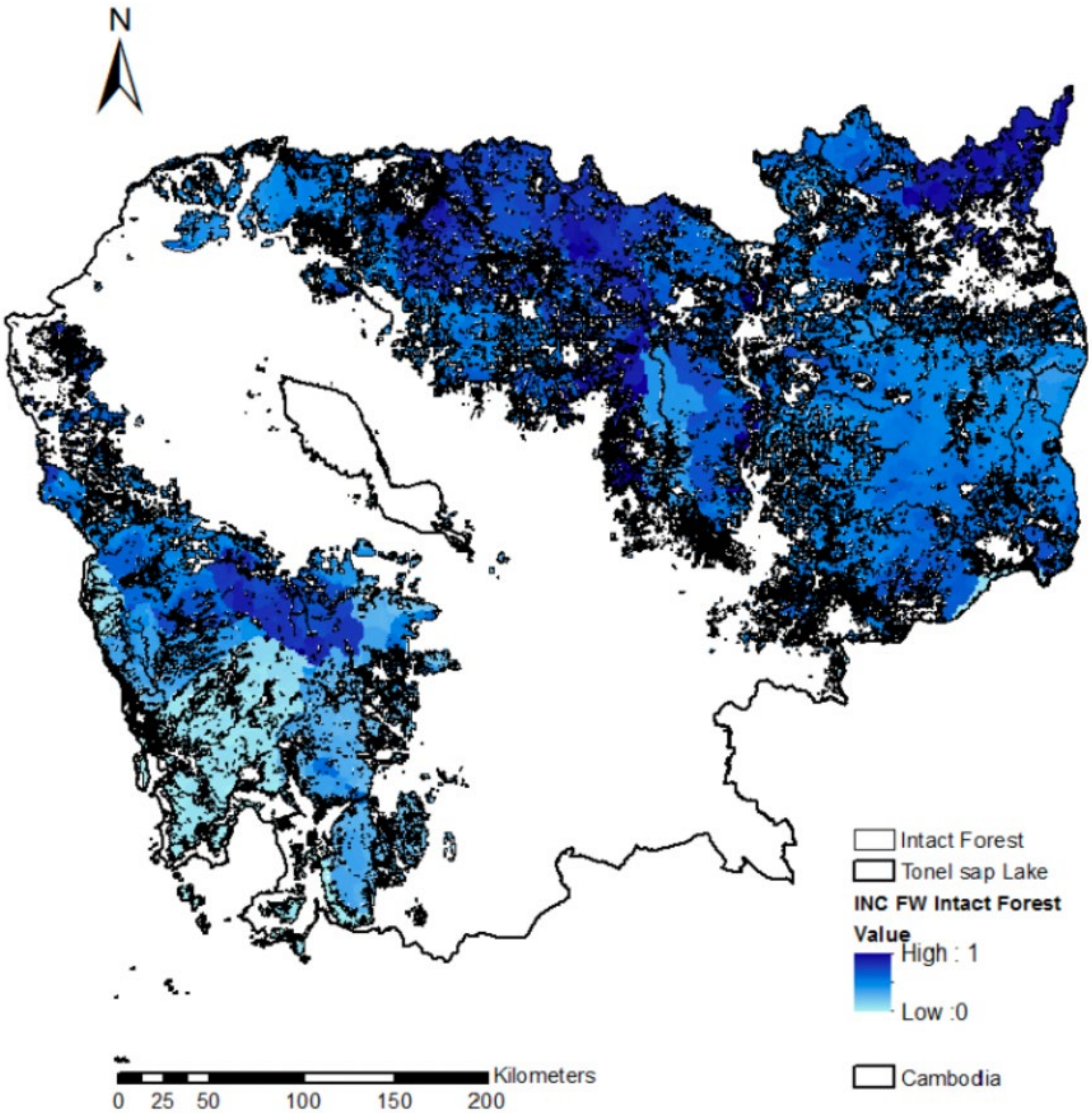
Hydropower Project	Installed Capacity (MW)	Cost (US$million)	Year of Operation
Lower Se San II	400 MW	800	Dec. 2018
Stung Tatai	246 MW	540	Aug. 2014
Russei Chrum Krom	338MW	500	Jan. 2015

Sources: Dreher and others 2017; Khmer Times 2015.

3 Erban and Gorelick (2016). Closing the irrigation deficit in Cambodia: Implications for transboundary impacts on groundwater and Mekong River flow

4 Persson and others (2010) examined the connection between ecosystem services and livelihoods in Kratie, Kampong Thom and Battambang provinces.

FIGURE 1.3: OVERLAPS BETWEEN FRESHWATER HABITATS AND FOREST LANDSCAPES IN THE EAST AND WEST MOUNTAINOUS AREAS OF CAMBODIA



Notes: Darker blue areas show important freshwater habitats which overlap with forest landscapes in the east and west mountainous areas of Cambodia

Source: Bottrill et al. 2015

1.2 Valuing Cambodia's Ecosystem Services is Relevant and Timely

"A priority for resource assessments is the valuation of the natural assets present in key protected areas to document their importance and to better evaluate the relative benefits (and costs) associated with investment for development purposes versus protection. Valuations should include both provisioning services (e.g. timber, firewood, NTFPs and agriculture) and regulating services (e.g. carbon storage and water). This type of economic analysis is key to sustaining financial support for protected areas as part of a national Green Growth strategy." **Excerpt from NPASMP, MoE (2017:7)**

Influencing the RGC's decision-making on investments in Protected Areas conservation and protection is among the core reasons for valuing ecosystem services in Cambodia. A large proportion of Cambodia's natural landscape and rich biodiversity is contained within PAs, which makes them important for conservation and protection but still they remain susceptible to illegal activities. For example, even though 62 percent of the Cardamom Mountains are under the PA system, it still faces threats from encroachment from cultivation, charcoal production, illegal timber harvesting and wildlife poaching.[5] MoE's foremost policy documents on PAs – The Protected Areas Law of 2008 and the National Protected Areas Strategy and Management Plan (NPASMP) 2017-2031 – strongly advocate the use of ecosystem service values in conservation planning and prioritization of areas in PAs for strongest protection efforts and helping to address drivers of deforestation. The NPASMP also contains performance targets for valuation studies influencing PAs development which emphasize the importance among the RGC for valuation.[6]

BOX 1.1: DRIVERS OF DEGRADATION IN PROTECTED AREAS

Forest degradation in PAs, like the Cardamom Mountains Protected Landscape, is mostly driven by small-scale clearings in the forest for the cultivation of crops such as rice, land grabbing, and charcoal and fuelwood collection. The principal cause of this type of forest clearing is the combination of in-migration and poorly defined property rights, compounded to an extent by local population growth. Infrastructure development is increasing access to the area for in-migration from outside. Land grabbing and speculation by powerful local actors has also been identified as a proximate cause of deforestation, with land often being cleared and sold to businessmen from nearby towns.

Reliance of local communities on forest resources for their subsistence, such as timber for housing, firewood, non-timber forest products, fish and bushmeat, can also have detrimental effects on forest biomass, although less severe.

Charcoal production is a significant cause of deforestation at eastern edge of the Cardamom Mountain Protected Landscape due to demand for charcoal in Phnom Penh, Pursat and Koh Kong. Despite the official logging moratorium, there are indications of small-scale (illegal) logging in the Cardamoms. Illegal logging is carried out by villagers who log and sell timber to make a living, and by migrants who are often employed by powerful local actors. It is mostly undertaken in the form of small-scale selective logging, targeting mainly luxury woods.

Sources: Conservation International (2012); Initial Forest Reference Level for Cambodia under the UNFCCC Framework (2016)

Cambodia's impending water crisis and the impacts of climate change will put increased attention on forests and the water flow regulation and disaster mitigation services that they provide. Forests also provide disaster mitigation benefits that help protect Cambodia's economic activities. Forests, in helping to maintain water flows especially during the dry season, help to reduce drought conditions. Seasonal water scarcity exists in the river basins of the Tonle Sap River Basin Group (e.g. in 2016, 18 out of 25 provinces

5 A National REDD+ Strategy undertook an analysis (for the entire country) on drivers of degradation, which helped identify the threats being faced in PAs (RGC 2017). This (government-led) analysis was used in the formulation of the government's forest investment plan in 2018.

6 A target of '5 PAs that have completed valuation studies' by 2021 has been set by MoE as part of its NPASM (2017-2031). It is expected that 20 PAs would have completed valuation studies by 2031 (MoE 2017).

are affected by droughts with around 2.5 million people lacking water) and existing reservoir storage capacity (less than 10 percent of total water generated) is insufficient to redistribute water significantly between seasons. In the wet season, forests also play important roles by acting as stores of water during rainfall events and regulating (slowing) the speed at which water enters rivers and streams. Drought and flooding are expected to be exacerbated in Cambodia because of climate change, with expected changes to be around an extra 1.5 months of drought, and with flooding expected to be more extensive particularly in the eastern areas of the country. Impacts of climate change on forests have not been studied in Cambodia, but evidence from similar tropical environments indicates that with drier conditions forests will be more susceptible to fires, and excessive rain can increase landslide occurrence. Conservation of forests as freshwater habitats is therefore critical.

Strong interest of the RGC in Payment for Ecosystem Services (PES) to support natural resources management underscores the need for ecosystem service valuation studies. PES initiatives are being piloted in Cambodia, with the support of Conservation International (CI) and UNDP. Following a visit of MoE officials to Costa Rica for a PES study tour, there was strong interest in developing a PES scheme in Cambodia. Two pilot sites have been selected by MoE to look at how to implement PES – Phnom Kulen watershed which provides water for Siem Reap, and Kabal Chay watershed which feeds Sihanoukville. UNDP commissioned a study to look at what PES mechanisms may be put in place for these two sites and some recommendations were made. These were more general recommendations, which provided ideas about the application of possible tourism fees to tourist areas (e.g. for Khulen mountain, or a surcharge for hotels in Sihanoukville), although practicalities on how to design and implement a PES system were not covered. Indeed there was a lack of funds to provide a detailed analysis on the stakeholders and user groups, and critically also on the willingness to pay.[7] This analysis will add to the growing body of work needed to design a comprehensive PES mechanism in Cambodia.

In order to meet the demand of the RGC for values-driven decision-making on forest and PAs, there needs to be development of government-endorsed valuation methodology, development of case studies of ecosystem services value assessments and capacity development, among other things. Economic analysis has played a limited role in determining how forests are managed and financed in Cambodia. Data, information and analysis by NGOs, including some economic analysis, have, over the years, influenced various national policies, including on forest management, and also in the development of the draft Environment Code. However, there has been little systematic economic valuation work at the national level that has determined decisions around how resources are allocated for forest protection at the national or subnational levels. There are two important opportunities now for the RGC integrating ecosystem service values into forest and PA decision-making: (i) the Cardamom Sustainable Landscape and Ecotourism (CSLE) project which focuses on improving the management and value addition of the natural capital in the Cardamom Mountains and Tonle Sap landscape, and (ii) a new landscape project being prepared which will focus on landscape management with a focus on integrated watershed management in PAs of the eastern river basins – Sen, Chinit, Upper Mekong and 3S (Sekong, Sesan, Srepok).

1.3 About this Analytical Work and Report

The analytical work is being undertaken as part of a broader effort of the World Bank in Cambodia to provide guidance to the RGC through technical assistance and analytical and advisory services on managing its natural capital through landscape approaches. The World Bank in Cambodia has agreed

7 A national dialogue on PES was organized by UNDP and CI in September 2019 to keep the dialogue on PES moving forward. It brought together people across different ministries as well as stakeholders from both Khulen and Kabal Chay (e.g., water utility in Kabal Chay, Angkor beer, etc.). It was a way to explain PES to various stakeholder and ministries as well as to gauge their thoughts on willingness to pay. Since then, UNDP did provide MoE with recommendations for steps going forward (e.g. a fund for Kabal Chay), but there’s been no further action on this to date.

within its Country Partnership Framework (CPF) to support the Cambodian government on strengthening the sustainable use of natural resources. Working through a landscape approach in the Cardamom Mountains, the Mekong Delta and in the upstream Mekong, the Bank is helping the RGC to better manage and add value to its natural capital through strengthening its links to the economy.

Accordingly, this study provides evidence of the importance of forests in the Cardamom Mountains in providing ecosystem services, inter alia, that are important for Cambodia's economy and climate and disaster resilience and helps the RGC to quantify and communicate the value of its natural capital to Cambodia's economy. This is done by quantifying ecosystem services provided by forests in biophysical and economic terms, and evaluating impacts of deforestation on forest ecosystem services. Methodologies for measuring and valuing forest ecosystem services have also been developed as well as discussed with the RGC, and documented for the government as a tool to assist in decision-making. These methodologies are expected to contribute to the growing body of literature on science-based policy and decision-making. Recommendations for scaling-up ecosystem services assessment and valuation are provided as a road map within this report and actions are proposed for how this work can inform investments for forest and PA management, namely conservation, protection and restoration in the Cardamom Mountains. The work will also provide the underpinnings for tools like PES as well as investments in forest and PA management, both of which will be developed under the CSLE project (Box 1.2 below), as well as tools such as natural capital accounting.

BOX 1.2: CAMBODIA SUSTAINABLE LIVELIHOOD AND ECOTOURISM (CSLE) PROJECT (US$55 MILLION)

This project's objective is to improve PA management and promote ecotourism opportunities and non-timber forest product (NTFP) value chains in the Cardamom Mountains Tonle Sap (CMTS) landscape in Cambodia. The CSLE project will also support the RGC in strengthening the legal and regulatory framework for the management of ecotourism investment projects (EIPs) in PAs.

To achieve this, the project will strategically invest in areas that are strongly aligned with RGC's development plans. There are three components:

- Strengthen Capacity for PA Landscape Planning and Management
- Strengthen Opportunities for Ecotourism and NTFP Value Chains
- Improve Access and Connectivity.

The analysis focused on selected ecosystem services provided by forests in the Pursat River Basin of the Cardamom Mountains: (a) seasonal water-regulation service, which affects the availability of water for irrigation; and (b) sediment regulation service, which affects the operability of hydropower. Another analysis was also done to assess the value of tourism and forest carbon in the same area. The selection of the Pursat watershed does not indicate its importance relative to other watersheds in Cambodia. Instead it was selected to strategically demonstrate how the valuation of ecosystem services is undertaken, particularly where there is a stream of benefits from the ecosystem flowing to well-defined users, and also to demonstrate how valuation can inform PA management. The biophysical and monetary assessments follow approaches consistent with guidelines proposed by the System of Environmental-Economic Accounting Experimental Ecosystem Accounts (SEEA EEA).

Focus on the Pursat River Basin

The Pursat River Basin is at an interesting juncture of its development trajectory. For millennia, the floodplains of this river have been used for cultivation. Dominated mainly by rice, the basin's agricultural rhythm had been dictated by seasonal changes. Agricultural irrigation has relied on rainfall, the flood pulse of the Tonle Sap and water from the Pursat River – which is fed by rainfall high in the Cardamom Mountains. Today, the river offers an opportunity to propel this region's economic and human development forward, by constructing irrigation infrastructure to stabilize and extend the growing season and also by harnessing the power generating potential of the river. As built infrastructure is developed in the region, it is important to also account for the basin's natural characteristics (in the form of terrestrial ecosystems in the Cardamom Mountains) and understand how ecosystem degradation could change the ability of the basin to reach its potential. The Pursat River Basin provides an excellent case study for ecosystem service valuation as it is an economically important area and there are clear beneficiaries of services being provided by the forest ecosystem there. As the basin supports a range of different uses from irrigation for rice production to hydropower and ecotourism as well as PAs, it can be considered a representative for other basins in Cambodia and so methodologies applied here can be used and replicated in other river basins in Cambodia.

The report puts forward three key messages (KMs) and three recommendations:

KM 1: The economic benefits from intact forests (estimated at US$99 million) are almost five times higher than the gains from cutting them down for small-scale agriculture and charcoal production, which is estimated at US$22 million.
KM 2: Investing in the maintenance of forest is good business. Annual public expenses to maintain the forest in the Pursat Basin are about 20 times lower than the benefits provided by them.
KM 3: Funding for the maintenance of those forests in the long run can be captured from private and international sources.
Recommendation 1: Focus forest protection and restoration efforts on upstream watersheds in the Cardamom Mountains protected area landscape to enhance resilience of water resources.
Recommendation 2: Explore the potential for private financing to support PA management.
Recommendation 3: Develop a road map for scaling up assessment of economic benefits provided by forest ecosystems across Cambodia using a Natural Capital Accounting (NCA).

1.4 Overall Methodological Approach to Valuing Ecosystem Services

The major analytical activities and methodological approach (described below) for this study focus on the measurement and valuation of hydrological services provided by forests. Work was also done to estimate the value of carbon and tourism benefits from forests, and the methods that were used are described in more detail in both Chapters 4 and 5 as well as in Appendices 4 and 5.

Using a Natural Capital Accounting Framework

Environmental and natural resources make important contributions to economic activity and human well-being, but these roles are often not recognized nor included in national accounts but rather attributed to other activities. As a result, these important resources are often thought to be without value and damage to them is not taken into consideration when policy decisions are made.

A system of environmental accounts has been developed to complement standard national accounts to remedy this problem.[8] These accounts

8 See https://seea.un.org/ for more information and technical manuals on the system of environmental accounts.

begin by identifying the stocks of environmental resources and the flow of services that they provide, then they track how these stocks and flows change over time. Taking the additional step of estimating the value of these stocks and flows allows their benefits to be quantified in a form that enables comparison to other economic activities. This is what this report seeks to do in the case of the Cardamom Mountains.

The economic value of an ecosystem — such as a forest — is estimated by summing the values of the various flows of benefits it is providing. For comparability with the value of other assets in the national accounts, this value is usually expressed as the asset value: the present value of the flows of benefits expected to be provided over a given time horizon.

For comparability of the forest asset with other assets in the national accounts, the flow of benefits is measured against the counterfactual in which the asset does not exist. This is relatively straightforward when it comes to the ecosystem's flows of benefits. Without a forest, there would be no timber for harvesting, so the flow of that service would disappear. Other services, however, would not necessarily disappear. Even if there were no forests, rain would continue to fall and so water would continue to flow — but it's flow would be different and the water would be dirtier, which would affect the level of benefits it provides. Estimating how these benefits would change in the absence of forests is one of the main challenges we face in a work such as this.

It is important to note that this asset value, while useful for comparison to the value of other assets, does not speak directly to the decisions facing policy-makers. The forests in the Cardamom Mountains, while under pressure, are in no immediate danger of vanishing entirely. For policy purposes, it is more relevant to examine how the value of the benefits they provide would change under likely changes, such as current deforestation rates. This is akin to asking how the value of the house would change if there was a leak in the roof that lets rain come in; the value of that damage would be less than the entire value of the house. In this report, we complement the analysis of the asset value of the forests in the Cardamom Mountains (which compares current benefits to those that would be received if the forests did not exist) with an analysis of the economic costs resulting from current deforestation rates (which compares current benefits to those that would be received if forests were partially lost).

Biophysical Assessment and Economic Valuation of Hydrological Ecosystem Services

The core component of the hydrological analysis was the setup, calibration and validation of a hydrological model for the river basin that could be used to analyze spatial and seasonal variation to water and sediment yield.

- After a brief survey of potential hydrological models that could be suitable for this study, a Soil & Water Assessment Tool (SWAT) hydrological model was selected and setup using data derived from local and global sources. Daily discharge from Bac Trakuon monitoring station was used to ensure the hydrological model for Pursat Basin provided river flow estimates that are representative of known records.
- The impact of current and planned infrastructure on the river discharge (mainly 3 dams currently designated as Dam 1, 3 and 5) was achieved through a simple dam model that ran on the time series results extracted from the hydrological model. This was done specifically because (1) at the time of model-setup, the operation rules for the 3 dams were not known; and (2) an external dam model allowed us the option to modify operation rules in real-time during stakeholder gatherings and examine together the impact downstream.
- Once the hydrological model performance was deemed satisfactory, the resulting time series of water and sediment yield (both overall and associated with different land covers) for two basin conditions was extracted to facilitate the monetary evaluation. The first condition represents the current land cover in the river basin and was based on official land cover for 2016 received from the Cambodia's Ministry of Environment. The second condition represents a hypothetical change - a 'no forest' counterfactual. Under this, all mature forest

in the basin was replaced by barren or bare earth land cover. As a note of explanation, the rationale of the counterfactual is to provide an indication of the total economic value of having intact forests and should not be confused with scenarios developed from policy and planning perspectives that will apply more realistic deforestation/ afforestation rates.

- A complementary aspect of deriving seasonal (monthly) water availability was estimating seasonal variation in water required for irrigation. For this, the net projected command area for the wet and dry season paddy crop was adjusted with known cropping patterns to an approximate total area requiring irrigation at any month in a year. Then, using rainfall and evapotranspiration estimated (from the hydrological model), crop water requirement from irrigation (for each month) was calculated using FAO's irrigation water demand assessment method.

Economic valuation in this analysis takes inputs from hydrological modeling. Two specific inputs are water supply to meet rice irrigation demand and soil erosion control services to avoid dam sedimentation.

- For water supply services a production function method (called Residual Imputation Method) was used. In this case, water is considered an input to rice production process alongside other inputs such as fertilizer, seed, chemicals labor etc. Although the prices of most inputs are known from market information, the price of water is not known because it is not traded in the market like other commodities. The purpose of the production function method is to tease apart the value of water based on information such as rice yield, market price and cost of all known production inputs. This value of water was then used to estimate the economic value of forests which affect water supply. This was executed by comparing water supply and demand in the presence and absence of forest as described above. We then estimated how much of that value is threatened by ongoing deforestation (at 0.25 percent rate) and also in a more aggressive deforestation scenario (at 1 percent rate).
- For valuation of soil erosion control services, we used soil erosion rates for different land cover types derived from hydrological analysis. These rates were used to simulate total sediment that is deposited in the dam in a progressive deforestation at 0.25 percent, 1 percent and no-forest counterfactual. This simulation was run for 100 years – which is assumed to be the lifecycle of the dam. The corresponding loss in hydro energy values was then estimated based on reduction in dam capacity due to sedimentation. We estimated total value of forest for provision of this service and at the same time estimated how much of the value is threatened by different rates of deforestation. Because of a long-time horizon of dam operation, we reported economic value in net present value (NPV) term as well as in annual values.

Estimating tourism and carbon benefits. Data on visitors to tourism sites in the Pursat Basin (arrivals, visitor spending and length of visit) was used to estimate benefits from tourism where forest ecosystems are the key tourism asset. Data was obtained from the MoE ecotourism records and assumptions about changes in visitor spending, visitor arrivals and length of day were agreed with MoE. Estimating carbon benefits followed standard Verified Carbon Standard (VCS) methodology VM0015 for assessing carbon stocks. Data on carbon stocks by forest type was obtained from forest carbon stock assessment done for Cambodia's REDD+ program and the price of carbon determined from emission reduction programs in Cambodia.

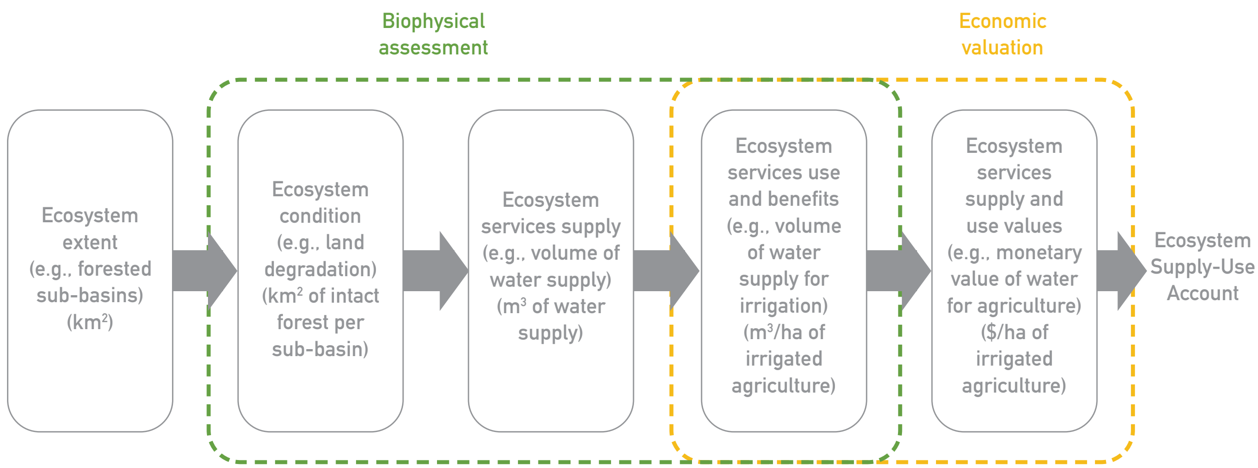
The estimated economic benefits of forests are the summation of benefits derived from the three studies on hydrological, tourism and carbon benefits. The counterfactual approach (if forests were removed) was used to estimate net present value of benefits of forest for irrigation, HEP and tourism. The deforestation scenarios approach was used to estimate annual benefits of forests for irrigation, HEP, carbon storage and tourism.

Estimates of benefits of forest conversion were determined by assessing the economic returns that could be gained if forests in the Pursat River Basin are converted at an annual rate of 0.25 percent (about 980 hectares) for charcoal and agriculture. The stream of benefits and costs of forest conversion were compared using net present value (NPV) analysis for a period of 50 years at 6 percent discount rate.

The study acknowledges that there are more ecosystem services provided by forests in the Pursat Basin like flood regulation and biodiversity regulation. If assessed and valued, these values will lead to a more comprehensive assessment of the benefits provided by forest ecosystems. This is a limitation of the overall study and it is recommended to be looked at in further work.

A schematic of the key tasks for biophysical modeling and ecosystem valuation is provided in Figure 1.4

FIGURE 1.4: SCHEMATIC DIAGRAM OF THE SEQUENCE OF BIOPHYSICAL AND ECONOMIC VALUATION IN SEEA EEA CONTEXT, WITH AN ILLUSTRATIVE EXAMPLE OF WATER SUPPLY FOR IRRIGATED AGRICULTURE

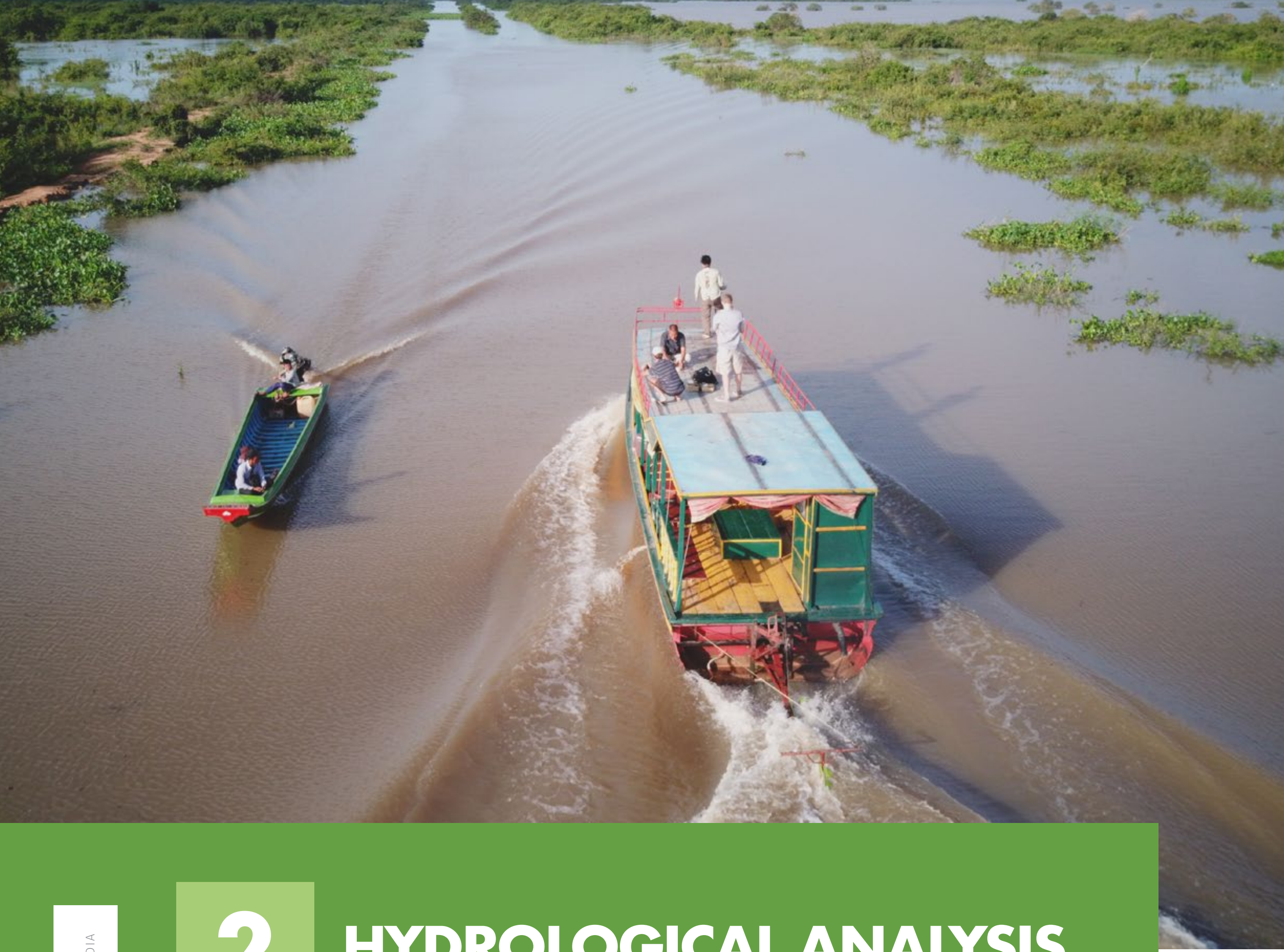


Data for Analysis

The data used in the analysis is listed in Appendix 1.

Structure

The rest of the report is structure as follows: Chapter 2 presents the results of the hydrological analysis for the Pursat Basin; results of the valuation of hydrological services in the Pursat Basin are presented Chapter 3; results of carbon and tourism valuation are presented in Chapters 4 and 5; and in Chapter 6 a discussion on policy implications of this work including recommendations for next steps is provided. An extensive methodology for the analysis is included as a separate document.



2 HYDROLOGICAL ANALYSIS

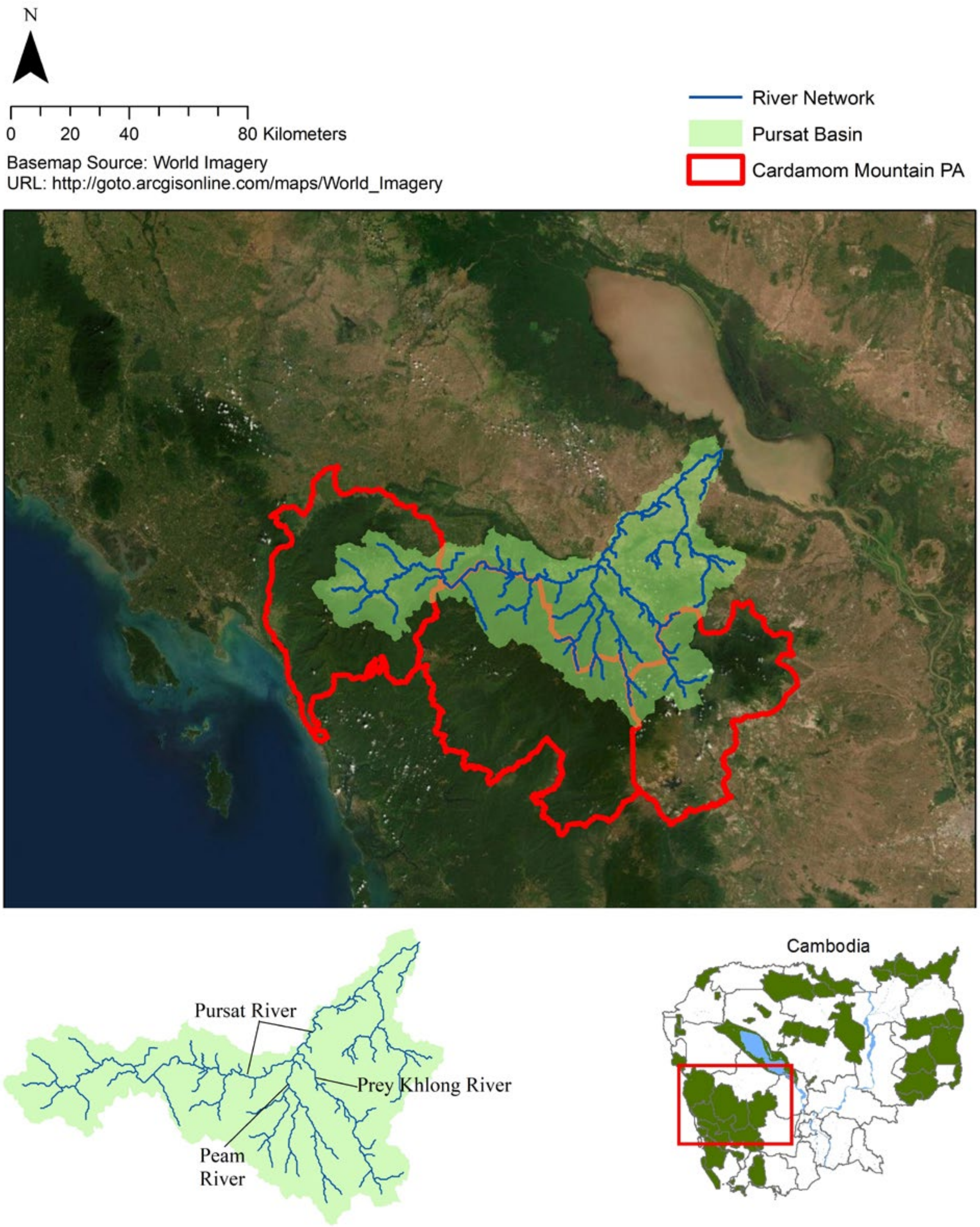
2.1 Overview

This chapter outlines the development of the mathematical modeling of seasonal flow variation and soil erosion in the Pursat River Basin, including data preparation, set up and results. The analysis derives seasonal estimates of changes in water availability, irrigation demand and sediment flows. The results from this analysis - specifically, estimates of water deficit relative to irrigation demand and sediment yield for different land cover scenarios—provides the basis for the economic evaluation in the next chapter. The overall objectives for the hydrological analysis can be summarized as:

- Develop a hydrological model of the basin to estimate current water and sediment yield;
- Understand spatial contributions and seasonal changes to these quantities;
- Understand the relation of water and sediment yield to land cover

Sebastian Troeng records drone photos and video footage while traveling across Tonle Sap Lake during the 2018 Asia Pacific Executive Leadership (APEX) meetings in Cambodia. © Conservation International/photo by Sebastian Troeng

STUDY AREA MAP



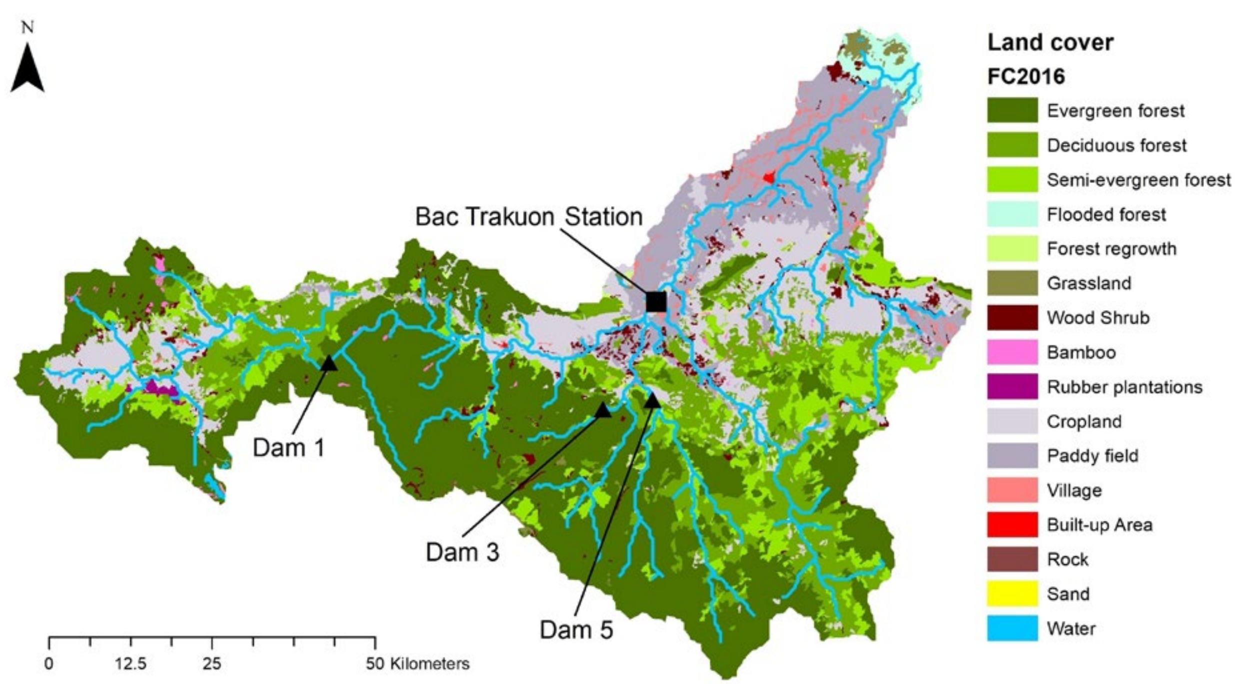
2.2 Pursat River Basin

The Pursat River originates in the Eastern slopes of the Cardamom Mountains and flows into the Tonle Sap. The basin has an area of roughly 5960 km2; the river is approximately 150 km long. Its two main tributaries, the Stung Peam and the Stung Santre (Prey Khlong), join the mainstream just above the gauging station of Bac Trakuon (Figure 2.1).

Water storage infrastructure in the Pursat River Basin supports hydropower and irrigation. Two dams (Dam 3 and Dam 5) have been constructed in the basin and are operational, and a third, larger hydropower dam (Dam 1) has been approved for construction. About 20 irrigation infrastructure works are at varying degrees of implementation, including irrigation schemes (Damnak Chheur Kram & Damnak Ampil) in which water from the Pursat River is to be diverted to the smaller Svay Daunkeo and Moung Ruessei streams, west of the Pursat Basin. The total command area for the schemes is listed in Section 2.4. In this study, we assume that most of the water for these schemes depends on the Pursat River, as the Svay Daunkeo and Moung Ruessei streams provide relatively little water.

Official land cover for the year 2016 was obtained from the MoE. A significant proportion of the basin (~ 68 percent) is covered by natural forested land - predominantly evergreen forest. However, the area upstream of the proposed Dam 1, within the Sam Kos Wildlife Sanctuary, appears to have already experienced significant changes in land cover, driven by conversion of forests to cropland and rubber plantations. It should be noted that the MoE classification system defines "cropland" as land cover that "includes arable and tillage land and agroforestry systems where vegetation falls below the thresholds used for the forest land category." Unlike the "paddy field" land cover category, this land is not associated with any specific crop. In at least some cases, these cropland parcels are likely to be in transition from natural land cover to agriculture. The area cleared for agriculture in Sam Kos Wildlife Sanctuary is largely of this land class and is expected to include cash crops, cassava and orchards.

FIGURE 2.1: LAND COVER 2016 MAP AND DISTRIBUTION

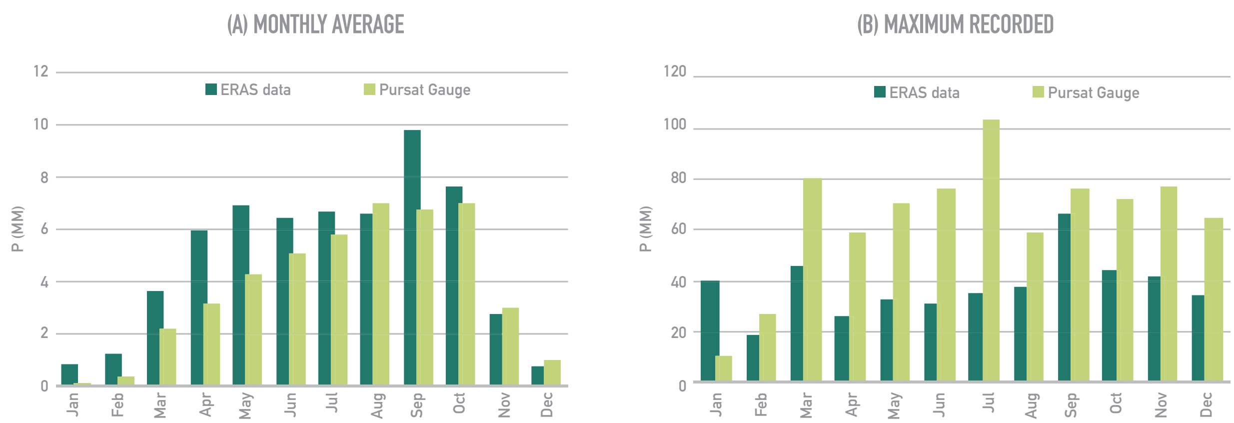


2.3 Key Hydrological Datasets

Precipitation Data

Daily precipitation data covering the period 2004-2018 is available from Cambodia's Ministry of Water Resources and Meteorology (MoWRAM) for a single precipitation gauge in the basin. Given the variability of altitude within the basin, daily precipitation estimates from the ERA5 global dataset at 13 points covering the basin have been extracted using the Google Earth Engine. ERA5[9] is a climate reanalysis dataset developed through the Copernicus Climate Change Service (C3S). After comparison of the two datasets (Figure 2.2), the ERA5 dataset was selected as the primary precipitation dataset used in the study owing to its superior coverage.

FIGURE 2.2: COMPARISON OF ERA5 ESTIMATES WITH VALUES MEASURED AT LOCAL GAUGE



Notes: (a) ERA5 monthly averages are in general higher than the local gauge while (b) ERA5 generally underestimates peak precipitation rate. Given that ERA5 provides areal averages rather than values at a specific point, both these trends are consistent with expected behavior.

Source: Authors' creation

Discharge Data

MoWRAM reported (pers. comm.) monthly water availability and discharge for the Bac Trakuon monitoring station based on monitoring from 1997 to 2011 (Table 2.1). Actual daily gauge data for the same station was made available by MoWRAM covering the period from 1 January 2007 to 31 December 2016.

The overall behavior is consistent between these two datasets (Figure 2.3). However, extremely low flows are recorded in the first quarter for the years 2014-2016. While drought-like conditions have been reported over this same period, the daily gauge reading of no flows (0 m3/s) from 7 January 2015 to 13 June 2015 appear uncharacteristic.

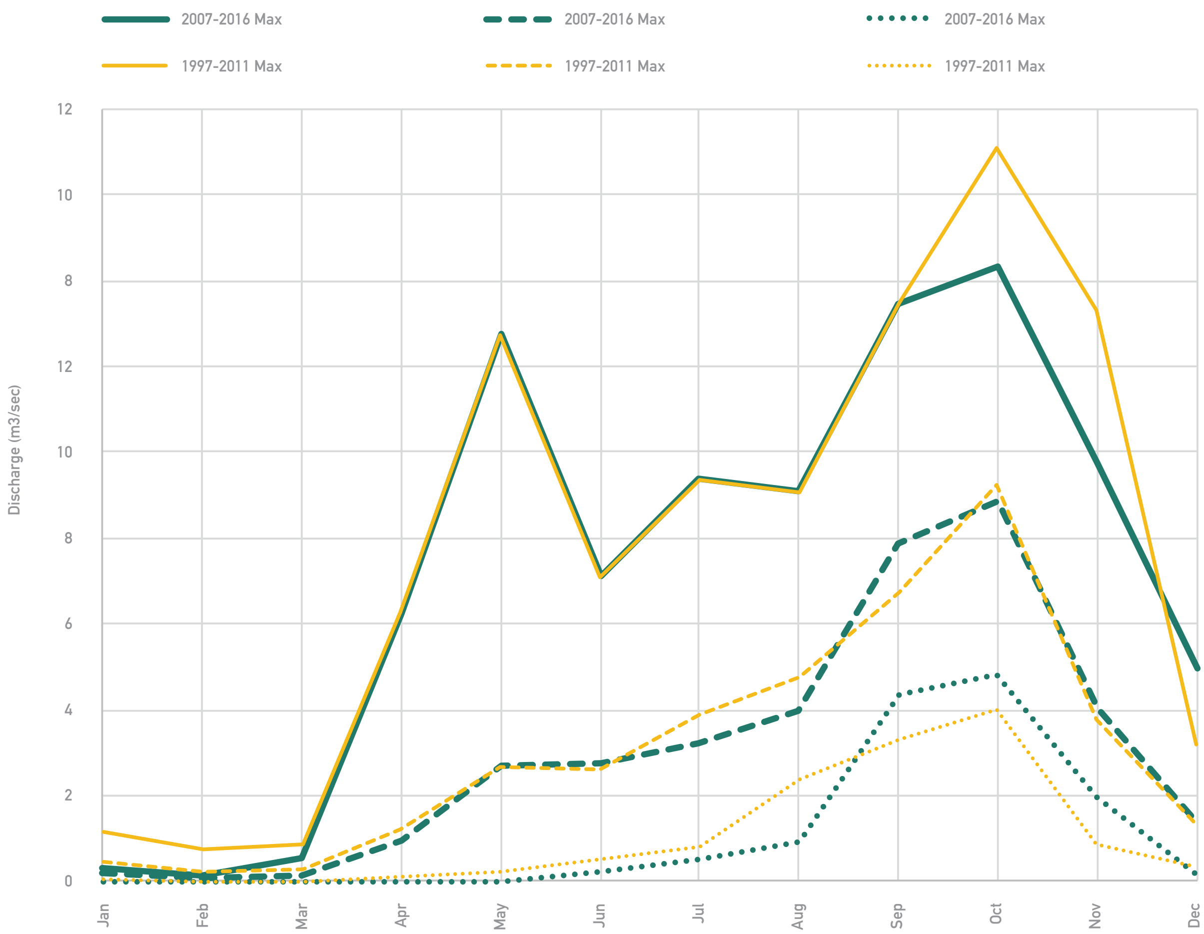
9 Data processing for ERA5 is carried out by the European Centre for Medium-Range Weather Forecasts (ECMWF), using ECMWFS' Earth System model IFS, cycle 41r2. The name ERA refers to 'ECMWF ReAnalysis', with ERA5 being the fifth major global reanalysis produced by ECMWF.

TABLE 2.1: WATER AVAILABILITY AT BAC TRAKUON STATION

	Water availability 1997-2001 (million m3)			Discharge 1997-2001 (m3/s)			Average discharge (m3/s)									
	Max	Average	Min	Max	Average	Min	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Jan	76.1	29.2	4.4	28.4	10.9	1.7	5.2	2.7	5.2	6.3	7.6	6.5	3.4	6.8	0.1	0.5
Feb	45.9	13.9	1.2	19	5.8	0.5	2.2	0.5	2.1	2.7	1.9	3.6	0.1	0.5	0	1
Mar	59.7	20.7	1.3	22.3	7.7	0.5	2.9	13	2.5	3.4	6	5.6	0.4	0	0	0.1
Apr	405	78.9	7.1	156.3	30.4	2.3	6.1	156.1	51.1	4.2	11.6	8.9	2.7	3.8	0	0.1
May	853	180	13.4	318.5	67.2	5	144.7	318.4	101.2	10.1	41.5	16	13.2	24.2	0	3.5
Jun	461	170	32.4	177.9	65.6	12.5	165.6	177.9	83.7	26.3	62.5	32.1	79.5	34.6	25.4	5.2
Jul	627	262	54.9	234.1	97.8	20.5	234.1	100.5	94	63.4	44.5	41	129.6	47.7	12.4	40.9
Aug	607	317	160	226.7	118.4	59.8	118	226.7	70.9	125.1	131	54.9	134	76.6	23	34.4
Sep	873	435	216	336.8	167.8	83.3	299.5	336.7	153.5	249.6	172.3	226.8	176	121.8	122.4	108.5
Oct	1146	617	270	427.9	230.4	100.8	156.7	120.2	193.1	358.7	281.6	242	286.8	178	151.1	250.3
Nov	864	246	55.3	333.3	94.9	21.3	84	133.9	102.5	66.3	49.5	95.7	243.1	57	70.1	110.1
Dec	212	89.7	23.5	79.2	33.5	8.8	11.1	64.7	32.9	23.3	13.9	24.2	29.7	14.6	3.5	124.2

Source: MOWRAM

FIGURE 2.3: COMPARING MONTHLY DISCHARGE STATISTICS FOR TWO TIME PERIODS



Source: MOWRAM

Other Input Data

Additional datasets used in this analysis include a 30m resolution digital terrain model (SRTM), 30 arc-second resolution soil layer (Harmonized World Soil Database v 1.2) and humidity, wind speed and solar radiation for the period 1979-2014 (National Centre for Environmental Prediction Climate Forecast System Reanalysis).

2.4 Dam characteristics

Construction of Dams 3 and 5 has been completed and in this analysis they are assumed to be operational. These two dams are focused on strengthening irrigation water supply. It is understood that permission has been granted for the construction of the third (Dam 1) that will include the generation of hydro-energy as one of its objectives. All three of these dams are upstream of the irrigation infrastructure outlined in the next section. Information on the characteristics of these dams (Table 2.2) were obtained from MoWRAM (2013) and Ministry of Mines and Energy (MME) (pers. comm.). Dam operation rules are currently unavailable and so simplifying assumptions were used in order to simulate the functioning and outflow from these dams.

TABLE 2.2: DAM CHARACTERISTICS

	Dam 1	Dam 3	Dam 5
Storage volume (million m³)	1385.6	25.5	24.5
Capacity (MW)	80		
Rated gross head (m)	113		
Dead storage (million m³)	228		
Normal storage level (masl)	180		
Low supply level (masl)	160		
Reservoir area at normal storage levels (NSL) (km2)	85.91		

2.5 Area Under Irrigation

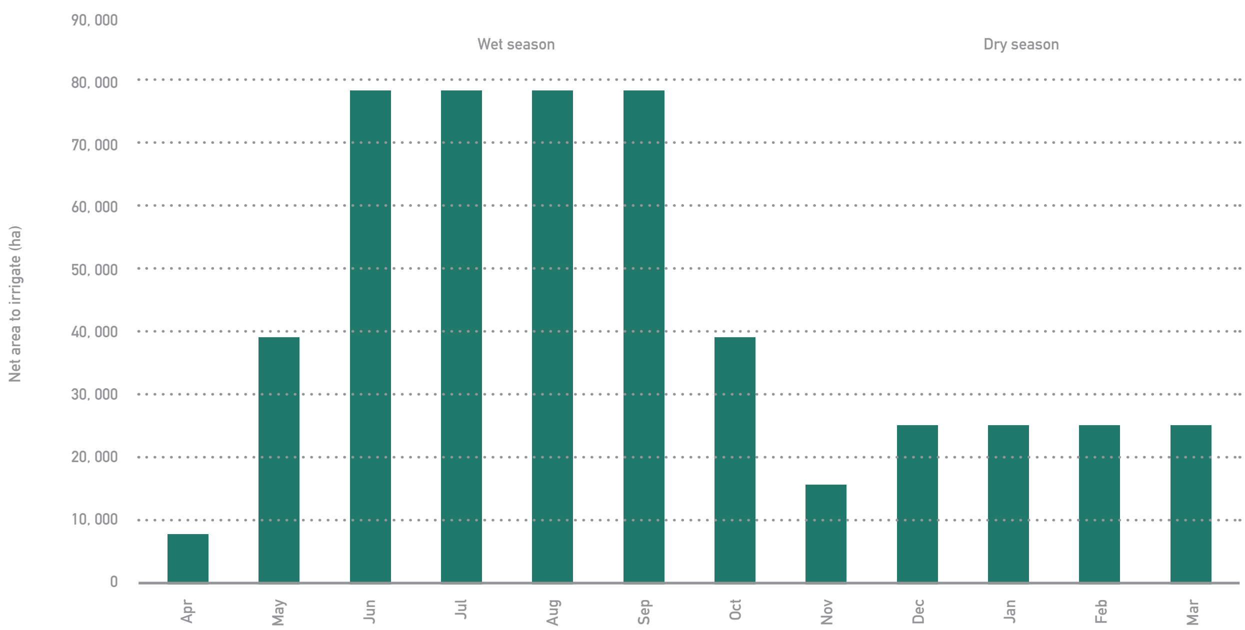
Target irrigated areas for wet and dry season paddy cultivation using water from Pursat River were obtained from a MoWRAM report (pers. comm.). These are shown in Table 2.3.

TABLE 2.3: TARGET IRRIGATED AREAS IN THE PURSAT RIVER BASIN

Project Name	Wet season (ha)	Dry season (ha)
Damnak Chheur Kram	16,100	16,100
Damnak Ampil	27,000	3,500
Charek	11,000	3,500
Chheur Touk (Santre)	1,142	50
Kampeng reservoir	380	100
Baktra	102	
Our Roka Reservoir	4,700	1,000
Lor Lork Sor	1,167	
Ang Andoung Wat Luong	2,410	
Khnorng Porpol reservoir	1,315	
Prey Nhi Reservoir	1,519	10
Preah Chambok	145	50
Koh Svay	350	160
Our Tatong	956	300
Roneam Chhlech reservoir	713	
Kbal Hong	7,270	
Kandieng station	120	
Phum Stueng	222	
Ou Sanlung	120	
Thlork	1,000	410
Tuol Kour reservoir	722	171
Total area	**78,453**	**25,351**

June to September are the core months for wet season paddy production in the Pursat Basin and December to March are the core months for dry season production (MoWRAM, 2013). Wet season production can use either direct sowing or transplanting techniques, and the growing season ranges from 105 to 145 days. Dry season cropping is reported to cover 90 days. The exact irrigation area for each cropping pattern is not available, so the maximum demand over a year is estimated by assuming that the total area in Table 2.3 is under a paddy crop for at least the core months of each season. In the wet season, 50 percent of the area is assumed to still be under cultivation in the other months (given the wider range of cropping days in the wet season), while in other months of the dry season, only 20 percent of the areas is assumed to be cultivated. As April does not fall in either cropping season, only 10 percent of the wet season cropping area is assumed to be cultivated. Figure 2.4 tabulates the area derived for each month.

FIGURE 2.4: ESTIMATED MAXIMUM AREA UNDER CULTIVATION IN THE PURSAT RIVER BASIN



2.6 Modeling Approach

The objective of the modeling in the hydrological analysis is to derive seasonal estimates of changes in water availability, irrigation demand and sediment flows from different parts of the river basin. These variables will form the basis of the economic analysis in the next chapter. To achieve these goals, the modeling can be broken down into four sub-components as follows:

1. Hydrological Response: A hydrological model capable of estimating the spatial and temporal response of water and sediment yield from different sub-basins of the Pursat River Basin was developed.
2. Monthly dam operations: Outputs of water yield from the hydrological model were used to drive a monthly dam operations model for the three dams, to provide estimates of water availability at the Bac Trakuon Station.
3. Irrigation water demand: Outputs of potential evapotranspiration and precipitation over agricultural lands (from the hydrological model) were used with FAO's irrigation water demand assessment method to estimate monthly water demand for paddy in the projected command area.

4. Soil erosion: Sediment yield estimates from the hydrological model were used to derive average soil erosion rates from different land cover types to lead to an estimate of sediment accumulation rates in the proposed Dam 1 reservoir under current conditions and a “no forest” counterfactual.

The sections below describe each step in more detail and provide references where applicable.

Hydrological Response Modeling

SWAT model

The Soil and Water Assessment Tool (SWAT) is a semi-distributed, continuous-time, process-based model (Neitsch et al. 2011). SWAT’s hydrological module allows explicit calculation of different water balance components and subsequently water resources at a sub-basin level (Abbaspour et al. 2015). SWAT divides watersheds into multiple sub-basins, which are then further subdivided into hydrologic response units (HRUs). These HRUs form the basic unit of assessment in SWAT and consist of unique land use, topographical and soil characteristics.

Watershed hydrology is simulated in two phases. The land phase controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin; and the routing phase controls the movement of water, sediments, etc., through the streams of the sub-basins to the outlets.

SWAT simulation for water yield from sub-basins and HRUs involves using the Soil Conservation Service (SCS) curve number method and the Green-Ampt infiltration method to simulate runoff. Peak runoff rate is estimated using a modification of the Rational Method, while groundwater flow contribution to total river flow is simulated by creating shallow aquifer storage (Arnold et al. 1993). Erosion and sediment yield are simulated for each HRU using the modified universal soil loss equation (MUSLE).

For the Pursat Basin, the SWAT model was set up using the hydrological datasets described above and with the QSWAT interface. The data from the first 3 years (January 2004 – December 2006) was used to spin up the hydrological model. Simulation outputs can be extracted at daily or monthly time-steps over the period January 2007 to July 2014. Spatially, the basin was divided into 125 sub-basins. The MoE 2016 land cover was mapped on SWAT land cover codes (classed under 10 different categories; Appendix 1) and with slope and soil type was the main basis of deriving HRUs. The SWAT model for Pursat had 1656 HRUs in total.

Model calibration and validation

The model was calibrated and validated based on daily and monthly discharge at the Bac Trakuon Station. The calibration used discharge data from January 2007 to December 2011 and was carried out using the sequential uncertainty fitting algorithm (SUFI-2) in SWAT-CUP (SWAT Calibration & Uncertainty Programs) (Abbaspour 2012). Fourteen parameters linked to discharge, which were shown to be sensitive for the basin (Oeurng et al. 2019), were selected for the calibration. The initial ranges of values for each parameter were set from the likely maximum range suggested in SWAT. Validation was carried out using discharge from the period January 2012 to July 2014.

Abbaspour et al. (2012) describe the application of the SUFI-2 algorithm to SWAT models as a method to map all uncertainties (parameter, conceptual model, input, etc.) on the parameters (expressed as uniform distributions or ranges) and capture most of the measured data within the 95 percent prediction uncertainty (95PPU) of the model through an iterative process. The 95PPU is calculated at the 2.5 percent and 97.5 percent levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. For the goodness of fit, two indices referred to as “P-factor” and “R-factor” (Abbaspour et al. 2012) are used. The P-factor varies from 0 to 1; and is defined as the fraction of measured data (and its error) bracketed by the 95PPU band. A P-factor value of 1 indicates 100 percent of the measured data within model prediction uncertainty i.e., a perfect model simulation considering the uncertainty. For discharge, the recommended value for P-factor is >0.7. The R-factor on the other hand is the ratio of the average width of the 95PPU band and the standard deviation of the measured variable. Abbaspour et al. (2012) reports a value of <1.5 as a desirable value for this index. Nash-Sutcliffe model efficiency coefficient (NSE) was an additional objective function used to assess the predictive power of the hydrological model.[10]

Under the calibration process, the following general approach was used:

1. Set up a SWAT-CUP run for the selected parameters and initial range. 200-300 iterations are performed in each batch, with parameter values extracted from the provided range through Latin hypercube sampling. As a post-processing step, 95PPU and objective function values are calculated.
2. Using the previous batch of iterations, the parameter ranges are updated based on new ranges suggested by the program. Once the new ranges have been reviewed, a new batch of iterations can be executed.
3. The above step is repeated until satisfactory results in terms of the P-factor and R-factor are reached or no significant improvements are seen in the NSE. This takes generally 3-4 batches of iterations. The set of parameters, which gives the best objective function fit, are used as the parameters for the calibrated model.

Hypothetical counterfactual

Valuing forests requires comparing current conditions to hypothetical counterfactual without forests. This is not intended as a realistic scenario, but solely as a counterfactual against which to measure the total value of forest benefits. This "no forest" counterfactual was created in the SWAT model by replacing all forest related land cover codes with a barren (bare earth) land cover. No other changes were made to parameters selected from the calibration and validation exercise, as described in the previous sub-section.

Monthly Dam Operations

A simple model of dam operation is used, which assumes targeting a stable monthly outflow, if reservoir conditions and inflow allow it.[11] Monthly inflows into the 3 dams' sites was extracted from the SWAT model and processed using the equations below in MS Excel/VBA script to estimate outflow from the 3 dams. The monthly dam operations model is adapted from the equations proposed by Yassin et al. (2019). Dam outflow for any month $i (S^i_{r,actual})$ is estimated from the capacity of the dam (V_c), its dead storage capacity (V_D) and the design discharge per month (S^i_r) using the following equations:

If $S^i_r > S^i_n$:

$$\Delta_{out} = \min(S^i_r - S^i_n, V^i_r - V_D)$$

$$V^{i+1}_r = V^i_r - \Delta_{out}$$

$$S^i_{r,actual} = S^i_n + \Delta_{out}$$

Else if $S^i_r < S^i_n$:

$$V^{i+1}_r = \min(V^i_r + S^i_n - S^i_r, V_c)$$

$$Spill = \max(0, V^i_r + S^i_n - V_c)$$

$$\Delta_{in} = V^{i+1}_r - V^i_r$$

where, S^i_n is the inflow (in m^3/month); V^i_r is the actual volume at start of the month (initial condition = V_C) and V^{i+1}_r is the volume at end of month.

This simple dam operations model was applied instead of SWAT's reservoir and dam modeling options because these options require more parameters to sufficiently describe the dam operating rules and reasonable estimates of these parameters were not available, especially for Dams 3 and 5. In the monthly dam operations model, V_C and V_D were extracted from

10 DNash–Sutcliffe efficiency can range from −∞ to 1. NSE = 1 corresponds to a perfect match of modeled discharge to the observed data, while NSE = 0 indicates that the model predictions are as accurate as the mean of the observed data. Positive values of NSE indicate a better model simulation while negative values of NSE indicate that the observed mean is a better predictor than the model being used. Most hydrological models are considered to have a 'good' fit if NSE is between 0.5 to 0.65.

11 More sophisticated models might seek to maximize outflows during the dry season, or to weigh the possibly competing demands of HEP and irrigation, as well as flood prevention. Additionally, since the model used runs as a post-processing step to the hydrological model results, it can easily be replaced by alternative models.

Table 2.2 (V_D was set to zero when not available). Design discharge per month (S_r^i) was set at a constant discharge throughout the year. For Dam 1, this value is based on MME specification of annual average discharge for the dam (42.3 m³/s). For Dams 3 and 5, this was set at the average annual discharge at the dam site as obtained from the SWAT model (1 and 21 m³/s respectively).

Estimating Irrigation Water Demand

The methodology proposed by FAO (Brouwer and Heibloem 1986) was used to estimate water demand for irrigation. This methodology calculates irrigation water requirements as the difference between crop-specific water needs and the portion that can be meet by rainfall, taking into account losses to evapotranspiration, deep seepage, evaporation, percolation, etc. The steps for calculating water demand for irrigation are:

Step 1. Estimate potential evapotranspiration (ETO): Average monthly estimates for agricultural lands were extracted from the SWAT model.

Step 2. Estimate average crop evapotranspiration coefficients (Kc) based on known cropping pattern and cropping stage: Coefficients for paddy were derived from Chapter 6 of Brouwer and Heibloem (1986) and adjusted to cropping pattern.

Step 3. Calculate for each month the effective rainfall using the formulae:

Pe = 0.8*P - 25 if P > 75 mm/month

Pe = 0.6*P - 10 if P < 75 mm/month

Average monthly estimates of actual precipitation (P) over the cropping area were extracted from the SWAT model.

Step 4. Calculate the irrigation water need: IN = ETO* Kc – Pe + PERC + WL + SAT

Where, PERC is the percolation and seepage losses depending on the type of soil; here estimated as 6mm/day on average.

WL is water needed to establish a water layer during transplanting or sowing and maintained throughout the growing season. Value used here is 100 mm for months of June and December.

SAT is water needed to saturate the root zone a month before sowing or transplanting. Direct rainfall is assumed here as the source of this and SAT is set as 0 mm.

Once demand per hectare has been established using the method above, the estimates of area under cultivation per month was used to estimate total irrigation water demand.

Estimating Soil Erosion Rates

The SWAT model generates a sediment yield estimate for each HRU based on its application of the MUSLE equation. As a post-processing step, HRUs in sub-basins above Dam 1 were sorted based on land cover and average sediment yield rates per month for each land cover type extracted. These values were further averaged over time to produce average annual sediment yield rates per land cover type (in tons per hectare per year).

2.7 Hydrological Modeling Results

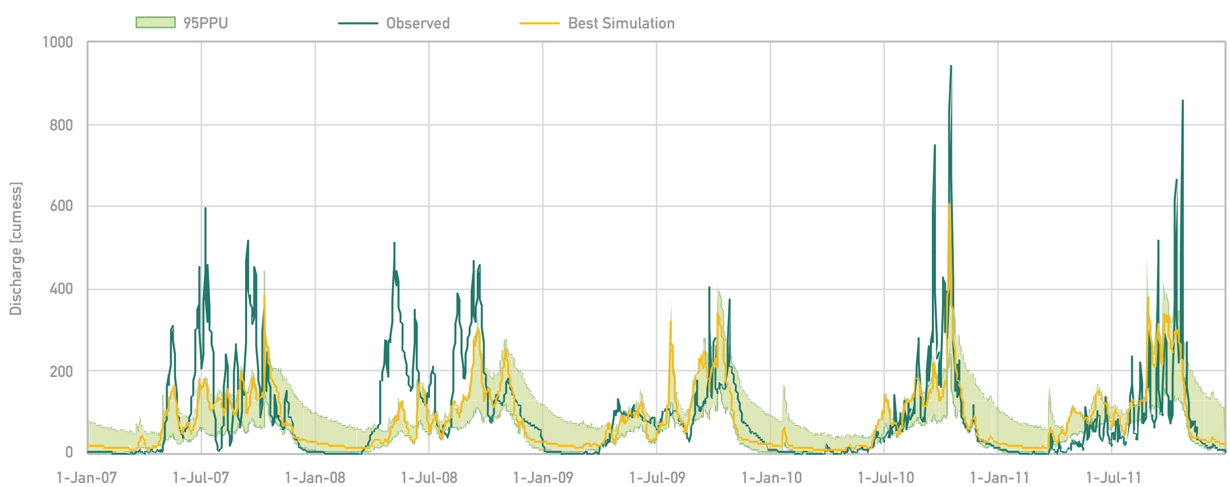
Performance of the Hydrological Simulations

The model was calibrated over January 2007 to December 2011 and validated over January 2012 to July 2014 period. The 14 parameters that the model used for the calibration-validation of the model are documented in Appendix 2. Batches of iteration with daily discharge as the calibration variable wer carried out using SUFI-2 in SWAT-CUP until NSE value stopped showing significant improvement (NSE=0.45). The R-factor obtained for this final batch of iterations (=0.73) is satisfactory, however, the P-factor (=0.5) is less than desirable when using discharge as the calibration parameter. A closer look at the discharge plot in Figure 2.5 shows that while low and mean flows generally fall within the 95PPU band, the observed peak discharges (especially for the period before 2009) fall outside. The explanation for this behavior appears to be beyond model parameter uncertainty and to be linked to one of the key underlying datasets. The comparison between gauge precipitation data and ERA5 global dataset (outlined above) notes the bias in maximum precipitation rate in the global dataset when compared to local gauge data. This was a trade-off to achieve improved spatial coverage by using the global dataset. The global dataset was found suitable in capturing average flows as seen in the model performance for monthly flows (NSE > 0.5;Figure 2.5).

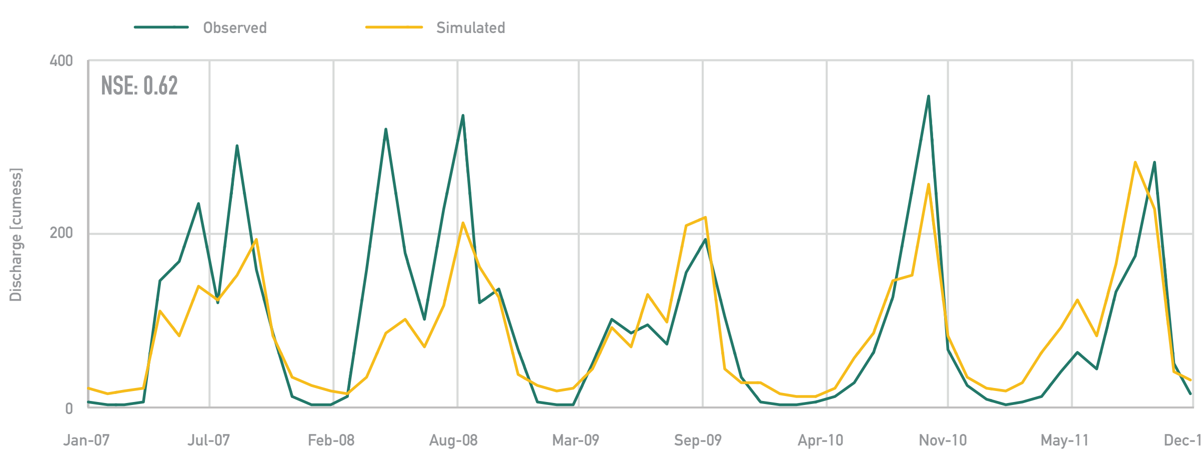
Figure 2.6 summarizes the model fit at both daily and monthly timescales. The satisfactory fit for monthly flows suggests that the current SWAT model is suitable to carry out the water allocation studies for irrigation and hydropower supply. The model might underestimate sediment yield as soil erosion rates are a function of rainfall intensity, but without monitored datasets to ground-truth the results, this will remain an area of high uncertainty. For using the model for flood magnitude or design related studies, it would be advisable to explore further improvement in the precipitation datasets. This could be achieved through obtaining additional gauge data (if available) or use of statistical methods to merge local gauge data with remotely sensed precipitation products (Xie et al. 2011; Verdin et al. 2015), which was beyond the scope of this project.

FIGURE 2.5: DATA FOR VALIDATION OF HYDROLOGICAL MODEL

(A) DAILY DISCHARGE WITH 95PPU PLOT FOR CALIBRATION

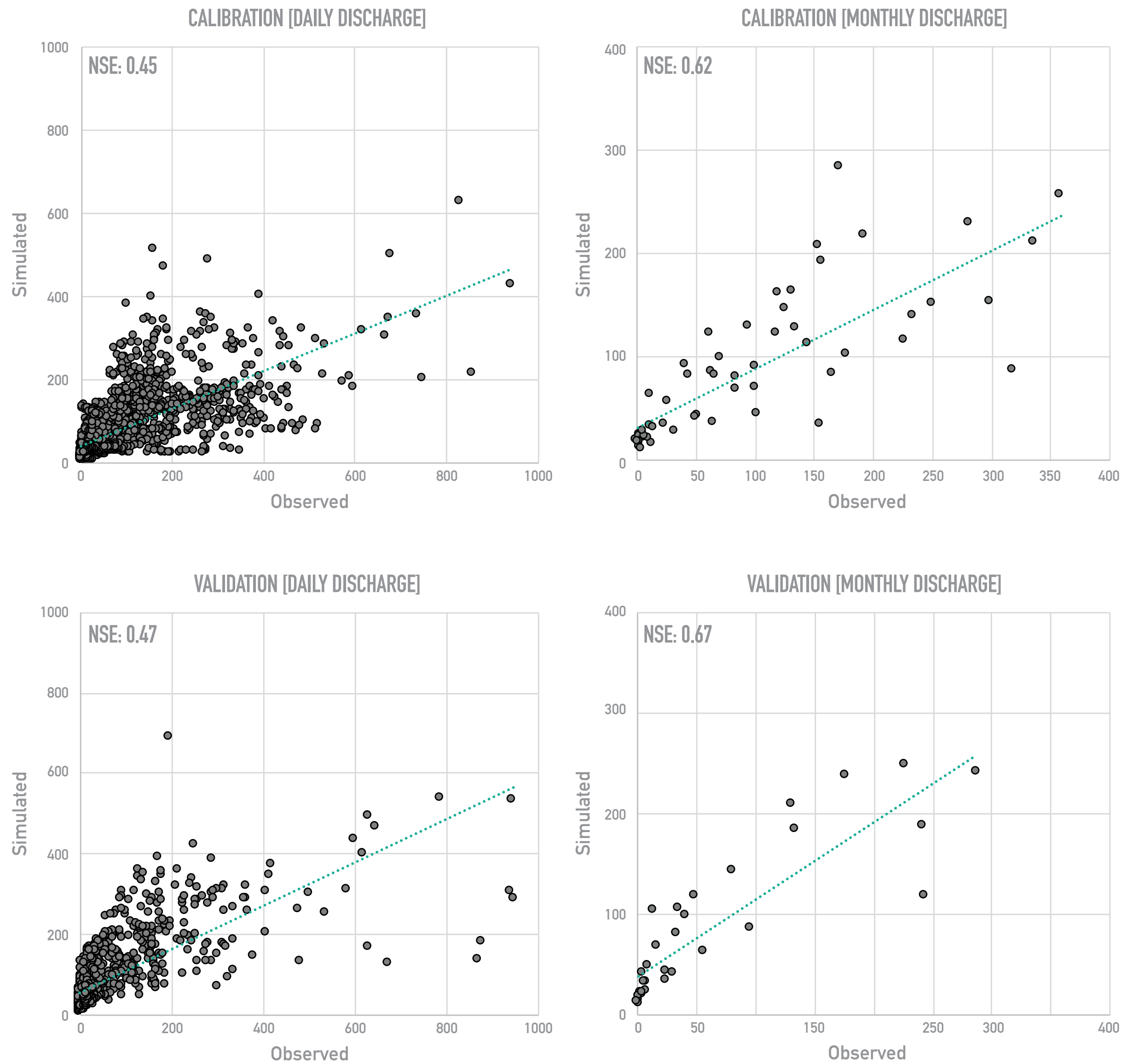


(B) MONTHLY DISCHARGE DATA OVER CALIBRATION PERIOD



Source: Authors' calculations

FIGURE 2.6: RESULTS FROM DAILY AND MONTHLY CALIBRATION AND VALIDATION

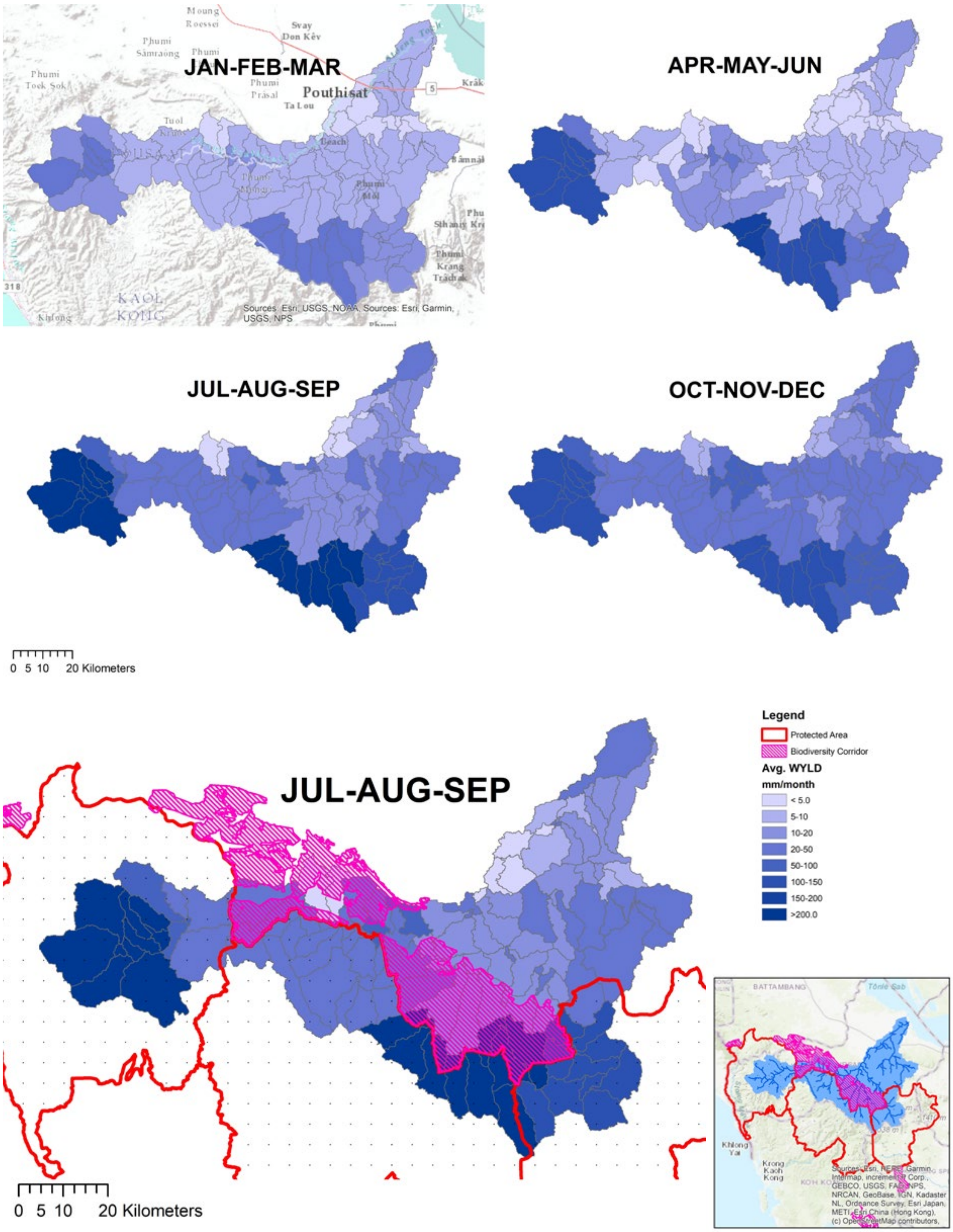


Source: Authors' calculations

Water Yield from Watershed

Water yield was analyzed for the period 2007 to 2014 using the SWAT model. The projected water yield at a sub-basin level (Figure 2.7) indicates a clear correlation of important source areas with elevation. Regions of the watershed that fall within the Cardamom Mountain PAs can have a water yield ranging from 2-4 times the downstream regions, depending on the seasonal pattern. For 3 of the 4 quarters in a year, the upstream source areas had a water yield exceeding 100 mm/month on average. These upstream source areas, therefore, are clearly important for securing good quality year-round supply of water. Land cover change that could disrupt the quality and timing of flows will have a direct impact on use downstream.

FIGURE 2.7: AVERAGE WATER YIELD DISTRIBUTION OVER SUB-BASINS AND QUARTERS OVER A YEAR

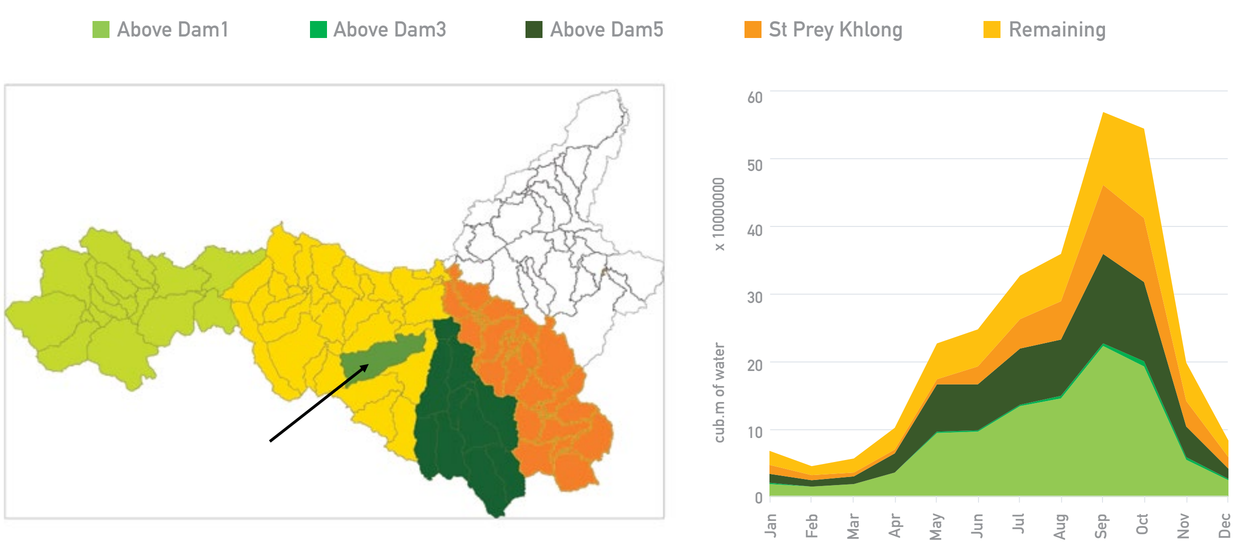


Source: Authors' creation

Based on the modeling results, elevation appears to be the primary driver of water yield in this basin (i.e., more precipitation at higher elevations), with land cover having a secondary but still discernible influence. As an example, water yield for the driest month in the simulation (January 2014) showed that water yield in land parcels converted from forests to agricultural land in the source region (within Sam Kos Wildlife Sanctuary) was about 4-8 percent lower than the surrounding forested regions, but these yields were still higher than the downstream (lower elevation) sections of the basin. This drop in yield is likely linked to the model's estimate of land cover's role in groundwater recharge. In dry months, groundwater stores provide the bulk of the water yield in the model dynamics. While land covers with a healthy soil layer are generally known to facilitate higher infiltration rates, this is not necessarily the same as high groundwater recharge rates (Portela et al. 2019: Filoso et al. 2017). In some cases, higher infiltration rates do lead to higher storage in the groundwater layer, thus allowing greater water yield in drier months. This appears to be the case indicated by the model, although confirmation through ground observations would build confidence in this outcome.

Another approach for analyzing water yield is comparing the cumulative yield for sites of interest in the basin. Figure 2.8 breaks down the portion of the Pursat River Basin upstream of Bac Trakuon Station into 5 sub-basins. These are: The sub-basin for Dams 1, 3 and 5 (marked on figure as a, c, and d, respectively), the sub-basin for one of the main tributaries, Stung Prey Khlong (marked as sub-basin e) and the remaining portion of the basin between the dams and the gauging station (marked as sub-basin b). Stung Prey Khlong is the largest tributary of the Pursat with no known major infrastructure works on its main stem. From the water yield results of the model, it is seen that the sub-basin for Dam 1 has the largest contribution to the flows at the gauging station, followed by the sub-basin for Dam 5. The conclusion that can be drawn from this is that besides the regulating effect of the natural infrastructure on the water flow, the set-up and operating rules of these two dams can potentially have a large impact on water availability downstream.

FIGURE 2.8: WATER YIELD DISTRIBUTION BY SUB-BASINS LINKED TO THE DAMS AND TRIBUTARY ST PREY KHLONG

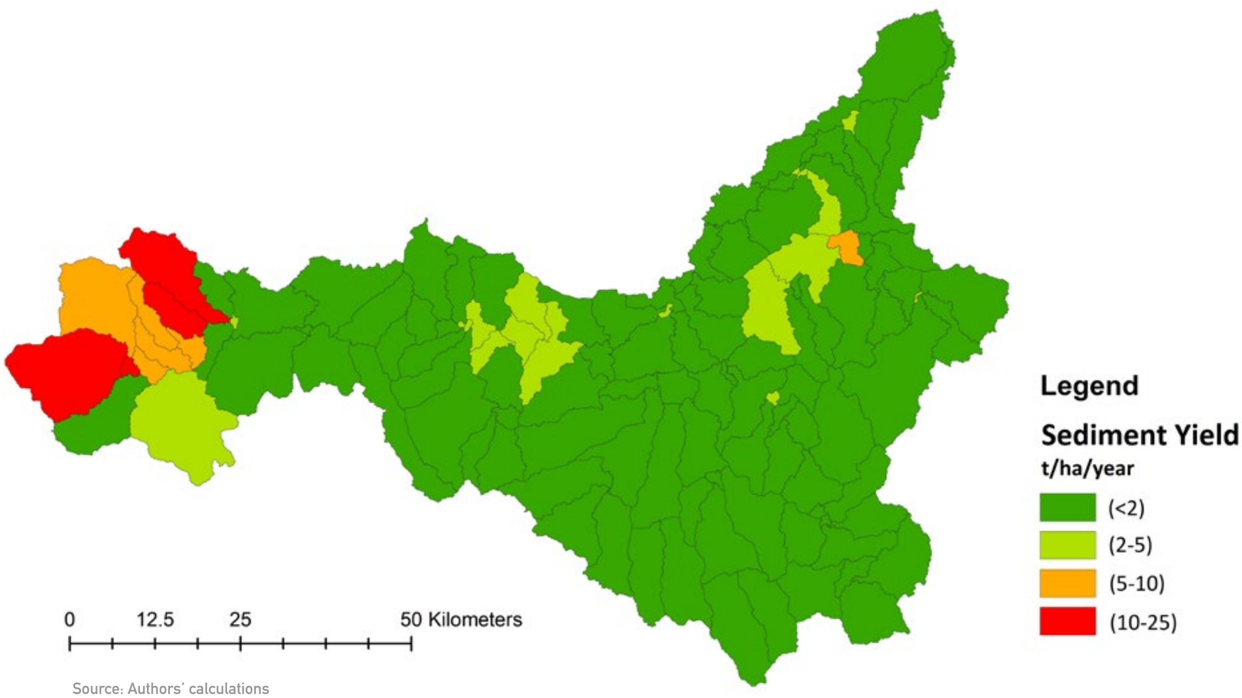


Source: Authors' calculations

Sediment Yield and Erosion Rate

The annual average sediment yield estimate from the model, showed that the majority of the basin still has low rates of erosion (<5 t/ha/year). As the precipitation dataset likely underestimates rainfall intensity, this is likely an underestimate or lower bound of actual erosion. However, the influence of land cover change in the upper-western region of the basin is clearly identifiable with these results (Figure 2.9). The model estimates that sediment yield may change from the range of 0.3 t/ha/year for forested lands to 20t/ha/year for other vegetated land covers like agricultural land use above the three dams. The loss of protective cover over regions with high rainfall intensity, creating these high sediment yield situations, will likely have numerous negative impacts downstream. Increased sedimentation rates for the downstream reservoir is the most tangible of these. Others could include sedimentation of irrigation channels leading to drop in conveying capacity of irrigation water and higher propensity to flood, drop in water quality impacting household and industrial usage as well as fisheries, for which these streams are important breeding grounds.

FIGURE 2.9: AVERAGE ANNUAL SEDIMENT YIELD FOR SWAT SUB-BASINS



Source: Authors' calculations

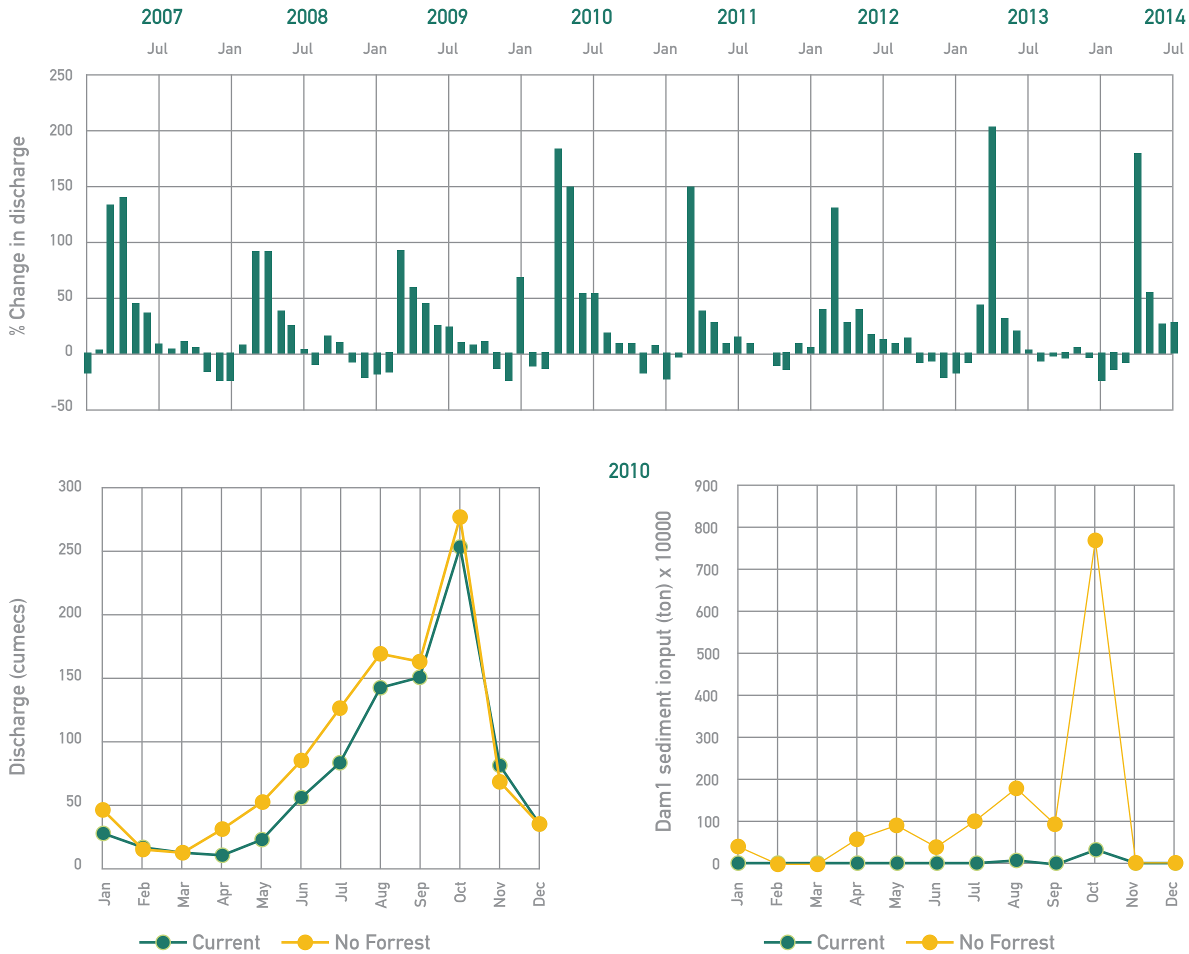
Role of Forests in Hydrological Flows

The change in seasonal pattern of flows between current conditions and no forest counterfactual can be seen in panels a and b of Figure 2.10. The increase in discharge during the earlier months of the wet season indicates a higher propensity to generate surface runoff from the cleared land. The rise of the hydrograph is sharper and the fall is steeper, in line with increased surface flow. The drop in dry season flows is relatively moderate, extending up to 25 percent lower flows when comparing current and no-forest simulations. The spatial pattern (Figure 2.11) for yield change in a dry month is similar.

As expected, sediment yield rates would see a marked change. The annual average sediment yield over the parcels where land cover type was changed would go from 0.3 t/ha/year for current conditions to 175 t/ha/year under the no-forest counterfactual, resulting in high sediment inflows into the reservoir for Dam 1 (seen in section c of Figure 2.10). On average, the model estimates that the sediment accumulation rate in the dam's reservoir could increase by 30-fold.

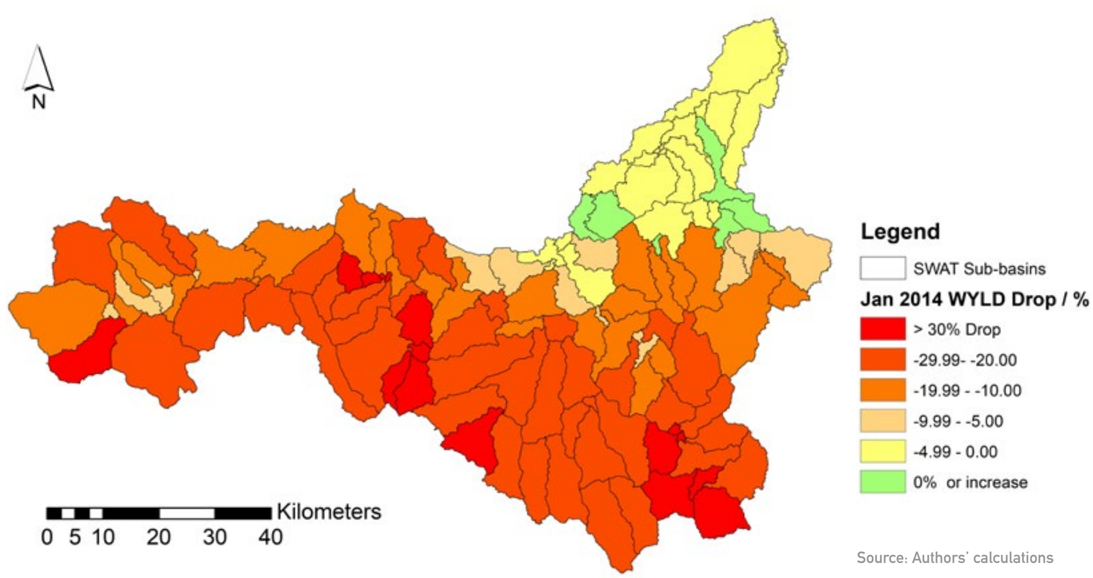
FIGURE 2.10: COMPARISON OF CURRENT HYDROLOGICAL FLOWS TO THOSE OF NO-FOREST COUNTERFACTUAL

(A): PERCENTAGE CHANGE IN DISCHARGE AT BAC TRAKUON STATION. COMPARISON BETWEEN (A) MONTHLY DISCHARGE HYDROGRAPH FOR BAC TRAKUON STATION AND (C) MONTHLY SEDIMENT INPUT FOR DAM 1



Source: Authors' calculations

FIGURE 2.11: SPATIAL CHANGES IN WATER YIELD UNDER THE NO-FOREST COUNTERFACTUAL COMPARED TO CURRENT CONDITIONS



Source: Authors' calculations

Water Availability and Demand

Monthly dam operations

With 62 percent of the water yield originating in sub-basins upstream of them, dam operations and storage can significantly alter the water availability downstream. As indicated in Section 3.2, current information about the dams is incomplete and hence a simple monthly dam operations model is applied.

Dam 3 only controls a small portion of total flow. It appears to have just enough storage to satisfy irrigation demand in its local vicinity during dry months but is not large enough to have a major impact downstream. Dam 5, on the other hand, receives significant flows, but its storage capacity is too small to significantly alter the flow. Consequently, inflows and outflows from dam 5 are nearly identical (Figure 2.12). Dam 1 appears to have both the storage capacity and the inflows to have a significant impact on water availability downstream. The water availability at Bac Trakuon Station will be sensitive to the operations rules set for this dam, so improving the representation of this dam in the model should be a priority for future iterations of this work. Under current operations, the discharge only managed to match the specified monthly target of 42.3 m3/s about half of the time.

FIGURE 2.12: COMPARISON OF INFLOWS AND OUTFLOWS FROM EACH DAM OPERATIONS UNDER CURRENT CONDITIONS AND UNDER THE NO-FOREST COUNTERFACTUAL

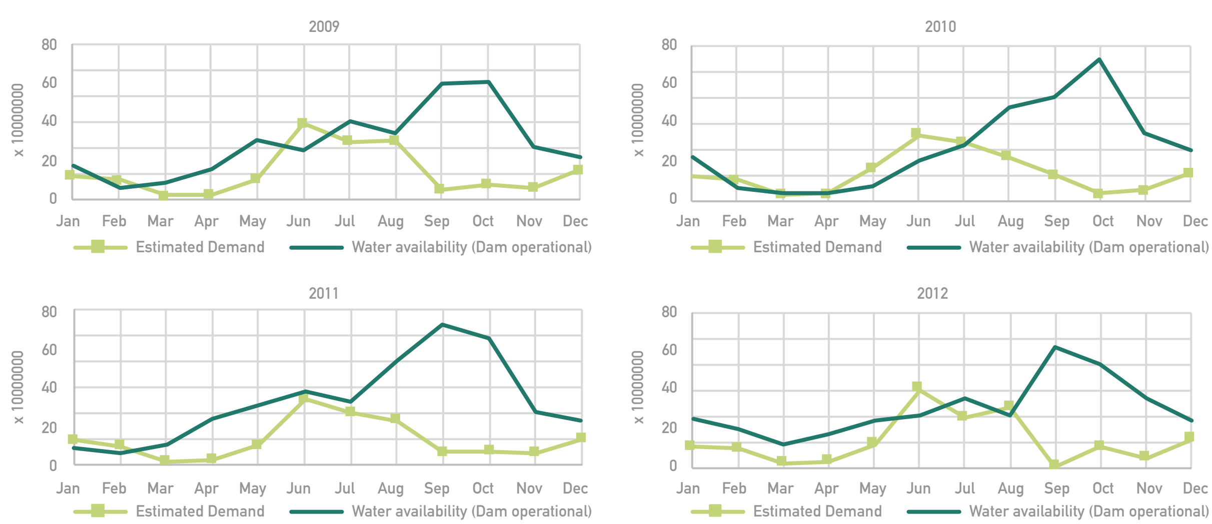
Source: Authors' calculations

FIGURE 2.13: EFFECT OF DAM OPERATION ON PROJECTED WATER AVAILABILITY, SELECTED YEARS

Source: Authors' calculations

Outflow from Dams 1, 3 and 5 is aggregated with the water yield from sub-basins below the dam and before Bac Trakuon gauging station in order to estimate total water availability at that gauging station. This requires the simplifying assumption that monthly water yield in these sub-basins is equal to monthly discharge and we therefore do not consider effects of stream routing. But given the monthly timescale and relatively short stream distance, the introduced error is generally low. In test conditions, this error was 1.01 percent on average (see Appendix 3). Ideally, use of more complete dam data will allow dam operation simulation to be included within the hydrological model and remove the need for this simplifying assumption. Figure 2.13 shows how water availability at the gauging station changes due to dam operations.

FIGURE 2.14: COMPARISON OF ESTIMATED WATER DEMAND AND ESTIMATES OF WATER AVAILABLE AT BAC TRAKUON STATION, SELECTED YEARS



Source: Authors' calculations

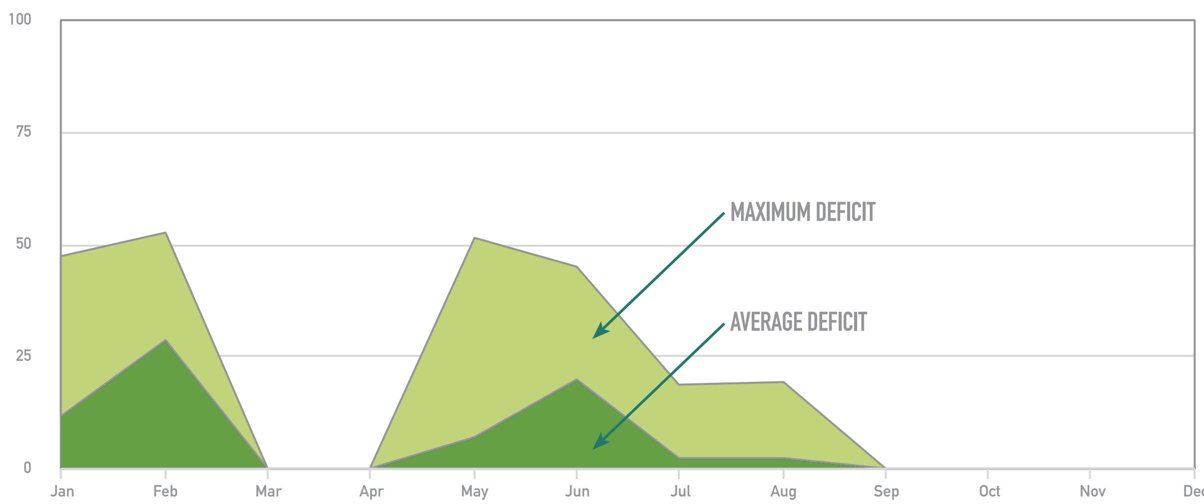
Estimating irrigation water demand

Over the simulation period, a spatially-averaged time series of precipitation and evapotranspiration values over cultivated lands is extracted from the hydrological model as an input to estimate irrigation requirement. This season-specific water requirement estimate varies significantly from month to month and year to year, ranging from 5.8 mm/month/ha to 453 mm/month/ha, with an average irrigation requirement of 273.4 mm/month/ha. A time series of total demand for irrigation water per month was estimate by combining the monthly per hectare requirement with the estimate of area under cultivation derived above. Figure 2.14 below compares the estimated water demand with the estimates of water available at Bac Trakuon Station.

Irrigation demand deficit

The results of estimated water availability and irrigation demand form the inputs for the economic analysis, which will continue in the next chapter. Over the 7-year simulation period, demand exceeded supply multiple times, most often in February and June (5 instances over the 7-year simulation) and sometimes in January (twice over the 7-year simulation), May, July and August (once each). The average and maximum magnitude of deficit is plotted in Figure 2.15. Matching the frequency, February and June have the highest average deficit, while January has the maximum-recorded deficit when normalized by area under irrigation.

FIGURE 2.15: ESTIMATED IRRIGATION WATER DEMAND DEFICIT UNDER CURRENT CONDITIONS



Source: Authors' calculations

2.8 Limitations of the Analysis

The main limitation and caveats in the modeling approach used for this study, either from the data perspective or from under-lying assumption in model setup, have been explored largely alongside the results in Section 2.7. In summary, the key limitations and caveats linked to the hydrological analysis are:

1. Model fit: The total period of data for which the model could be calibrated and validated was short (Jan 2007- July 2014) and the daily model fit, even though comparable to a published model for the same region, was below the range accepted as a "good" fit. Improvement in precipitation data is likely key to improve these model results;
2. Lack of sediment yield data: Absence of any monitored sediment data – either at the plot scale or at downstream gauging stations or local soil maps, leads to sediment yield results that could not be compared to real measurements. Although the estimates are close to the values used by

Ministry of Mines and Energy (MME) in planning the hydropower dam – other studies in the region have shown a large variation in this estimate;

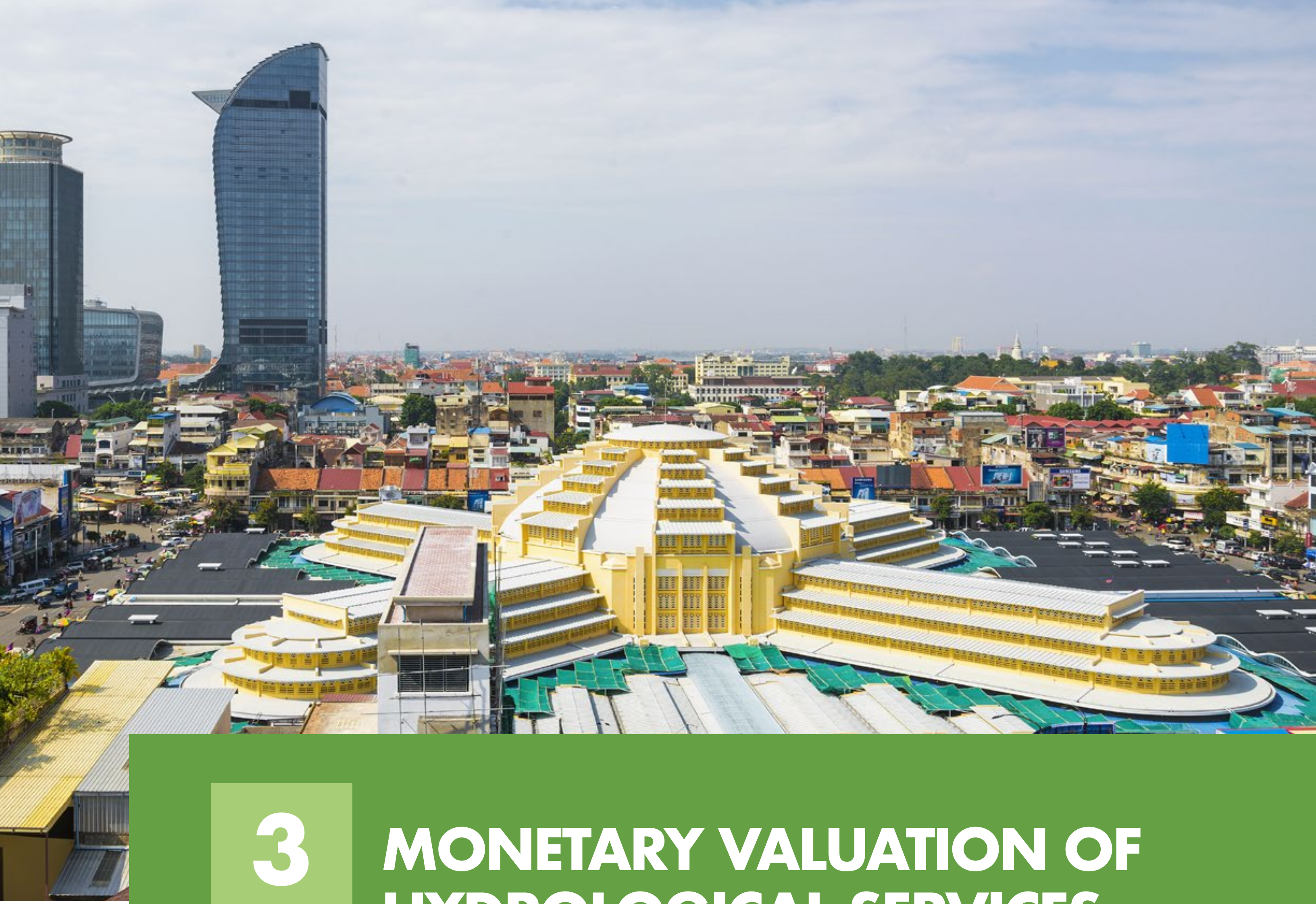
3. Caveat on characterization of dam operation: Partially because the main dam (Dam 1) has not been constructed yet and limited data available on its design, dam operations rules were not available to incorporate in the models. Consequently, dams were represented by simplified operation rules and added as a post-processing step to facilitate improvement through stakeholder interaction. Moving these dams from a post-processing step and into the hydrological model would be advisable in a future iteration of this work;
4. Caveat on link between shallow infiltration and groundwater recharge: As noted earlier, while land covers with a healthy soil layer are generally known to facilitate higher infiltration rates, this is not necessarily the same as high groundwater recharge rates. Our ability to represent this dynamic in hydrological models generally remains poor (disciplinary constraint). Additionally, in this region, the extent and state of aquifers, recharge areas, etc., have not been surveyed (data constraint).

2.9 Summary of Key Results

The erosion rates estimated for different land use as well as the water availability/demand results from both the current conditions and no forest counterfactual will be used as inputs for the economic analysis of the hydrological ecosystem services (to continue in the next chapter). Table 2.4 below summarizes the main outcomes from the hydrological analysis when considering the impact of changes occurring in the Pursat River Basin.

TABLE 2.4 SUMMARY OF MAIN PROJECTED HYDROLOGICAL IMPACTS OF LAND USE CHANGE IN THE PURSAT RIVER BASIN

Impact of	Level (uncertainty)	Comments/Explanation
Upstream deforestation on water yield during low flows	Mid to low impact (high uncertainty)	Water yield maps correlate more to elevation and rainfall patterns than land cover. However, the information on aquifer extents and groundwater drainage is poor in the model, contributing to high uncertainty.
Establishment of agriculture upstream on water yield during low flows	High impact (low uncertainty)	Based on estimates of irrigation water demand, the region being converted to agricultural land use above Dam 1 could divert low flows significantly. The "no-flows" in recorded discharge from 2014 onwards for first quarter of the year (if not an instrumentation error) could be likely linked to this.
Upstream deforestation on sediment output	High impact (high uncertainty)	Monitored sediment data is unavailable, so this is largely modeled figures without real-world validation. The results do indicate that each land parcel deforested, could for a period increase the sediment output by at least one order of magnitude.
Upstream deforestation on floods/ peak flows	High impact (low uncertainty)	The no forest counterfactual is not realistic, however, it does confirm a pattern of higher discharge in rainy season. The actual magnitude will not be like the 100 percent to 150 percent increase, but the trend is robust.



3 MONETARY VALUATION OF HYDROLOGICAL SERVICES

3.1 Overview

The annual water deficit estimated in the hydrological analysis was used to estimate the forgone agricultural revenue based on area under cultivation. This information, in combination with additional data on crop yield and production cost was used to estimate the economic value of water. Detailed methods for calculating unit monetary value of water for irrigation are described under section 2.1. Soil erosion and sediment deposition in the reservoirs were similarly quantified using different deforestation scenarios and the estimates were used to calculate reduction in water storage and resulting changes in hydro energy production. The monetary value of water for hydro energy production was estimated using the methods described in section 2.2. All the modeling and analysis was done using standard Python programming libraries and MS Excel. Overall objectives are the following:

- Estimating impact of upstream forest cover on water supply in monetary terms;
- Measuring long term impact of sediment erosion on hydro dam capacity;
- Estimating monetary value of sediment retention by upstream forests and avoided hydropower loss due to sediment deposition).

Central Phnom Penh City in Cambodia

3.2 Methodology

Deforestation Scenario for Irrigation

From the 7-year hydrological simulation results from both current conditions and no-forest counterfactual, spatially and temporally averaged monthly water yield response curves (cub.m per hectare per month) were derived for 4 land cover types above Bac Trakuon monitoring station, namely for: Forest, Agricultural, Barren and Others. Based on deforestation rate considered in the scenario, the area under each land cover type is calculated. It is assumed that as part of the process of forested land being converted to agricultural, any deforested plot remains without vegetation (barren) for that year and becomes part of agricultural usage the following year. With area under each land cover known, the monthly water yield time series is recombined using area as weights to estimate the overall water availability in each month.

The economic analysis shows that out of the total estimated value of irrigation benefits US$16 thousand per year is threatened if current rate of deforestation continues at 0.25 percent. In an accelerated deforestation of 1 percent a proportionate value of US$64 thousand per year will be under threat.

Valuation of Water in Irrigation

Several methodological frameworks and techniques for estimating the monetary value of water for irrigation have been proposed (Speelman et al. 2008; Mesa-Jurado et al. 2010; Berbel et al. 2011). The most common approach is the "production function" approach. There are a few variants of this methodology known by different names, such as Residual Imputation Method (RIM), Net-back Analysis, Net Return to Water, Net Income, etc. Each variant takes a residual value approach, where the value of a given input is inferred from other inputs to production. Many of those variants were extensively discussed with case studies and examples in the System of Environmental-Economic Accounting for Water SEEA-Water (UNSD 2012).

In RIM, the total value of a product is divided into the opportunity cost of all inputs, until the total amount is completely exhausted. The assumption is that in a perfectly competitive market the value of a commodity (i.e. output X price) is exactly equal to the opportunity cost of all inputs. So, if opportunity cost of all non-water inputs is known, the shadow price of water would be the difference between the value of outputs and cost of non-water inputs.

We used data collected in a nation-wide farm survey held between 2012 and 2013 (World Bank 2015) to value water for irrigation services. This survey collected data on a range of agricultural products using a structured survey of individual farmers (drawn from a random sample stratified by provinces, districts, communes and villages) in combination with focus group discussions and key informants. Data were disaggregated according to farm size, technology used and seasonality. The data collected include a range of financial and farm characteristics such as cultivated area, yield, input cost, labor cost, cost of services and irrigation.

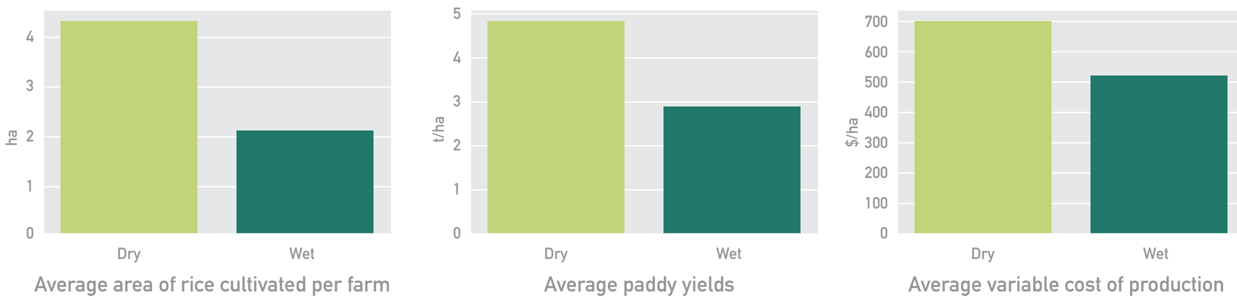
Farm characteristics

In the Pursat River Basin, the average farm cultivates 4 ha of rice in the dry season and about 2 ha in the wet season (Figure 3.1). Most farms are small (average size is less than 1ha) and they tend to grow rice only during the wet season, using traditional techniques (Figure 3.2).[12, 13] Large farms, on the other hand, are more likely to grow under both wet and dry seasons and use modern techniques. The total area under rice production in the wet season (78,000 ha) is more than three times higher than in the dry season (25,000 ha).

12 <1 ha is for small farms only, and 2-4 ha is averaged across all small and big farms. Although the number of large farmers is comparatively smaller, this size differences made the overall average larger.

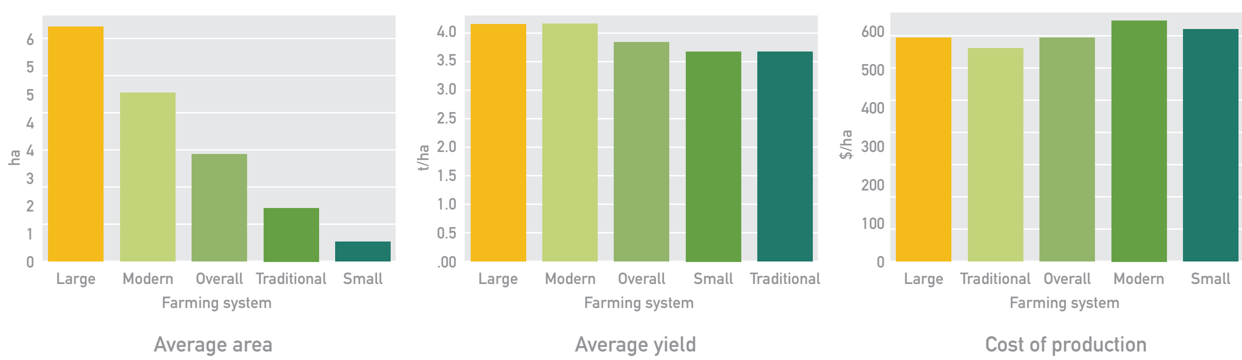
13 (a) Average farm size (cultivated areas) is about 3 ha, with large farms having >6 ha and smaller farms <1 ha. On average technologically improved farms are bigger than traditionally cultivated farms. (b) The yield of rice across farm types falls between 3-4 tons/ha. Yields are not significantly different across farm types. (c) Total variable cost was estimated to be around US$600 per ha rice production and do not vary much according to farm types.

FIGURE 3.1: PADDY RICE PRODUCTION DATA, BY SEASON



Source: Authors' calculations

FIGURE 3.2: KEY CHARACTERISTICS OF FARMING SYSTEMS



Source: Authors' calculations

Dry season rice cultivation has higher yields (4.5 tons/ha) than in the wet season (3 tons/ha), a difference also confirmed by other studies (Lee and Kobayashi 2017). High productivity in the dry season is generally attributed to the use of high-yielding seeds and better irrigation management.

Total variable cost was estimated to be around US$696 per ha in the dry season and US$510 per ha in the wet season. This difference is primarily due to higher inputs use. Because of this high cost of production farmers, dry season returns are low despite the higher yields, as also noted in other studies (Srean et al. 2018). Under current condition total value added from rice cultivation is US$40.7 million (gross income US$89 million).

Unit monetary values

The unit value of water estimated using the RIM approach ranges from 0.05-0.09 US$/m3, the higher values being for dry season rice cultivation. These values are within the range estimated in other studies (Hussain et al. 2007). Correspondingly, the economic return to water ranged from 175 US$/ha for wet season rice to 311 US$/ha for dry season rice (Table 3.1).

TABLE 3.1: VALUE OF WATER AS AN INPUT TO PRODUCTION IN DIFFERENT FARMING CATEGORIES

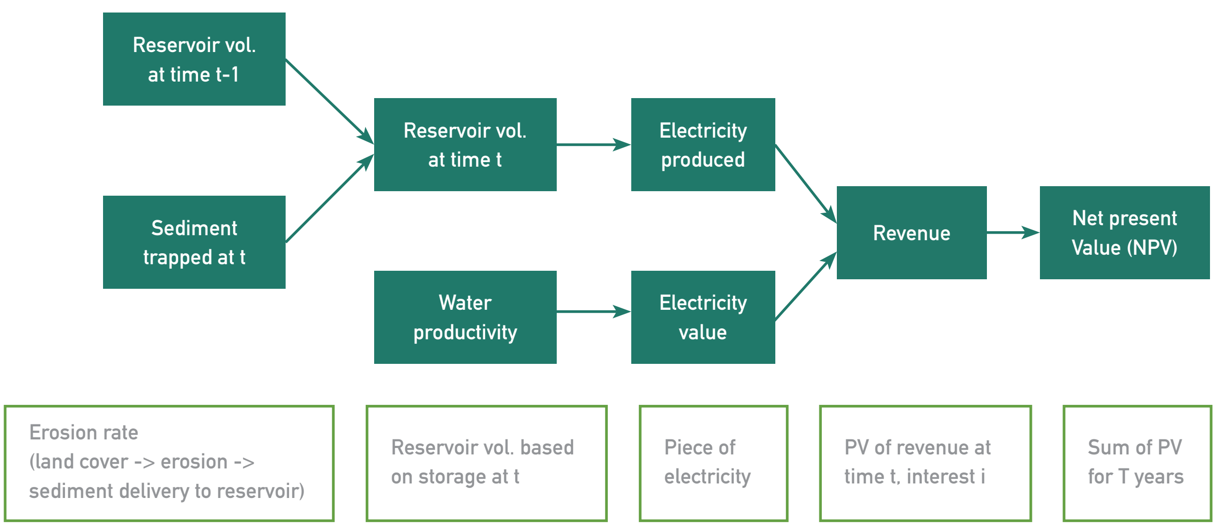
			Farm categories			
Unit	Small	Large	Traditional	Modern	Dry	Wet
US$/m3	0.089	0.075	0.069	0.063	0.089	0.05
US$/ha	185	261	242	220	311	175

Source: Authors' calculations

Valuation of Sediment Impacts on Hydroelectric Power Production

The economic return to water for hydroelectric power (HEP) production was estimated based on the effect of sedimentation on the capacity of the reservoir, which in turn affects the dam's ability to generate electricity. The approach is depicted in Figure 3.3. Note that because sedimentation is a cumulative problem, its impact is small initially, but increases over time. Therefore, results are presented in present value terms rather than in annual terms.

FIGURE 3.3: METHODOLOGICAL PROCESS FOR VALUATION OF HYDROLOGICAL SERVICES USED FOR HEP



Source: Authors' creation

The rate of sedimentation depends on erosion rates, which depend on land cover in the upper watershed. As before, we compare current land cover to a hypothetical no-forest counterfactual, which enables us to value the role of forest as a whole in protecting HEP production. We also examine two policy-relevant scenarios, one with a deforestation rate of 0.25 percent per annum (business as usual) and on with a deforestation rate of 1 percent per annum (high deforestation). In each case, the mathematical model was run twice, comparing the sedimentation impacts to those that would be experienced under no deforestation, the difference between each pair of values indicating the impact.

The process of valuation starts by estimating the sedimentation rate and how it affects reservoir capacity. In any year t, the reservoir volume V_t was estimated by reducing the previous year's active storage by the amount of sediment deposited (Sed_t) in that year.[14]

$$V_t = V_{t-1} - Sed_t$$

This reservoir volume at time t was used to estimate total amount of electricity generated for that year using an estimate of the water productivity of electricity (i.e. kwh produced per m^3 of water; Miglietta et al. 2018) and of the unit value of electricity. This process was repeated for a 100-year dam lifecycle (*T*) with corresponding changes in forest cover and soil erosion. Finally, a net present value (*NPV*) was estimated using a discount rate (*i*) of 6 percent.

To calculate a unit monetary value of water for HEP production, the Resource Rent approach proposed in the SEEA-EEA methodological guidelines was used.[15] A rent in this case is the residual value, calculated as the surplus generated by producing one unit of HEP, above the cost of inputs. However, as data on energy production cost and other inputs are available for the study site, however, the unit value was derived based on the consumer price of electricity (US$0.25 /kwh) and assuming an average cost of production US$0.04/kwh.

We made several assumptions for calculating the economic value of water for HEP production. Key data required were water supply, water demand and soil erosion (estimates described in biophysical chapter). Additional data on dam parameters (such as electricity price, dam storage, electricity capacity, dam lifetime) were collected from MOWRAM (2013). The following table provides key modeling parameters and assumptions.

TABLE 3.2: KEY ASSUMPTIONS USED IN VALUATION OF HEP

Assumptions	Unit	Baseline
Electricity capacity	Kwh/y	400 million
Electricity price	US$/Kwh	0.25
Electricity cost of production	US$/Kwh	0.04
Deforestation rate	percent	0.25
Erosion rate	t/ha/y	0.3 forested 20 other land use 175 barren land
Discount rate	percent	6
Water productivity of electricity	Kwh/m3	0.47
Time frame	years	100
Sediment trapping efficiency	percent	90 percent
Soil bulk density	g/ml	1.2

14 Sediment loads estimated by the SWAT model (in tons) were converted to a volume equivalent (m3) using a constant bulk density of 1.2 g/l.

15 An alternative approach would be to compare the cost HEP to that of other energy sources such as diesel, renewable energy, thermal sources, or firewood, that would used if HEP was not available.

3.3 Results

Economic Value of Ecosystem Services to Farmers

The hydrological modeling calculated the quantity of water supplied by the Cardamom forest ecosystems by comparing water yield under existing land cover with that under a hypothetical no-forest condition. As described above, water availability is better with forests than it would be without them. Indeed, without forests the total value of irrigated crop production would be US$0.6 million per year lower. In other words, the presence of forests in the Pursat River Basin makes farmers better off by US$0.6 million a year.

Moreover, in the absence of forest, increased soil erosion would cause further losses to farmers, estimated at US$1 million per year, by reducing the ability of the dams to regulate the flow of water to irrigation. Increased sedimentation in the absence of forests would also increase maintenance costs in the irrigation systems, as sediment would clog distribution canals. However, these costs could not be estimated for lack of data.

Thanks for the presence of forests in the Pursat River Basin, farmers in the irrigated areas in the lower basin are thus better off by at least US$1.6 million per year than they would be in the absence of forests. The present value of this benefit stream over a 100-year time horizon, discounted at 6 percent, is US$28 million.

Economic Value of Ecosystem Services to Hydropower Operators

The presence of forests in the Pursat River Basin protects the soil from erosion. In the absence of forests and their soil retention role, the reservoir of Dam 1 would lose all its capacity for electricity generation in just 65 years (Table 3.3). Under the gradual deforestation scenarios, the erosion would increase more slowly and so the reservoirs would fill more slowly, but they would still be significantly affected. With current annual deforestation rates of 0.25 percent, reservoir capacity would be reduced by 23 percent by the end of its 100-year life cycle; at a higher annual deforestation rate of 1 percent, storage would be reduced by more than 60 percent.

This reduction in capacity would, in turn, reduce the ability to generate electricity. Without forests, the value of electricity production would decline from about US$76 million a year to almost nothing after 65 years. In present value terms, the value of electricity production would be US$18.2 million lower than it would be with forests. That is, the presence of forests increases returns to HEP in the Pursat River Basin by US$18.2 million over the reservoir's lifetime. This is equivalent to an annual benefit of about US$1.1 million.

Gradual deforestation would have the same effect, but more slowly. At current rates of forest loss (0.25 percent a year), the annual value of electricity would decline from US$76 million to US$58 million in 100 years. As most of the losses would come in later years, however, the reduction in present value of electricity production would be US$0.8 million than with no deforestation. At a high deforestation rate of 1 percent a year, the annual value of electricity would decline to US$30 million in 100 years - a reduction in present value of electricity production of US$2.8 million (equivalent to an annual cost of about US$0.17 million).

TABLE 3.3: EFFECT OF LAND COVER CHANGE ON VALUE OF HEP

	Business as usual deforestation (0.25%/year)	High deforestation (1%/year)	No-forest counterfactual
Change in reservoir capacity (%)	23	61	100 (65 years)
Reduction in value of HEP (US$million)	0.8	2.8	18.2

Note: Present value of reduction in value of HEP computed over 100 years with a discount rate 6 percent.

3.4 Summary

The analysis shows that forests in the Pursat River Basin have a value of at least US$46 million dollars, based on the net present value of the services that they provide to irrigation and HEP. The main beneficiaries of these forests are the farmers in the Pursat plain, who are able to irrigate a greater area than they would if there were no forests as well as the HEP producers (and so, also their customers) who are able to produce more electricity.

This estimated value is an underestimate for two reasons. First, the estimated value does not include the effects of climate change, which are likely to exacerbate the damage that would be suffered in the absence of forests. Climate change is likely to result in more intense rainfall and in higher temperatures, which would tend to increase erosion and reduce dry season flow and probably even total water availability. Under these conditions, the role of forests would become even more important. Second, the estimated value does not include some aspects of the hydrological services that forests provide. For example, the savings in maintenance costs that the forests' erosion reduction service generates are not included, and neither is the reduction in flood risk that forests provide. Again, these benefits are likely to become even more important with climate change (the following section examines the carbon sequestration benefits that forests provide).

Of course, this value would not be lost all at once. With gradual deforestation, benefits to both farmers and HEP producers would gradually decline, with the extent and rapidity of this impact dependent on the rate of deforestation. It should also be stressed that this estimate only applies to the forests within the Pursat River Basin, which is only one of the 42 watersheds in the Cardamom Mountains Tonle-Sap basin. The forests in the rest of the Cardamoms are also generating substantial benefits. This study provides a methodological framework that could be replicated in other watersheds of the Cardamom Mountains, or elsewhere in Cambodia.

Limitations/Caveats

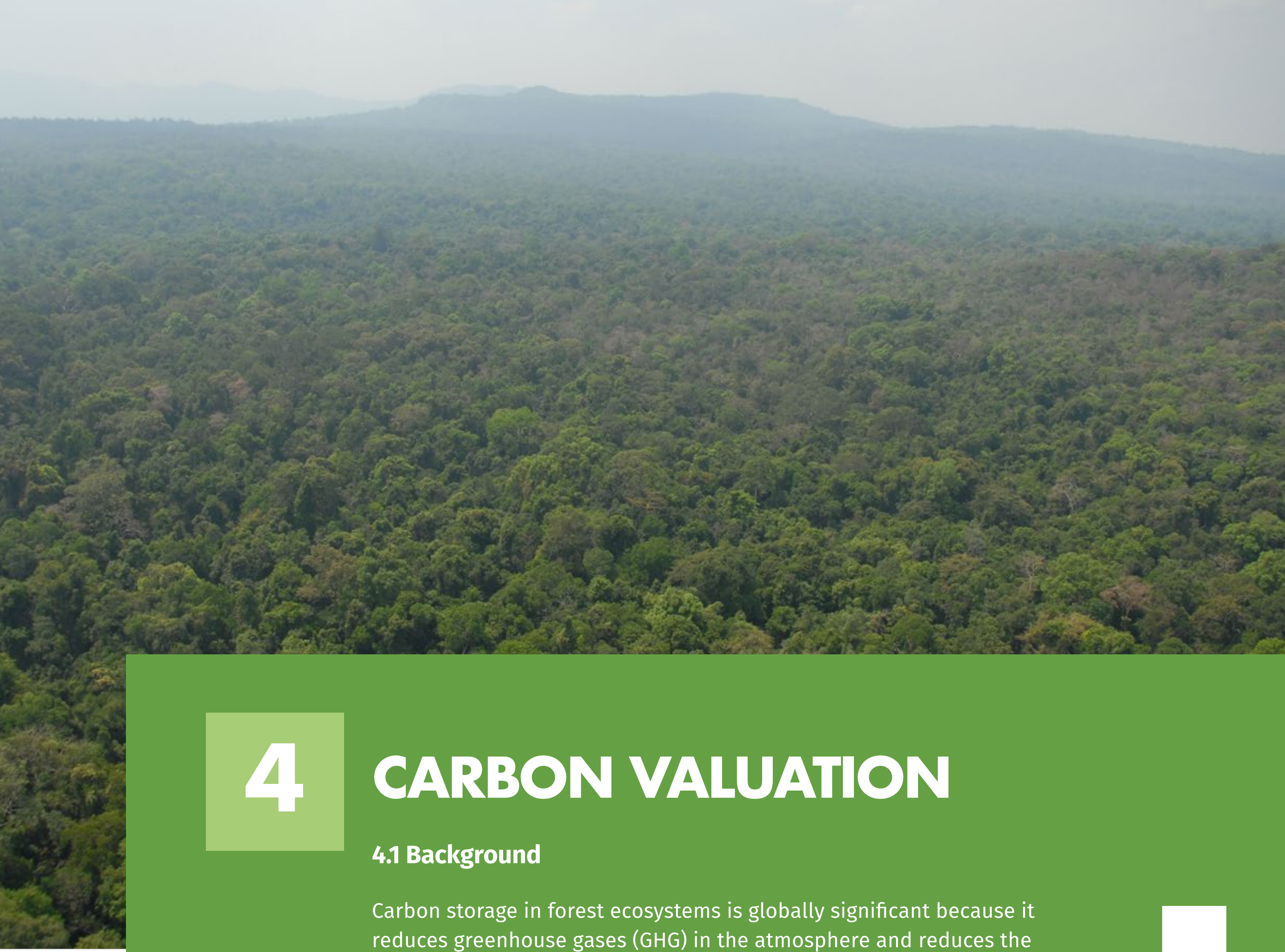
This study is subject to a number of limitations, particularly due to data availability. Some of these limitations result in entire problem areas being omitted from the analysis. Others (such as limited rainfall and sediment load data) affect the reliability of the hydrological modeling. Resolving these problems would lead to both more precise and more reliable estimates. Some of the data used to estimate the value of irrigation was collected some years ago and may not fully reflect current conditions. As noted, the results are underestimating the true value of services, so with better data the estimated value would almost certainly increase.

There are also some methodological limitations. Water demand for paddy rice production is met by both surface and ground water, for example, but the analysis focuses solely on surface water. Although ecosystems play a role in ground water infiltration, surface water is directly regulated by ecosystems, which is the focus of this study. A simple model of dam operations is used; a more sophisticated model would better capture the dam's role in ensuring water supplies for irrigation and HEP. The analysis uses average value as a proxy for a marginal value, assuming a constant return to scale. Determining return to scale is a difficult exercise, as this needs to be determined empirically for each crop and each site. Therefore, to simplify, a constant return to scale is assumed in this analysis.

The deforestation scenario is clearly a simplified approach but is helpful to provide an initial rough estimate of likely continued loss of seasonal water regulation service over time. Two main caveats to note, alongside the results are that the method: (1) assumes water yield, at any point in the basin, becomes available as discharge downstream within the same month; (2) ignores the spatial variability of water yield. Even the agricultural lands, above the gauging station, are on comparatively lower altitude than the forested lands and so any average water yield curve derived will also be biased by lower precipitation rates of the agricultural lands, rather than impact of land cover alone.

One of the key limitations of the study is the ability of the hydrological model to reliably link large changes in land cover and hydrologic variables. In this study, SWAT was calibrated and validated for current conditions, however, due to equifinality (where the potential output - in this case, basin discharge - can be met by many possible combinations of input states), as well as unavailability of data to validate the model in the new (no forest) conditions, the outputs derived for the new state are reliant on the rigor of mathematical representation of the relevant processes in the model as well as their parameterization. New physically-based models that improve the representation of vegetation are continuously being developed and refined – however, data required to run these models, is, at many times, hard to obtain from existing monitoring programs. Going forward, improvement in data (as per some of the recommendations in this study) will first likely lead to improvement of the characterization of the current model and consequently help refine the methods and models as this field of study further develops.

Economic analysis is tightly interlinked to biophysical analysis and physical quantification of ecosystem services. Therefore, the outcome of economic analysis is naturally sensitive to underlying assumptions made and inputs used into biophysical modeling. Specific to economic analysis, we made several assumptions and inputs choices that will have different level of outcomes at different scales and locations. An example is the unit value of water that is derived from a residual value approach that is highly sensitive to opportunity cost of labor. Since labor cost varies a lot, depending on location and employment opportunities, this needs to be carefully chosen in scaling up efforts. Similarly, sediment maintenance cost of irrigation channels was not available in our analysis but it is an important part of measuring impacts of upstream land management on downstream ecosystem services assessment. In cases of HEP, the determination of the unit value of hydropower has one of the largest impacts on economic value. Furthermore, and as valuation takes into consideration a long time horizon (100 years in our case), discount rates and other associated uncertainties (e.g. future demand, supply, policy, incentives etc.) therefore need to be carefully considered in scaling up.



4 CARBON VALUATION

4.1 Background

Carbon storage in forest ecosystems is globally significant because it reduces greenhouse gases (GHG) in the atmosphere and reduces the warming effect. Cambodia is one of the many signatories to the Paris Agreement, which states that “Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of the GHGs … including forests” (UNFCCC 2015). Cambodia’s Nationally Determined Contribution (NDC) contains explicit commitments to reducing GHG emissions through forest conservation and restoration. Enhancing storage and sequestration of carbon in forest ecosystems in Cambodia is a priority of the Royal Government of Cambodia (RGC) (NCSD 2019).

The analysis in this chapter focuses on the carbon storage ecosystem service. The value of carbon in forests is determined through the potential benefits for human well-being that come from minimizing the stock of carbon in the atmosphere where it can contribute to global warming.[16]

Aerial shot of the Cardamom Mountains, Cambodia.
© Conservation International/photo by David Emmett

16 Notwithstanding the lack of consensus among practitioners about whether carbon storage should be considered an ecosystem service determining the value of carbon storage is useful for building consensus on the value of forest ecosystem services. See discussions on carbon storage as an ecosystem services in Keith et al. (2019).

4.2 Carbon Pool and Stocks

The average carbon stock of an ecosystem is determined by the environmental conditions, land use and regime of natural and anthropogenic disturbances (Keith et al. 2019).

Land Cover

Land cover in the Pursat Basin in 2016 is shown in Table 4.1, based on official data obtained from the MoE. Forest cover was determined from Landsat 8 satellite images from October 2015 to May 2016, as well as from data from RapidEye, SPOT5, Sentinel-2 and images from Google Earth for verification of land use/cover classification with 1651 verified points covering 25 capital-provinces nationwide. The 2016 land cover was generated with 22 categories of cover, in which forest classes that fell under 13 categories and non-forest were in 9 categories with minimum mapping 5 ha (MoE 2018).

Estimating Carbon Stocks

Data on carbon pools is drawn from analysis conducted by Flora and Fauna International (FFI) as part of a REDD+ feasibility study for the Central Cardamom Protected Area (Kempinski and Ramos 2013). FFI determine carbon pools based on the general requirements of the Verified Carbon Standard (VCS) methodology VM0015 (Pedroni 2012). The carbon pools included in this methodology are: above ground biomass (trees); below ground biomass (roots); dead wood; and wood products. A biomass inventory was used to calculate carbon stock and estimate 95 percent confidence intervals of the sample.[17] These figures were found to be comparable with previous carbon inventories for similar areas and forest types; including those reported by Sasaki and Yoshimoto (2010), which suggests a stocking of 172 t C/ha (Pedroni 2012) (see Table 4.2). An estimate of the carbon pool for mangrove forest of 1,094 t C/ha was drawn from Kauffman and Bhomia (2017) who determined an average carbon pool for mangroves in East Asia based on several studies.

TABLE 4.1: LAND COVER IN THE PURSAT RIVER BASIN, 2016

Land cover	Area (ha)	Percent of total
Evergreen forest	242,989	40.8
Deciduous forest	100,903	16.9
Cropland	93,453	15.7
Paddy field	66,812	11.2
Semi-evergreen forest	53,223	8.9
Wood shrub	12,337	2.1
Flooded forest	7,033	1.2
Village	7,033	1.2
Grassland	4,053	0.7
Bamboo	2,324	0.4
Water	1,788	0.3
Forest regrowth	1,490	0.2
Rubber plantation	1,132	0.2
Sand	894	0.1
Built-up Area	536	0.1
Rock	60	0.0
Total	**596,060**	100.0

TABLE 4.2: CARBON STOCKS BY FOREST TYPE

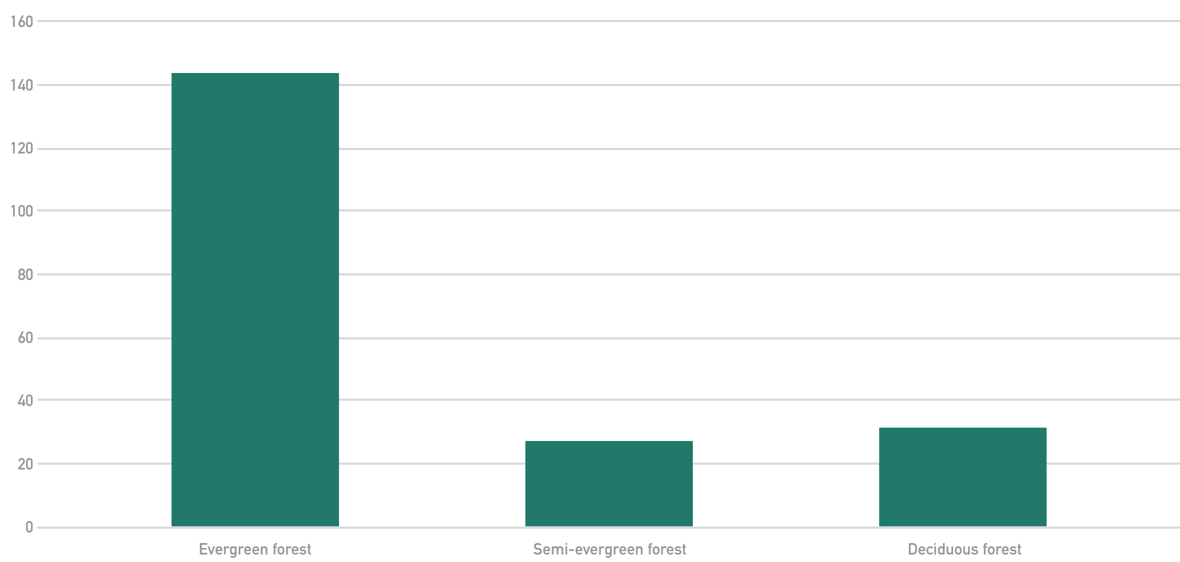
	Evergreen	Semi-evergreen	Deciduous
Lower Limit (t C/ha)	140.3	109.7	73.7
Upper Limit (t C/ha)	183.0	166.7	94.0
Average (t C/ha)	161.7	138.2	83.9
Average (t CO¬2e/ha)*	593	507	308

Note: C to CO2e is determined with a conversion factor of 3.67

Source: Pedroni 2012.

Carbon stocks for the forest assets in the Pursat River Basin were estimated for evergreen, semi-evergreen and deciduous forest types. The total estimated forest carbon stock for each forest type is shown in Figure 4.1.

FIGURE 4.1: CARBON STOCKS FOR MAJOR FOREST TYPES IN THE PURSAT BASIN



Source: Authors' calculations

Annual Carbon Value

There are two options for estimating the value of carbon storage ecosystem services provided by the forest in the Cardamom Mountains. The first is to value the entire stock of carbon stored in these forests; this option is appropriate when estimating the value of these forests as an asset. The second approach is to value the change in stock resulting from current deforestation, or the sequestration that would result from reforestation; this approach is more policy relevant.

To obtain the total value, these quantities are then multiplied by the unit value of carbon emissions. The unit values to be used depend on whether the value is being considered from the national or the global perspective. Carbon emissions resulting from deforestation would affect the entire world by contributing to GHG concentrations in the atmosphere and hence to global climate change. Various efforts have been made to estimate the cost of the damage that would be caused by incremental emissions. The World Bank, for example, has prepared a range of estimates of the Social Value of Carbon (SVC). These range from a low estimate of US$37/tCO2e in 2017 rising to US$78/tCO2e in 2050 and a high estimate of US$75/tCO2e in 2017 rising to US$156/tCO2e in 2050 (World Bank 2017). However, the value of these emissions to Cambodia itself is much smaller: Even though Cambodia is, of course, heavily threatened by climate change, the contribution to climate change of these specific emissions is small. From Cambodia's perspective, these stocks have concrete value if the country receives compensation for maintaining them (that is, for avoiding emissions). Thus, from Cambodia's perspective, the stocks should be valued at prices such as it could realistically receive under an emission reduction payment agreement (ERPA). A value of US$5/ tCO2e is applied by the Green Climate Fund for REDD projects and can be used to provide a first estimate of the value of the forest carbon stocks in the Pursat Basin. Note that as there is no ERPA in place for avoided deforestation in the Pursat Basin, the resulting estimates are of potential benefits: How much Cambodia could realistically expect to receive if it succeeded in avoiding forest loss and the resulting emissions.

From an asset value perspective, the value of the entire stock of carbon stored in forests in the Pursat River Basin is US$1 billion if valued at US$5/tCO2e and of US$7.5 billion if valued at the SVC.

About US$2.5 million in carbon value is lost every year in the Pursat Basin. At the current 0.25 percent annual deforestation rate, the estimated value of emissions is US$2.5 million/yr if valued at ERPA prices of US$5/ tCO2e and of US$19 million/ yr if valued at the SVC (average of high and low estimates). If there was an emissions reduction program that would reduce deforestation in the Pursat watershed to zero, an annual payment of about US$2.5 million could be negotiated.[18]

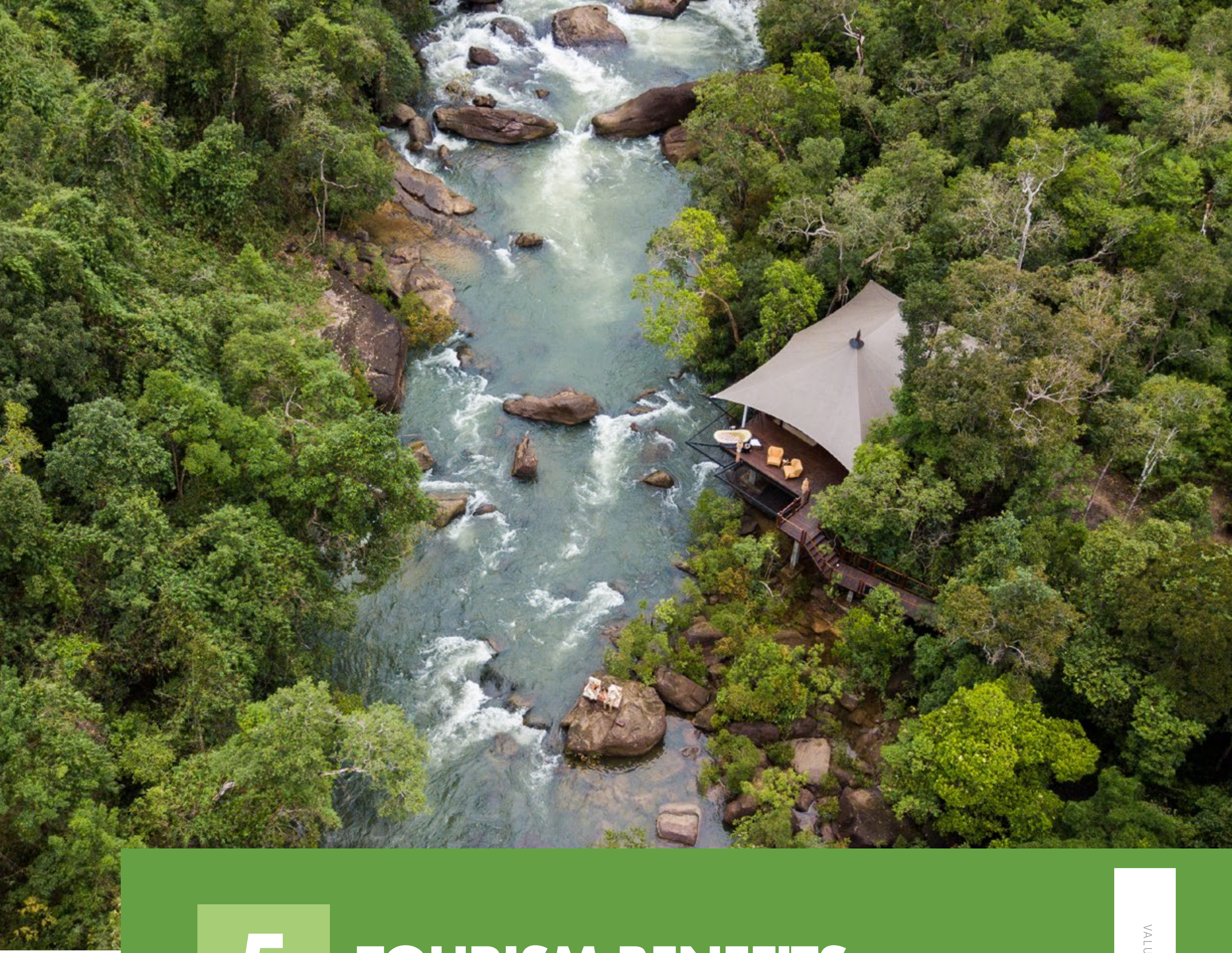
TABLE 4.3: ESTIMATED CARBON EMISSIONS FROM DEFORESTATION IN THE PURSAT RIVER BASIN

		0.25% deforestation scenario	
Forest type	**2016 forest cover (ha)**	**Average annual forest loss (ha)***	**Estimated annual CO2 loss (t CO2e)**
Evergreen	242,989	601	360,000
Semi-evergreen	53,223	132	67,000
Deciduous	100,903	250	77,000
Total	397,115		504,000

Notes: This analysis assumes the same deforestation rate for all forest types. In reality, there may be some differences in the deforestation rates of the different forest types.

* Avg. over 10 years (2016-2025)

18 This payment would be contingent on reducing deforestation to zero. Should deforestation be only partially reduced, the payment to the country would be correspondingly smaller.



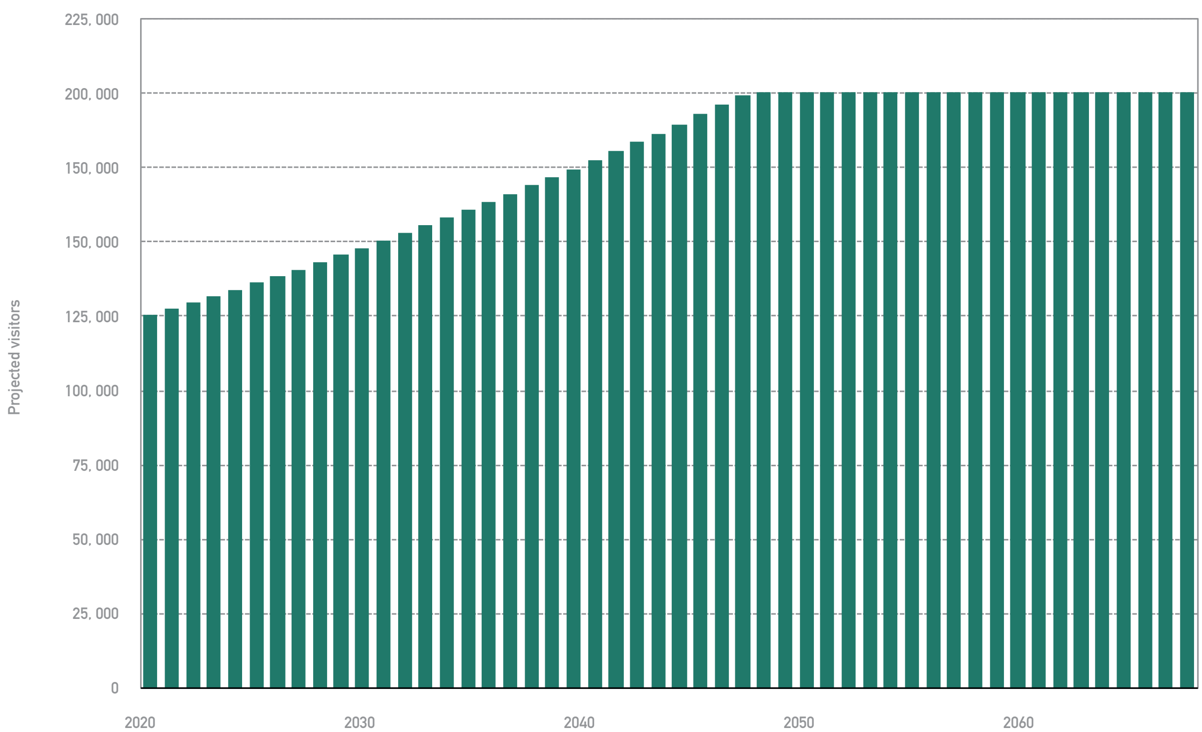
5 TOURISM BENEFITS

In addition to the downstream benefits they provide to water users, the forests in the upper part of Pursat River Basin also provide benefits to those who come to visit them. Cambodia's spectacular and pristine natural assets are exactly what ecotourists look for and the opportunities for supporting the expansion of this industry are great. There are already examples of successful mid- to high-end ecotourism operations in Cambodia which suggest that ecotourism products have great potential. In addition, iconic landscapes like the Cardamom Mountains offer the opportunity to develop new and exciting multi-day itineraries that take advantage of the biodiversity, lush forests and rugged terrain that is perfect for adventure tourism.

Shinta Mani Wild resort in the Cardamom Mountains © Shinta Mani Wild

Estimates prepared for the Cambodia Sustainable Landscape and Ecotourism (CSLE) Project show that ecotourism in the PAs of the upper Pursat River Basin is generating revenue of about US$3 million a year (about 125,000 visitors a year, each spending US$22/ day and staying a little over a day).[19] Moreover, this revenue is projected to gradually increase over time as the number of visitors, their spending and their length of stay are all slowly increasing. Assuming current trends continue (but capping the number of visitors at 200,000 a year to avoid placing excessive pressure on the PAs), the present value of tourism revenue over 50 years, at a 6 discount rate, is estimated to be about US$210 million.[20] However, part of this revenue is spent on providing these visitors with accommodation, food, facilities, guides, etc. Assuming conservatively that about a quarter of revenue represents a net benefit to Cambodia, **the net value of ecotourism benefits generated by the forests in the upper Pursat River Basin is estimated at about US$53 million.**

FIGURE 5.1: PROJECTED VISITORS TO PAS IN THE UPPER PURSAT RIVER BASIN



Source: Estimates prepared for the CSLE project.[21]

Benefits of Improved Tourism

Continued deforestation, even at current low rates, would result in a reduction of the benefits provided by forests in the Pursat River Basin. Conversely, investments could help increase them. The recently approved Cambodia Sustainable Landscape and Ecotourism (CSLE) Project, for example, aims to increased benefits from tourism and carbon storage services by supporting RGC investments in ecotourism

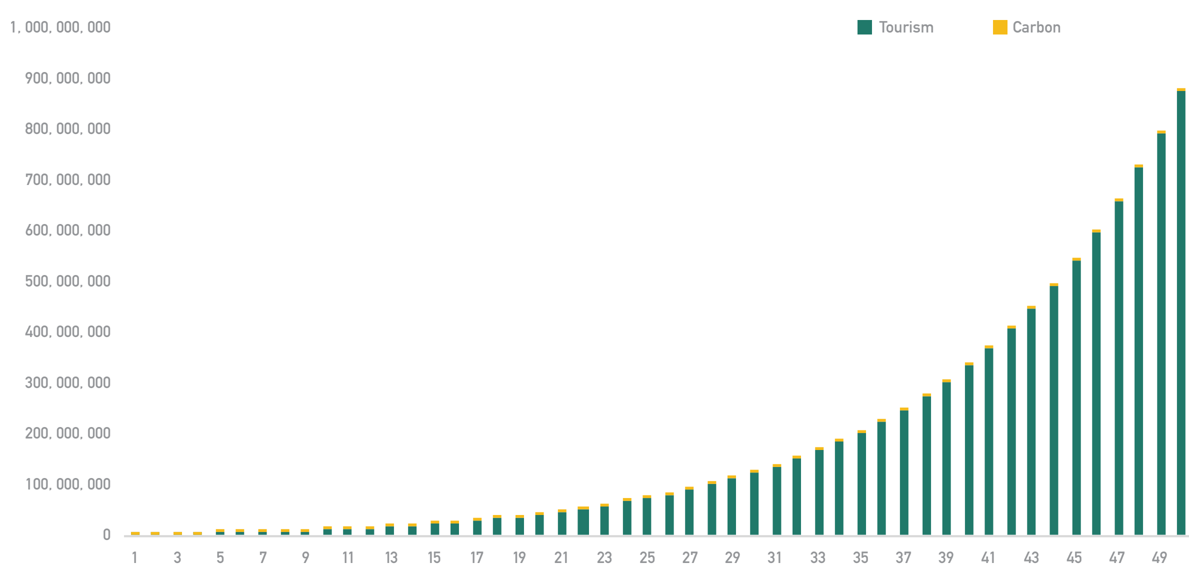
19 Visitor numbers were estimated from data provided by the Ministry of Environment on tourist arrivals to the Chrok La Eng Waterfall, Anlong Svay and Phnom Chreav Waterfall in Phnom Aural Wildlife Sanctuary. The estimate of average visitor spend is based on data from community-based ecotourism operations (CBETs).

20 These estimates do not take into account the impact of the COVID emergency, which will reduce ecotourism significantly in the short term.

21 CSLE project: http://documents.worldbank.org/curated/en/934211559527272828/Cambodia-Sustainable-Landscape-and-Ecotourism-Project development and protected areas management and law enforcement. The CSLE project, which is being implemented over a six-year period from 2020 to 2025, is expected to cost US$55 million. It will support PA management, planning and enforcement at seven sites, which will reduce forest cover loss by more than 2 million ha in the Cardamom Mountains Tonle Sap landscape, thereby increasing carbon storage in the Cardamom forests. The project will also increase access to ecotourism sites from main hubs by improving infrastructure, thereby increasing the number of visitors. New ecotourism activities will also be developed at the project sites (visitor and interpretation centers, hiking trails, tourism facilities), thereby increasing both the visitors' length of stay and their daily spending. Increased income in the beneficiary communities will lead to greater tax revenue for the RGC. There will also be multiplier effects of the tourism spending in the country and in the target landscapes.

A model was developed to compare the stream of benefits and costs under various scenarios to assess the incremental benefits generated by the project in the Pursat RB. In the "without project" scenario, in the target areas, the environmental situation is likely to continue to decline, with continued forest loss and degradation, declining soil quality and agricultural output and continued high emissions of GHGs. Poor access to tourism sites and limited tourism options would limit both the number of visitors, as well as the length of their stay and daily spending in these destinations. Communities and smallholder farmers would continue subsistence agricultural practices, with low productivity and value added and limited diversification toward other economic opportunities. In these conditions, project interventions would be considered positive even if they only slowed the continuing negative trends. The analysis compared the balance of the "without" and "with" project scenarios for each benefit stream, discounted over a 20-year time horizon using a 6 percent discount rate to determine the value addition of the project in relation to its financial input. To place a value on the benefits of reducing carbon emissions a conservative value of US$5 t/ CO_2e was used. Explanations of the scenarios developed for each benefit stream and further details of the benefits analysis are provided in Appendix 5. Based on these scenarios, **the benefits of improved tourism and carbon storage from the forest in Pursat River Basin are estimated to be US$95 million** (see Figure 5.2).[22]

FIGURE 5.2: PROJECTED INCREASE IN TOURISM AND CARBON BENEFITS FROM THE CSLE PROJECT



Source: Authors' calculations

22 Note that these estimates assume that tourism would begin to grow beginning in year 2 of the project. The COVID emergency will almost certainly delay the tourism benefits, perhaps significantly.

Limitations

Determining the real revenue value of project sites was the greatest constraint to this analysis. Data for the analysis was limited and incomplete and have not been subject to validation or ground-truthing.

As a direct result, the analysis has aimed to significantly reduce the original assumptions of the impact of the project. However, it would be important to address these data challenges during the implementation stage to validate the NPV assumptions.

6 RECOMMENDATIONS

As earlier stated, this analytical work is being undertaken as part of a broader effort of the World Bank in Cambodia to provide guidance to the RGC through technical assistance and analytical and advisory services on managing its natural capital through landscape approaches. The earlier chapters presented results of the benefits of forest ecosystem services, which provide evidence of the returns on investments that the RGC will gain through the strengthening of forest ecosystems through the Cambodia Sustainable Landscape and Ecotourism project. Methodologies on how to undertake measurement and valuation of ecosystem services were presented so that this work can be repeated in other places. In this chapter, recommendations to guide the RGC in some important next steps are provided.

Flooded Forests, Tonle Sap
© Conservation International/photo by Tangkor Dong

Key Messages of the Study

1. The public benefits from intact forests estimated at US$99 million are nearly five times higher than the private gains had from cutting them down for small-scale agriculture or charcoal production estimated at US$22 million.
2. Investing in the maintenance of forest is good business. Annual public expenses to maintain the forest in the Pursat Basin are about 20 times lower than the public benefits provided by them.
3. Funding for the maintenance of those forests in the long run can be captured from private and international sources.

This work proposes three recommendations that are intended to: (i) help the RGC better integrate ecosystem service values into forest and PA management decision-making; (ii) indicate some priority geographic areas within the Cardamom Mountain landscape for action on prioritization of forest protection and management efforts; and (iii) expand efforts to address drivers of forest degradation in Cambodia with financial instruments like payments for ecosystem services (PES).

The results in this report lead to two sets of recommendations: (1) policy recommendations for the Pursat River Basin (Recommendations 1 and 2) and (2) recommendations aimed at scaling up the analysis to ultimately cover all of the country (Recommendation 3).

Recommendation 1: Focus forest protection and restoration efforts on upstream watersheds in the Cardamom Mountains protected area landscape to enhance resilience of water resources

Cardamom forested lands act to slow down high discharges during wet season and supplement low flows during dry season. Upstream deforestation in the Sam Kos Wildlife sanctuary, above Dam 1 linked to improved accessibility by access roads, possesses a quantifiable risk to the operation of irrigation and hydropower infrastructure downstream. These are, in the form of changes to the pattern of seasonal water yield, higher consumption upstream in water stressed months for irrigation and increased sediment accumulating in downstream infrastructure. Measures to arrest rate of deforestation and engage in options for afforestation would be recommended to protect this resource. The results showed that important areas for water yield are overlapping with PAs in the Cardamom Mountains, but also overlapping with an area of the Cardamom Mountains that has experienced high rates of degradation due to agricultural encroachment (Figure 5.1). With climate change projections for the region suggesting that there will be lower rainfall during dry season and higher rainfall in wet season (Figures 5.2 and 5.3), these forests act as natural protection infrastructure and therefore will contribute towards countering the trend enforced by the shifting rainfall pattern. Deforestation and forest degradation, on the other hand, will reinforce the impact of the climatic trends, magnifying the risk of extreme events like floods in the basin. Protection of upstream forestlands takes on renewed importance in this light.

The RGC has some important decisions to make with regards to prioritizing areas in the PA landscape for attention, additional resources for management

and even restoration activities. In this context, and under this recommendation, there are some strategic actions proposed for the government.

Action 1: Prioritize zoning and development of PA management plan in Samkos Wildlife Sanctuary and Biodiversity Conservation Corridors. MoE is already taking a step in this direction through the inclusion of Samkos Wildlife Sanctuary as a priority PA for zoning, PA management planning and boundary demarcation. The PA management planning should assess the best options for reducing forest degradation and conversion and should include a plan for restoration of degraded landscapes. This analysis provides information that MoE can use such as areas of high sediment yield and high-water yield (Figures 2.7, 2.9 and 2.11) in prioritizing areas within Samkos for interventions.

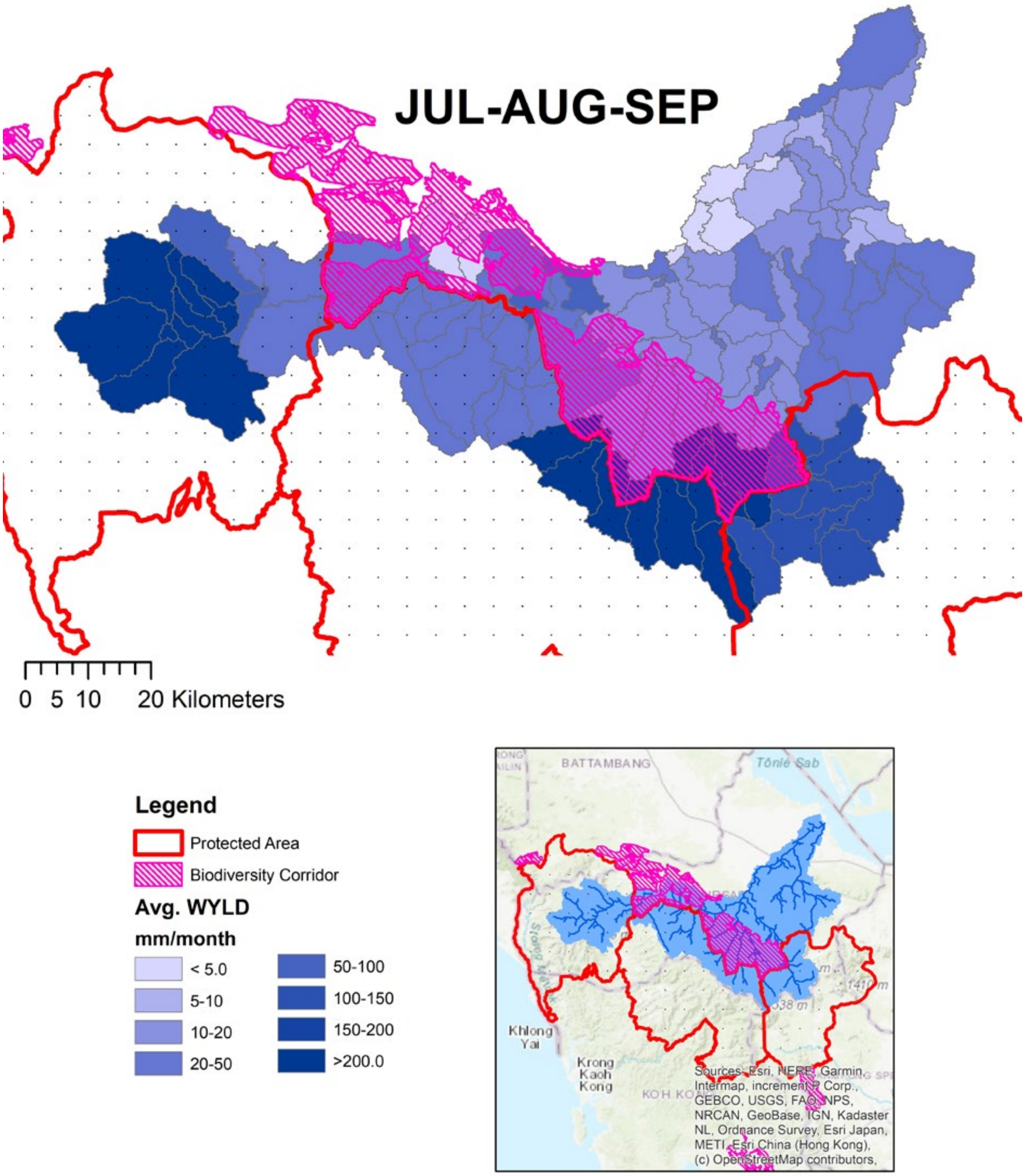
Action 2: Assess opportunities for agroforestry on existing agricultural lands within forested areas. Halting forest degradation and conversion is one of the key objectives of MoE's management of PAs. As agriculture is a key driver of forest change in the Cardamoms, it is important that this is addressed in a manner that is pro-poor, recognizing that forest communities need livelihood support. Developing agroforestry is a way of creating additional value on lands that have been converted to agriculture and restoring trees to provide some important ecosystem services like sediment regulation. The interventions that are decided from the assessment should also be included in the PA management plan.

Action 3: Develop interventions for reducing the pressure on forest resources from charcoal, including more sustainable charcoal production and environmentally friendly alternatives to wood charcoal. The charcoal industry can be a significant opportunity for Cambodia's rural PA economies if done right. GERES (2015) assessed the industry to be worth about US$177 million per year and RGC will need to play a key role in leading the organization of this industry in order to reduce its potential negative impacts on forests. Sourcing wood for charcoal from existing plantations can help to address the wood supply needs for the charcoal industry. At the same time, improving the wood-to-charcoal conversion efficiency could also help to reduce pressure on forests for wood. Four key measures proposed for further action on moving towards more sustainable charcoal production are: (i) formalization of existing small-scale charcoal producers and linking these with private sector plantations who can provide a consistent source of wood and through which a certification system for charcoal could be developed; (ii) refining existing charcoal producing techniques and technologies to improve energy efficiency of the firewood conversion into charcoal in a cost-effective way; (iii) developing small-scale woodlots within community use zones and sustainable use zones to meet wood needs for charcoal; (iv) exploring opportunities for more environmentally-friendly options for charcoal, like coconut husks.[23] Again, the link to the private sector would be strategic for investments and management of the wood lots.

23 Green Fuel is a company operating in Cambodia that is producing charcoal from coconut husks. More information available in https://www.khmertimeskh.com/57549/converting-coconut-husks-into-charcoal/

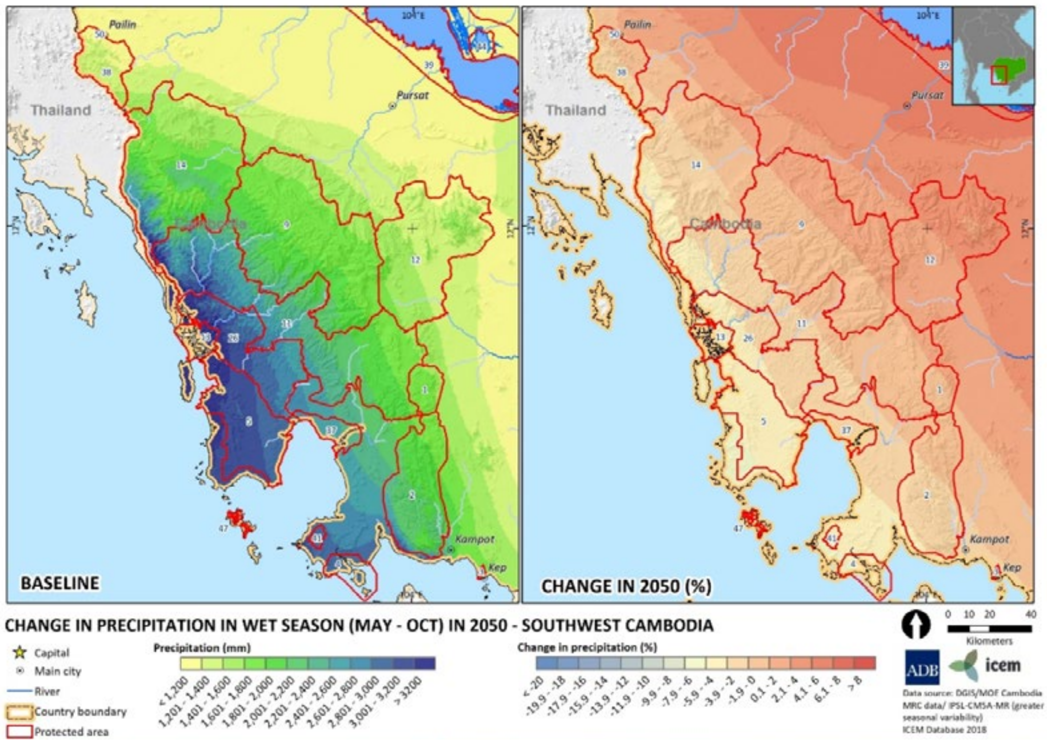
FIGURE 6.1: AREAS OF HIGH WATER YIELD WITHIN PAS IN THE CARDAMOM MOUNTAINS

IMPORTANT AREAS OF WATER YIELD OVERLAP THE SAMKOS WILDLIFE SANCTUARY, CENTRAL CARDAMOM NATIONAL PARK, AURAL WILDLIFE SANCTUARY AND BIODIVERSITY CORRIDOR. THIS TYPE OF MAP CAN BE USED AS AN INPUT IN THE ZONING ACTIVITIES FOR THESE PROTECTED AREAS UNDER THE CSLE PROJECT, TO INFORM THE DESIGNATION OF CORE ZONES.



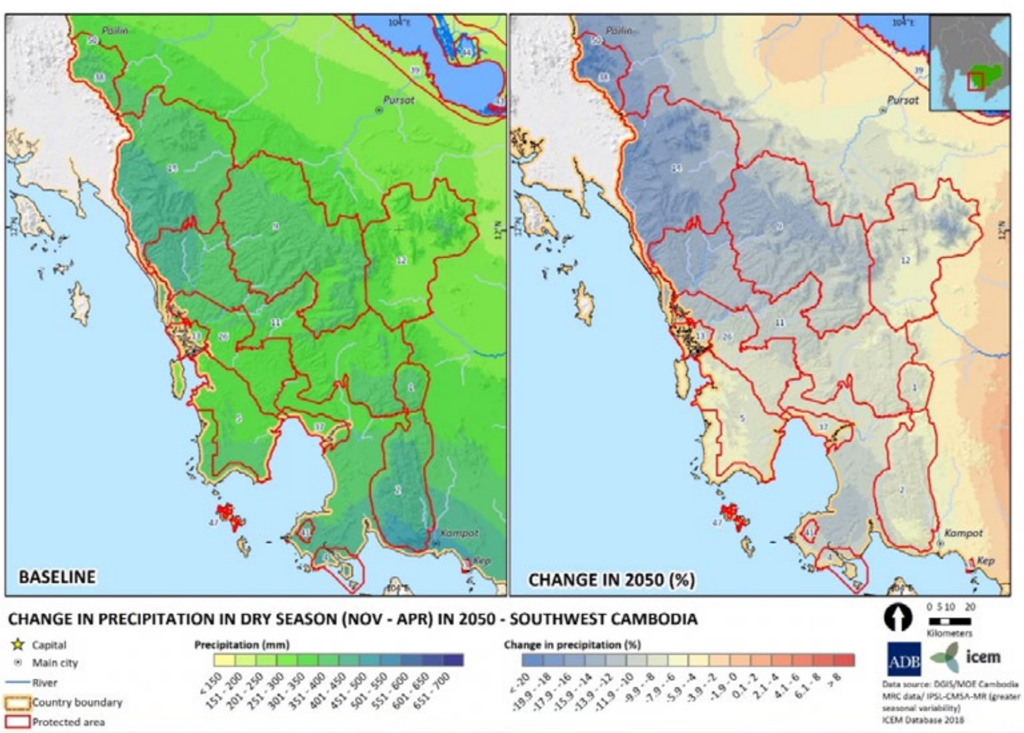
Source: Authors' creation

FIGURE 6.2: PRECIPITATION IS PROJECTED TO INCREASE IN THE WET SEASON OVER CARDAMOM MOUNTAINS



Source: International Centre for Environmental Management (ICEM) [24]

FIGURE 6.3: PRECIPITATION IS PROJECTED TO DECREASE IN THE DRY SEASON WITH CLIMATE CHANGE



22 See ICEM maps at https://icem.com.au/portfolio-items/mekong-arcc-climate-change-maps/

Recommendation 2: Explore the potential for private financing to support PA management

NCA can help inform government decision-makers, but it will not by itself change the incentives facing actors on the ground. In the Pursat RB, these actors receive only a small subset of forest benefits but stand to receive the bulk of the benefits from alternatives such as agriculture.

Public sector resources are needed in the short term to finance maintenance of forests, but the RGC should consider developing over the medium term a financing approach that integrates financing from private sources for the management of forests. This approach is an important emerging trend in conservation. If undertaken effectively, private capital investment can serve as a complement or alternative to traditional conservation funding. With the prospect of more stable long-term funding than traditional granting, this approach can provide deeper conservation and livelihood results. Payment for ecosystem services (PES) for water and payments for carbon under REDD+ (Reducing Emissions from Deforestation and Degradation) are already being undertaken in Cambodia and a critical step for the RGC is organizing these as part of an overall system of financing for forest management.

PES and REDD+ are realistic opportunities in Cambodia for directing private financing to support PA management. There is strong interest of the MoE in establishing PES with ongoing pilots helping to inform development of PES. Payments from international private sector under the REDD+ mechanism are already being received in Cambodia and could scale-up. There are very good studies already on evaluating carbon resources (stocks) and important is developing the right benefit-sharing mechanisms and ensuring that these link to an overall revenue system that support protected areas.

The present study contributes to the development of PES in several ways. First, it clearly documents the benefits provided by forests. Second, it identifies several important groups of beneficiaries of these services (irrigated farmers and electricity users) and quantifies the damages they would face if these services were lost or reduced. Third, the hydrological model developed for the analysis provides tools that would permit PES conservation efforts to the areas where they would be most effective.

To be sure, much more needs to be done. The quantification of benefits provided by this analysis, for example, only provides an upper bound of willingness to pay to avoid damages. For example, the analysis shows that at a deforestation rate of 1 percent a year, the losses suffered by HEP producers would be about US$0.17 million a year. This figure is the maximum such producers would be willing to pay for a PES program that stopped all deforestation completely - including both the costs of the payments to participants and the costs of implementation of the program. The corresponding figure on damages that irrigated farmers would suffer from deforestation would add to this amount and if an ERPA can be negotiated, carbon payments would increase it even further.

Designing and implementing a PES program to reduce deforestation in the upper Pursat River Basin would require:

1. Using the hydrological model developed for this analysis to identify the critical areas in the upper basin, the areas which, if they were to be deforested, would result in the greatest impact on hydrological flows and sediment loads;
2. Undertaking a threat assessment of these areas, to see how likely they are to be actually deforested, based on factors such as their suitability for agriculture, proximity to roads, etc. and quantifying the potential benefits to local people of converting these areas to other uses (taking into account likely crop yields, costs of production, etc.);
3. Measuring any benefits that retaining forests could generate for local communities, for example through the sustainable collection of NTFPs and through activities such as ecotourism;
4. Estimating the cost of a PES program to protect these critical areas, based on their size (number

of ha to be protected), the size of payments needed to induce forest conservation, and the net costs to local communities of conserving them (potential benefits from conversion to agriculture minus local benefits from retaining forests). Also the likely implementation costs of the program, based primarily on the cost of monitoring, which is affected by the size of plots to be monitored, their dispersion and their accessibility;

5. Based on these estimates, determining whether the program is feasible (i.e. the total costs are less than total willingness to pay); putting in place arrangements to collect funding from service users (such as irrigated farmers, HEP producers and/or carbon buyers) and; make appropriate payments to service providers (upstream communities who refrain from deforesting). The analysis conducted provides a substantial start on this road map, but clearly much more needs to be done.

Lastly, it would be important for any PES scheme to be part of ongoing plans within the government for strengthening the institutional framework for emissions reduction payments. The national REDD+ strategy and REDD+ nesting framework, that is currently being established, also provides the opportunity to provide payments from reducing carbon emissions through undertaking forest conservation, conservation compatible livelihood activities etc.

The kind of analysis undertaken in this study provides a basis for the levels of investment needed to holistically ensure and incentivize more emissions reduction payments. In addition, we recommend the RGC to:

1. Provide oversight and management of REDD+ activities as is being proposed in the REDD+ Regulatory Framework (Prakas), which is being developed;
2. Set up the national system for emissions reduction payments which includes a benefit sharing mechanism that will make clear investments for forest conservation and protected area management, including co-management, etc.;
3. Enhance and promote the attractiveness of Cambodia for REDD + payments with clear rules and regulation for the system;
4. Ensure that PES and REDD+ payments are well integrated into the overall financing mechanism for PAs. Recent work for the Greening Prey Lang project identified a number of fund sources including the Environment and Social Fund, the Forestry Administration National Forest Development Fund and private conservation funds that needed to be managed and used in an integrative way to be efficient and effective.

Recommendation 3: Develop a road map for scaling up assessment of economic benefits provided by forest ecosystems across Cambodia using a Natural Capital Accounting (NCA) Approach

The advantages for Cambodia of a natural capital approach (NCA) verses one-off economic valuation studies are: (i) standardizing how ecosystem service values are determined and integrated into regular decision-making of the RGC, for example in determining national budget allocation for MoE for PA management; and (ii) that data and information will be more reliable and less costly if data collection, analysis and access are standardized under an NCA approach. The analysis of the Pursat Basin demonstrates the potential benefits of undertaking NCA both to identify the need for interventions and to help design them and elucidates some key lessons for replication and scaling up. Lessons include: (i) the need for thorough analysis of the interactions of beneficiaries with ecosystem services; and (ii) the importance of a robust data collection plan and early commitment on data sharing from relevant ministries.

Moving from a single case study to a comprehensive approach requires a road map that includes:

1. Conducting a “scoping” exercise that identifies (i) policies, decision-making and planning processes for which the implementation of NCA could provide critically important information; and (ii) data availability/needs, institutional framework,

financial, technical resources and capacity required for NCA;

2. Identifying and informing key institutional partners that should be engaged (i) at the ministry level, such as MoE, Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Rural Development (MRD), Ministry of Agriculture, Forestry and Fisheries (MAFF), Ministry of Interior (MoI), Ministry of Economy and Finance (MEF); (ii) at the provincial level, including Provincial Department(s) of Environment (PDoE); and (iii) NGOs and Development Partners like Conservation International, Flora and Fauna International (FFI) and World Wildlife Fund (WWF) who currently undertake related work on ecosystem valuation;
3. Considering a phased approach, starting with basin-specific accounting-compatible assessments with a small set of key ecosystem services – such as those in the current report - and evolving towards a more encompassing exercise that would in time be extended to the country's national boundaries. A phased approach could initially focus on representative watersheds where there are clear beneficiaries, as in the case of the Pursat Basin. Criteria for prioritizing areas for undertaking ecosystem service accounting-compatible assessments may include: Areas that are most at risk from degradation and forest loss; watersheds important for hydropower and irrigation, water production and sediment regulation. Additional ecosystem services that should be considered include water flow regulation with a particular focus on drought. Estimation of economic benefits of hydrological, carbon and tourism ecosystem services should be prioritized for the following reasons:
    a. Cambodia is experiencing a serious water shortage which is expected to be exacerbated by climate change. It is therefore important that RGC, through MoE and MOWRAM, strengthen management of important watersheds, like the Cardamom Mountains and Kulen Mountains, with protection of existing forest resources and restoration of degraded important watershed areas. Analysis of hydrological ecosystem services, as undertaken for this study, will be instructive for prioritizing areas for watershed management.
    b. Cambodia has invested significantly in hydropower plants on the Mekong River, and as well in the Cardamom Mountains. Ensuring as close to maximum operation capacity of these hydropower plants will be important for energy security in Cambodia especially in the dry season, and this means protecting forest watersheds that are upstream of this dam. Valuation of hydrological services can support schemes for hydropower companies to provide finance that can support the management of forest resources that provide critical water flow regulation and sediment regulation for the operation of hydropower plants.
    c. Carbon storage, as an ecosystem service, is strategic to analyze as there are well-established methodologies for doing this. The well-established carbon market establishes a price which often accounts for regulating ecosystem services (which have no market and/or are difficult to value) and biodiversity that facilitate carbon storage.
    d. Ecotourism development in PAs is a priority of the RGC to boost the overall tourism sector in terms of jobs and value added, provide incomes for rural and forest communities and generate resources that can help with PA management.
4. We would recommend that initial consideration for geographic priorities for undertaking such an assessment to include the watersheds that feed into the Tonle Sap and Kulen Mt. and Kbal Chay where the government is pursuing pilot PES projects;
5. The scoping and road map would most certainly highlight the need for enhancement on monitoring and generation of data for similar assessments and ultimately for accounting efforts:
    a. As changes in soil erosion and sediment accumulation are significantly affected by forest change and can result in large costs, it is recommended that monitoring of suspended sediment and bed load, at least at the site of the future dams or at the main gauging station be undertaken. Additionally, experimental plots

to monitor soil erosion rates could be helpful in verifying soil loss projections.

b. Rainfall variability in the mountainous region is high. Weather monitoring needs to be strengthened to derive accurate estimates to water resources available. This will become especially important as precipitation patterns continue to shift with a changing climate. A more extensive network of rainfall gauges is needed.

c. Groundwater often plays an important role, but data on groundwater are even less available than for surface water. Improved groundwater mapping and monitoring is needed to better understand the role that it plays. The first essential step of this should be to map the major aquifers, followed by identifying important recharge areas and travel time. Without this, we risk incomplete protection for water source areas, as we are limiting our source region of the rivers based on visible terrain slope contributing to the river water.

6. The benefits of forest for disaster reduction – flood mitigation and forest fire prevention – would also be important to capture in subsequent analysis. Data on the flood, drought and fire damages would be important for determining the benefits provided by forest in terms of disaster risk reduction;
7. Additional benefits that would be important to capture include: Water used for domestic purposes; recreational ecosystem services from ecotourism should be considered for areas where this is significant; non-timber forest products (NTFPs); and charcoal.

7 CONCLUSION

The development of a methodology for undertaking an ecosystem services assessment and valuation, including the results of this work, creates several strategic opportunities for the RGC to enhance its decision-making capability on investing in forests and Protected Areas and to quantify and communicate the value of its natural capital to Cambodia's economy. The contribution of this work is summarized as the following:

8. The hydrologic model developed in this analysis is a key contribution for:
   a. Quantifying what would happen if forest ecosystem were lost and therefore understanding the contribution of forests in helping to provide water flow regulation and sediment regulation services;
   b. Identifying and prioritizing areas in the landscape for forest conservation because they are important for water provisioning.
2. On the economic side, this work shows that the costs of losing forests are significant, and they negatively impact parts of the economy. Beneficiaries of the services are identified and these benefits quantified in monetary terms that allow for easier comparison with the costs of investment.
3. Upstream activities like land use conversion (e.g. forest to agriculture) have significant impacts for people in the downstream impacted by flooding, sedimentation and impaired water flows and there upstream-downstream linkages have been spatially identified and quantified in this work.

Akal village on Tonle Sap lake

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APPENDIX 1: DATA REQUIREMENTS

Date requirements	Description	Data used in this study
Precipitation & other climate data	Rainfall data from precipitation gauges and observatories in basin. Alternately, global remotely sensed datasets. Ideal coverage: at least most recent 10 years.	• Daily precipitation data made available by Cambodia's Ministry of Water Resources and Meteorology (MoWRAM) for a single precipitation gauge in the basin with coverage 2004-2018. • Daily precipitation estimates from the ERA5 global dataset at 13 points covering the basin has been extracted using Google Earth Engine (this was used for the hydrological model). • Humidity, wind speed and solar radiation for the period 1979-2014 from National Centre for Environmental Prediction Climate Forecast System Reanalysis.
Discharge	Observed discharge data at least recorded daily and based on segment downstream of the area under study. Ideal coverage: at least most recent 10 years.	• Discharge data for single downstream gauge (Bac Trakuon monitoring station) made available by MoWRAM & covering the period from 01-Jan 2007 to 31-Dec 2016.
Sediment yield and soil erosion data	Sediment yield studies, Turbidity data, Basic data layers for Universal Soil Loss Equation (USLE) model	• 30 arc-second resolution soil layer (Harmonized World Soil Database v 1.2) • No local monitoring data available
Land cover/ land use maps and terrain data	Validated land cover map of the region under study	• Official land cover for the year 2016 obtained from the Cambodia Ministry of Environment (MoE) • 30m resolution digital terrain model (SRTM)
Irrigation demand	Agricultural production maps, Irrigation requirements, Formally Irrigated land, Informally irrigated land and Rainfed irrigation land, Drought yields. Physical inputs to production and market price of those inputs	• List of irrigation works in the progress and total target irrigated areas for wet and dry season paddy cultivation (from MoWRAM). Rough information of local paddy crop pattern derived from MoWRAM reports Inputs: • Seeds • Manure • Fertilizers • Herbicide and insecticide

Date requirements	Description	Data used in this study
		Labor: • Land preparation • Plantation & transportation • Weed control • Crop management • Harvest & post-harvest Services: • Transportation • Irrigation
	Area of rice under cultivation in the study area Size of a typical rice farm (ha)	
Irrigation infrastructure	Scope, plan and status; Maintenance cost, Damage and repair costs, operation status of infrastructure	
Hydroelectricity	Location of hydropower dams (operational plus those under development) For each dam unit: *a.* Reservoir capacity/operation rules if available *b.* Actual electricity output (not capacity) per year *c.* Active lifetime *d.* Water use statistics *e.* Price of electricity *f.* Any data on sediment dredging dredging cost (if any), incl. dredging frequency *g.* Operating cost	• Location of 3 dams from global datasets • Some operating parameters for the planned hydropower dam (Dam 1) from Ministry of Mines and Energy (MME) • Electricity price • Cost of production • Total electricity generation • Soil bulk density • Discounting information • Dam lifecycle
Extreme events	Floods and droughts in the basin	• Anecdotal, from newspaper articles

APPENDIX 2: SWAT PARAMETERS

TABLE A2-1: SWAT LAND COVER CODES

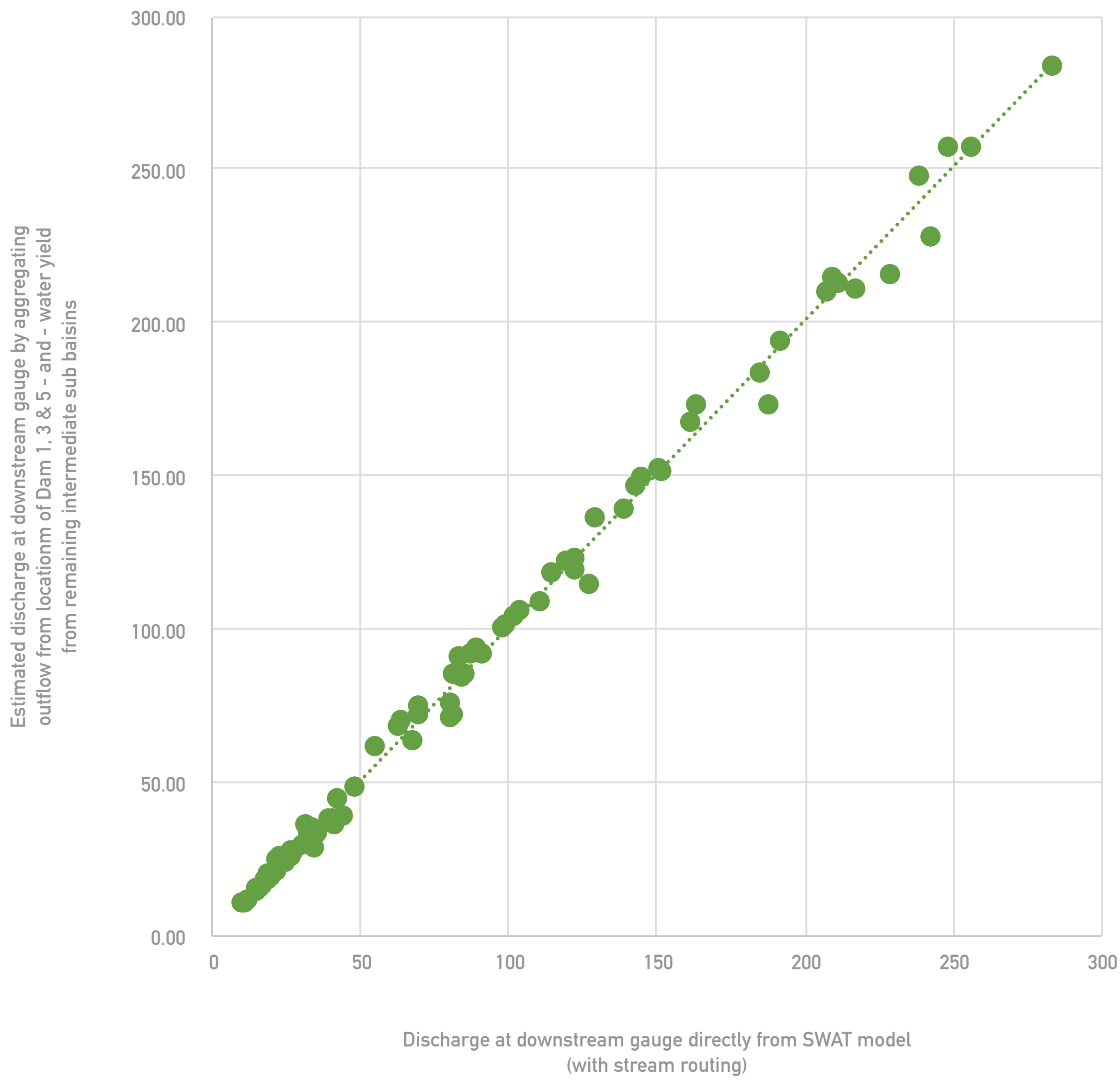
LC	Name
PAST	Pasture
RNGE	Range-Grass
FRST	Mixed Forest
FRSD	Forest-Deciduous
FRSE	Forest-evergreen
AGRL	Agricultural Land-Generic
WATR	Water
WETF	Wetland-forested
SWRN	South Western Range
BERM	Urban Medium Density

Source: https://oldgeni.isnew.info/landuse.html

TABLE A2-2: SWAT CALIBRATION PARAMETERS

SWAT Parameter	Min	Max	Best Simulation
v__ALPHA_BF.gw	0	1	0.743932
v__GW_DELAY.gw	0	500	4.276659
v__GWQMN.gw	0	5000	2950.77832
v__GW_REVAP.gw	0.02	0.2	0.147688
v__REVAPMN.gw	0	500	423.24704
v__RCHRG_DP.gw	0	1	0.180437
v__LAT_TTIME.hru	0	180	105.478706
v__SLSOIL.hru	0	150	95.762405
v__CANMX.hru	0	100	61.229294
v__ESCO.hru	0	1	0.793162
v__CH_N2.rte	0	0.3	0.174933
v__CH_K2.rte	0	50	39.94957
v__CH_N1.sub	0.01	0.3	0.091888
v__CH_K1.sub	0	50	35.175396

APPENDIX 3: SCATTER PLOT OF MONTHLY WYLD FROM SUB-BASINS AS DIRECTLY CONTRIBUTING TO MONTHLY DISCHARGE



APPENDIX 4: FOREST CONVERSION FOR AGRICULTURE AND CHARCOAL AND FOREST PROTECTION ESTIMATES

A spreadsheet model was developed to compare the stream of benefits and costs of forest conversion using net present value (NPV) analysis. NPV was determined to be US$22.1 million for 50 years at 6 percent discount rate. The assumptions and data tables that follow pertain to this. The analysis pertains to a 0.25 percent deforestation scenario which estimates that about 980 hectares of forest in the Pursat RB are converted each year.

0.25% deforestation scenario

Forest type	2016 forest cover (ha)	Average annual forest loss (ha)*	Estimated annual CO2 loss (t CO2e)
Evergreen	242,989	601	360,000
Semi-evergreen	53,223	132	67,000
Deciduous	100,903	250	77,000
Total	397,115	983	504,000

* Avg. over 10 years (2016-2025)

Assumptions:

i. Forestland conversion is done mainly for agriculture: 90 percent of conversion is to agriculture and 10 percent to charcoal.
ii. Cost of production is 50 percent lower than lowland paddies. Upland rice farming still follows traditional practices such as slash and burn for ethnic people while some have already adopted advanced technologies including land preparation, fertilization and pest control. Wet season yield - 1.2 t/ ha Source: Var et al. (2016) from MAFF Statistic
iii. Rice is grown only in the wet season as it is rainfed. Price is based on average price of Ibis Rice (Jan-Mar 2020) from Cambodia Rice Federation

http://www.crf.org.kh/?page=api_location_detail&menu1=592&menu2=1110&menu3=&menu4=&menu5=&id=1071&lg=en

iv. 6.41 kg of wood is needed to produce 1 kg of charcoal (GERES 2015).
v. Share of total above ground biomass used for charcoal of 80 percent (GERES 2015).
vi. This analysis assumes the same deforestation rate for all forest types. In reality, there may be some differences in the deforestation rates of the different forest types.
vii. Average price of charcoal at US$350/t (GERES 2015).

Inputs to Charcoal Production

	Unit	Unit Cost (US$)	Number of Units	Total (US$)
Labour	Man-days	7	28	196
Fees	Kowyun	0.50	50	25
Equipment	Kiln	50	2	100
Total	T Charcoal		25	321

Source: UNDP 2017

Biomass Estimation

Forest type	ABV Biomass (t/ha)	Avg annual forest loss (ha)	ABV Biomass loss (t)
Evergreen	163	601	97,963
Semi-evergreen	243	132	32,076
Deciduous	85	250	21,250
			151,289

Source: Cambodia Forest Reference Level 2016

Charcoal Production Estimates	
Est. ABV Biomass lost (t/ yr)	151,289
Est. Charcoal produced (t)/ yr	3,776
Est. benefits from Charcoal US$/ yr	1,321,714

Rice Production Costs	
Wet season US$/ha	50
Wet season US$	39,320

Rice Production	
Wet Season yield (t/ha)	1.2
Area converted (ha) for Ag	786.4
Rice price (US$/t)	178
Total yield (t)	943.7
Ag, Benefit (US$)	167,975

APPENDIX 5: TOURISM AND CARBON NPV ANALYSIS

Tourism benefits. Tourism benefits are quantified primarily based on expected changes in visitation data of tourists at project sites, average daily spending and average length of stay over a 50-year time horizon. Visitation data to tourism sites in Pursat province, and that were used where available, averaged over the two-year collection period. Average tourism spending and average stay length were derived from tourism statistics available from Cambodia's Ministry of Tourism and the Ministry of Environment. The "without project" scenario assumes that visitation continues at an estimated 9 percent annually over the project period, based on historical arrivals data at ecotourism sites nationally, over the preceding seven years. It assumes that spending per tourist remains constant (in real prices) in the absence of any infrastructure and capacity improvements (currently US$37.88 per day). The average length of stay continues to increase according to national historical growth rates (0.3 days increase over the project period), from a baseline of 2.5 days.

The "with project" conservatively estimates a 3 percent annual visitation growth above the "without project" projections, starting in Year 3 of the project (assuming infrastructure and capacity building spending is effectively implemented). It projects an annual 5 percent increase in overall tourist spending starting in Year 3 and the average length of stay increases by 1.5 days from a baseline of 2.5 days. This analysis is intentionally conservative and expects results beyond the projections considered, given the extremely low daily spending and length of stay baselines. Furthermore, multiplier benefits of the tourists' spending on local food, transport and lodging and the employment created are not quantified in this analysis as no value chain analysis (VCA) data were available but represent an additional stream of benefits that helps ensure that the overall conclusion is based on conservative assumptions. The number of visitors is capped at 200,000 as anything beyond this is likely to be unsustainable.

Emission reduction benefits. The value of emission reductions is estimated based on an updated GHG analysis using data from the Cambodia's Initial Forest Reference Level under the UNFCCC Framework report and estimations of GHG emissions reductions were modeled using the Food and Agriculture Organization (FAO) EX-ACT model. The analysis follows the "with" and "without project" scenarios to model the reduction in rate of forest loss and degradation. To place a value on the benefits of reducing carbon emissions a conservative value of US$5 t/ CO2e was used.

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