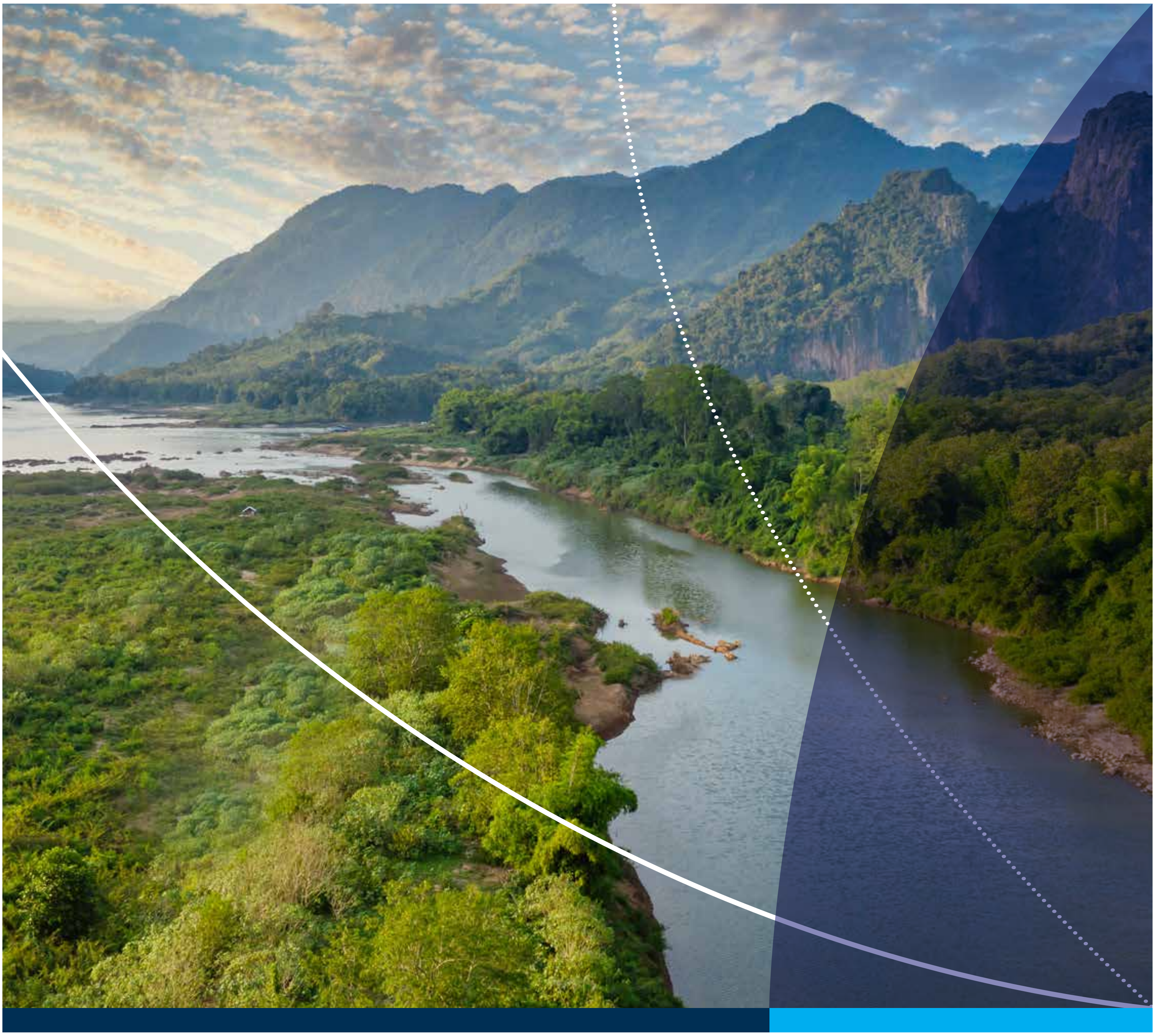

Cumulative Impact Assessment and Management of Renewable Energy Development in the Sekong River Basin, Lao People's Democratic Republic

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Table of Contents

APPENDIXES

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

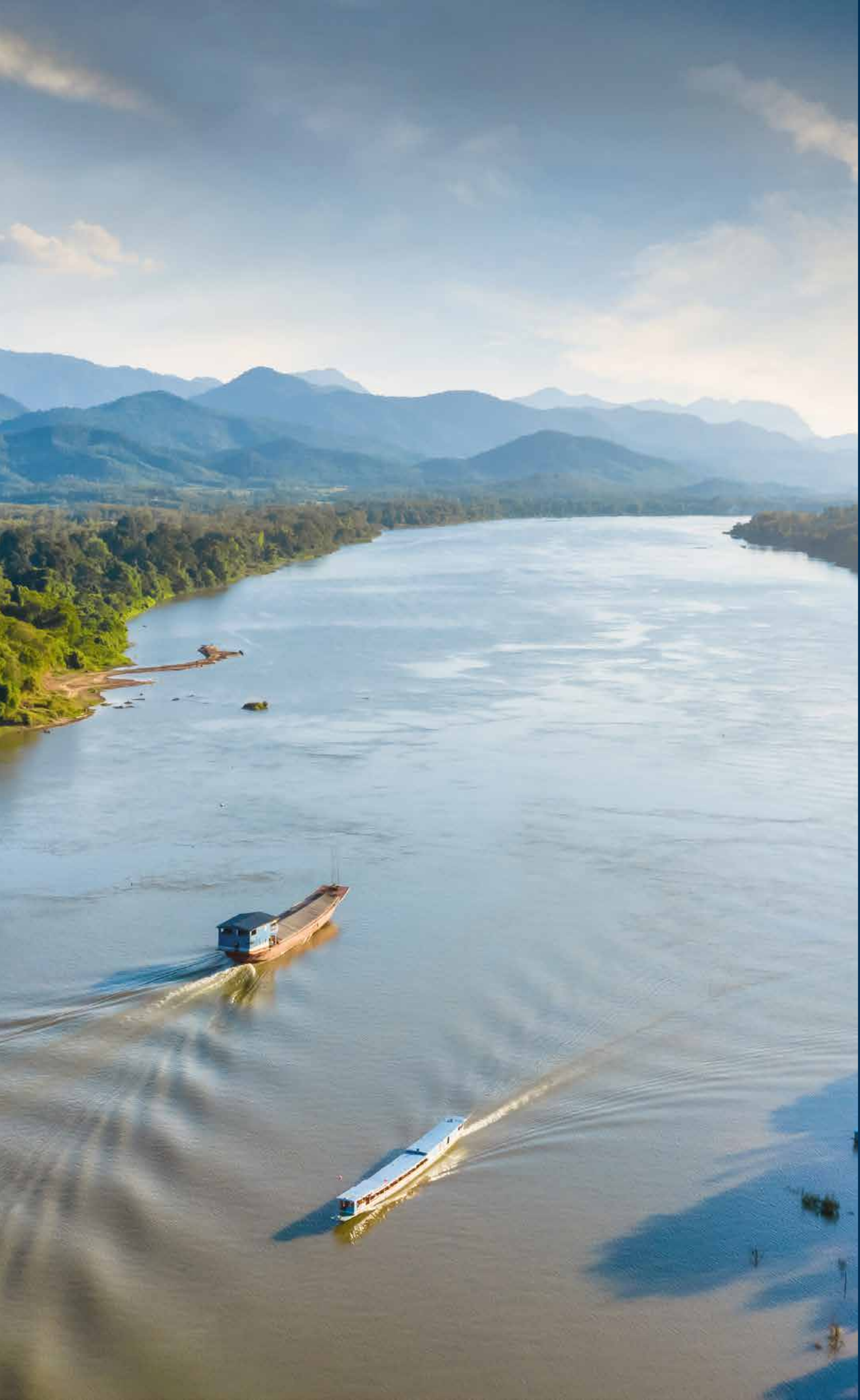
LIST OF BOXES

LIST OF PHOTOS

Acronyms and Abbreviations

3S	Sekong, Sesan, and Srepok
CIA	Cumulative Impact Assessment
COD	Commercial Operation Date
EDL	Électricité du Laos
EFlow	Environmental Flows
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EVN	Électricité du Vietnam
EWN	Energy-Water Nexus Project
FO	Fuel Oil
FS	Feasibility Study
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
GMS	Greater Mekong Sub-Region
GWh	Gigawatt-Hour
HEC-HMS	U.S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System
HEC-ResSim	U.S. Army Corps of Engineers, Hydrologic Engineering Center, Reservoir System Simulation
HPP	Hydropower Plant
IBAT	Integrated Biodiversity Assessment Tool
IFC	International Finance Corporation
IPSL	Institut Pierre Simon Laplace
IUCN	International Union for Conservation of Nature
kg	kilogram

km^2	square kilometer
kV	Kilovolt
kWh	kilowatt-hour
Lao PDR	Lao People's Democratic Republic
LCG	Lao Consulting Group
masl	Meters Above Sea Level
MEM	Ministry of Energy and Mines
mm	millimeter
MRC	Mekong River Commission
MSWEP	Multisource Weighted-Ensemble Precipitation
m^3/s	Cubic meter per second
Mt	Million Tons
MW	Megawatt
NPA	National Protected Area
NPF	National Protected Forest
NTFP	Non-Timber Forest Product
PDA	Project Development Agreement
PDP	Power Development Plan
RCP	Representative Concentration Pathway
ROR	Run-of-River
SRB	Sekong River Basin
SRTM	Shuttle Radar Topography Mission
TSS	Total Suspended Solids
TWh	Terawatt-Hour
VEC	Valued Environmental Component



EXECUTIVE SUMMARY

The present Cumulative Impact Assessment (CIA) and Management of Renewable Energy Development in the Sekong River Basin of the Lao People's Democratic Republic aims to support decision making for sustainable development of renewable energy resources. In the past, private sector interests have largely directed developments in the basin on a first-come, first-served basis. The findings of the CIA indicate the need for a Sekong Basin power development master plan incorporating renewable energy (hydropower, solar, and wind) and thermal power. There is an opportunity to establish the trajectory of future development based on a strategic assessment of local and regional power demand and with consideration of the range of potential uses of natural resources in the basin. This approach would result in greater investment efficiency, a close match between power production and demand, and more opportunities to address adverse impacts through the full range of options available in the mitigation hierarchy.

The Sekong River is an important transboundary river in the Lower Mekong region, with a total length of 516 kilometers. It originates in the mountains of Vietnam, flows into Lao People's Democratic Republic (Lao PDR), and continues into Cambodia, where it eventually joins the Mekong River. The Sekong River Basin (SRB) covers a total area of 29,000 square kilometers, of which 78 percent is within the territory of Lao PDR. It is one of the few remaining major Mekong River tributaries with high biodiversity value and relatively few hydropower projects in operation.

Topography in the basin comprises a mix of steep mountains in the upper watershed, high plateaus, lowland hills, and floodplains. Annual precipitation rates are high (1,400–2,900 millimeters) and seasonal, resulting in a large difference in flow in the Sekong River between the wet season—about 1,200 cubic meters per second on average in August and September—and dry season (about 100 cubic meters per second average in April). The Sekong, Sesan, and Srepok river basins, combined called the 3S basin, contribute approximately 23 percent of the annual flow and (in an unregulated state) up to 25 percent of the sediment load in the Lower Mekong River.

A rapid expansion of power generation in the SRB is planned for the next decade, increasing from 12 hydropower projects today—1,550 megawatts (MW) of installed capacity—to 35 projects by 2030 (3,512 MW). Several feasibility studies for wind and solar projects in the SRB are under way; it is estimated that there will be at least 600 MW for each by 2030. A coal-fired thermal power plant is proposed in Kalum District, Sekong Province.

The focus of power generation is mostly export to neighboring Thailand, Vietnam, and Cambodia, where demand forecasts are strong. Lao PDR has an agreement to export 5,000 MW of electricity to Vietnam by 2030, and much of this could be sourced from the SRB, given the proximity to southern Vietnam, where population density and demand is considerable.

Although hydropower and renewable energy development has the potential to help Lao PDR meet national development targets, the pace of change carries risks of significant environmental and social impacts.[1] *Individually*, hydropower projects can affect the aquatic and terrestrial environment, ecosystem services, communities, and peoples' livelihoods. *Cumulatively*, multiple projects within the same river basin can magnify these adverse impacts by greatly altering the flow regimes of the rivers, water quality, and sediment transport, with effects on aquatic life and terrestrial habitats and natural resources, which in turn affect local people's livelihoods.

In recognition of these challenges, the government of Lao PDR has strengthened policies and regulations for assessment of cumulative impacts and promoting integrated water resource management. One such initiative has been preparation of Cumulative Impact Assessment (CIA) Guidelines for Hydropower Projects in Lao PDR by the Ministry of Natural Resources and Environment. The objective of the guidelines—currently in draft form—is to improve and strengthen CIAs for individual hydropower projects and to help developers and regulators go beyond individual project-level impact assessments for sustainable basin-scale planning and integrated management of natural resources.

IFC, in partnership with the Ministry of Energy and Mines and other stakeholders, has undertaken this CIA of renewable energy in the SRB to support decision making for sustainable development of renewable energy resources and to

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[1] For the purposes of this cumulative impact assessment, renewable energy development focuses on hydro, wind, and solar power.

pilot the draft guidelines on CIAs. Specific aims of this CIA are the following:

- To plan and execute an integrated assessment of the cumulative impacts of renewable energy development in the SRB, including power optimization and development scenarios
- To lead the participatory design of a framework for ongoing river basin co-management in the SRB, including collaborative environmental and social impact monitoring and management
- To strengthen the skills of SRB stakeholders in CIA approaches and co-management.

Method and Approach

Successive and incremental environmental and social impacts from multiple developments over time can result in significant cumulative impacts that would not be identified through even the most thorough project-specific environmental and social impact assessment. A CIA is a systematic process of identifying and analyzing potential environmental and social risks and impacts resulting from past, current, and anticipated developments.

This is accomplished through a screening process that identifies environmental and social attributes that actions, projects, and activities within the scope of the CIA are likely to affect significantly. These attributes are termed *valued environmental components* (VECs). VECs considered important in assessing risks may be the following:

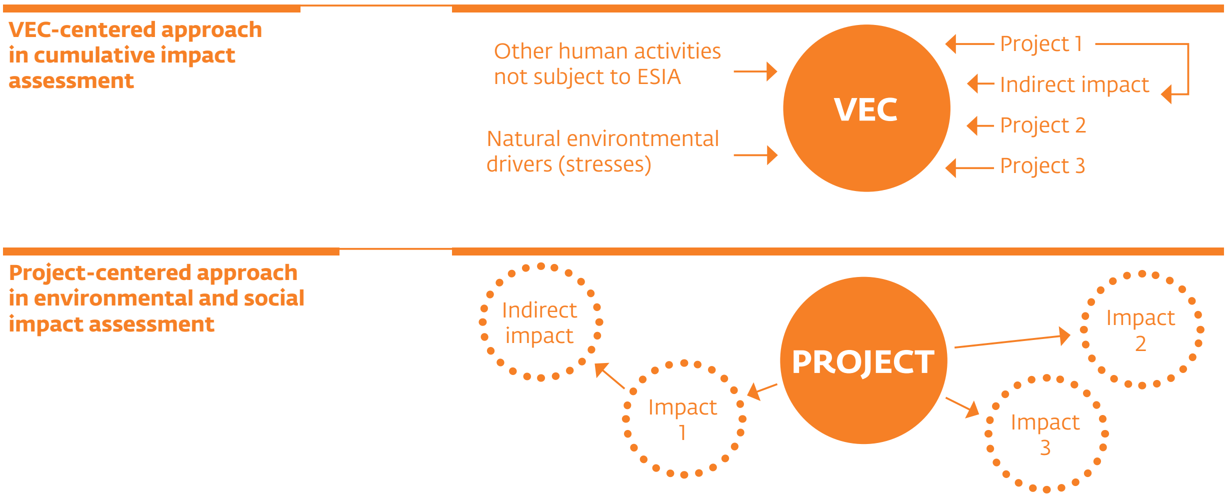
- Physical features, habitats, and wildlife populations (for example, biodiversity)
- Ecosystem services
- Natural processes (for example, water and nutrient cycles and microclimate)
- Social conditions (for example, health and economics)
- Cultural activities (for example, traditional spiritual ceremonies)

VECs are selected based on scientific data and feedback from stakeholders. The CIA guidelines for hydropower plants in Lao PDR define VECs as any part of the environment and social fabric that the proponent, local communities, environmental specialists, social scientists, and government consider important after a thorough assessment.

These VECs are the focus of the CIA process. The difference between a CIA and an environmental and social impact assessment (ESIA) is illustrated in Figure ES.1.

Substantial data modeling was undertaken for this CIA. Global satellite data were used in conjunction with available rain-gauge data to produce daily rainfall series across the SRB for a 24-year period, from 1991 to 2014. Together with climate-change modeling, this provided inputs for a hydrological model—U.S. Army Corps of Engineers, Hydrologic Engineering Center

Figure ES.1: **Comparison of Cumulative Impact Assessment and Environmental and Social Impact Assessment**



Note: VEC = valued environmental component; ESIA = environmental and social impact assessment.

Hydrologic Modeling System (HEC-HMS)—and the results of this model became the input for the Reservoir System Simulation Hydropower Model (HEC-ResSim), which was used to model sediment transport and simulate power generation for different configurations of hydropower in the SRB. Modeling was also conducted to explore opportunities to optimize power production through coordinated reservoir operations along the mainstream of the Sekong River.

Assessment Steps

The CIA for the SRB follows the six-step process illustrated in Figure ES.2 as per IFC's *Good Practice Handbook on Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets* (2013).

Step 1: Determining Spatial and Temporal Boundaries

The primary spatial boundary of the study area is the SRB, although downstream and transboundary impacts on the Mekong River in Cambodia and Vietnam as far as the Mekong Delta were also considered. On a sub-basin scale, hydrological modeling was conducted to evaluate the local effects of hydropower projects on river flows in Sekong tributaries.

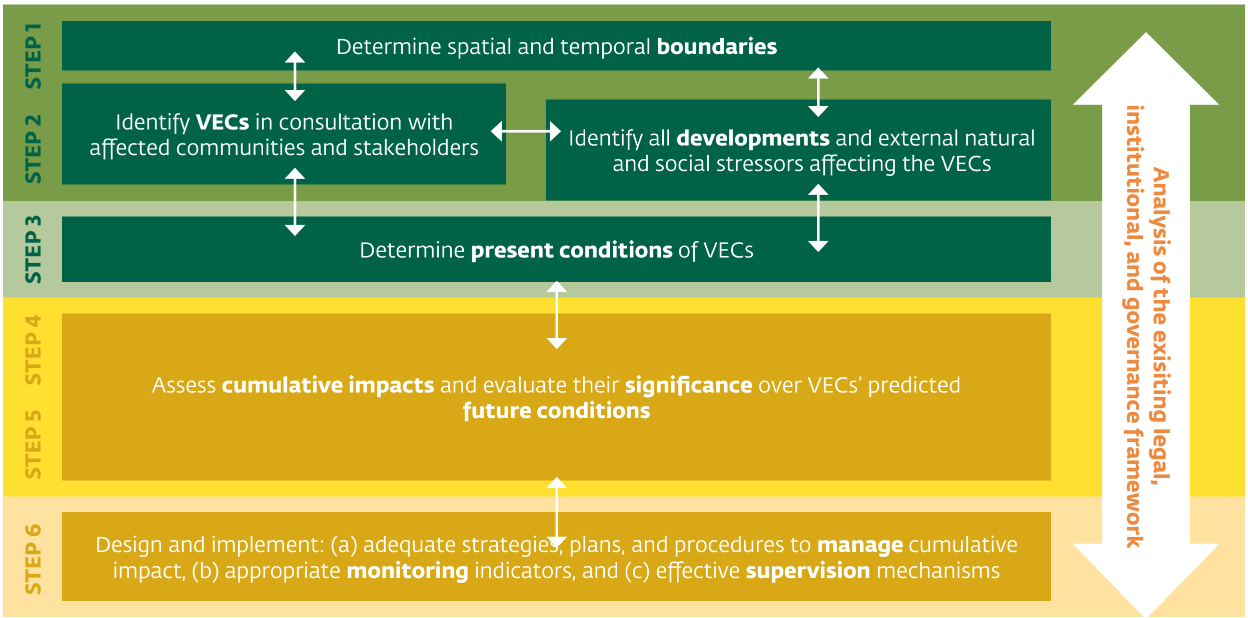
The primary timeframe for the CIA is 2030, when most proposed hydropower projects for the SRB are planned to be operational. Climate change effects are modeled over a longer period—until 2090.

Step 2: Identify VECs, Developments, and Stressors

The CIA focuses on four broad categories of environmental and social values (Table ES.1). These were identified through field visits, a literature review, specialist advice, and consultation with a diverse range of stakeholders. Key stakeholders in Lao PDR, Cambodia, and Vietnam included the following:

- Government—central government ministries and local authorities involved in planning, assessment, and permitting processes for renewable energy projects and infrastructure, such as roads, irrigation, and mining in the SRB
- Project developers—owners and operators of renewable energy projects in the SRB
- Development partners and other stakeholders—donors, lenders, non-governmental organizations, and research organizations with interest in the SRB and questions related to renewable energy, biodiversity, and rural livelihoods
- Local communities—riparian villages in the SRB

Figure ES.2: **Cumulative Impact Assessment Process**



Source: IFC 2013.
Note: VEC = valued environmental component.

Table ES.1: Valued Environmental Components Identified and Evaluated

Component	Description
Aquatic biodiversity and ecosystems	• Aquatic habitats, flora, and fauna with important conservation status (threatened and endangered species) • Super endemic fish (found only in the SRB) and migratory species
Terrestrial biodiversity and ecosystems	• Habitats important for biodiversity and ecosystem functions • Designated protected areas and conservation sites • Endangered and critically endangered terrestrial species
Natural resource–dependent livelihoods	• Habitats, flora, and fauna (terrestrial, riparian, and wetland) important for rural livelihoods and food security • Timber resources, including wood for construction, firewood, and charcoal • Non-timber forest products for food security, medicine, construction, and trade • Capture fisheries in the Sekong mainstream and tributaries • Wet-rice agriculture on river flood plains, upland fields, and dry season riverbank gardens
Culture and heritage	• Cohesive communities • Linguistic and cultural diversity, traditional knowledge, and ethnic identity • Gender roles and opportunities

Within the SRB, a range of mainly human activities may affect the condition of VECs. For this CIA, the following were identified and examined:

- Large and medium-sized hydropower projects
- Wind and solar power projects
- Associated supplementary infrastructure (for example, transmission lines, and roads)
- Industrial and agricultural development (for example, mining and plantations)
- Water abstraction (irrigation, water supply, and water diversion)
- Extraction of river resources (fisheries, sand, and gravel)
- Extraction of forest and wetland resources
- Climate change effects on the hydrological regime of the SRB

Hydropower development is likely to be the single biggest stressor on most VECs in the SRB over the next decade due to the substantial hydropower development over the past decade and ambitious plans over the next 10 years (Table ES.2).

In addition to the 12 projects currently operational or nearing completion, private investors have proposed 23 projects for development.

Accurately predicting future developments in the SRB is challenging for two reasons. First, some proposed renewable energy projects at the early design stage may be unfeasible for technical or economic reasons. Second, limited domestic power demand in Lao PDR means that the commercial viability of many proposed projects will hinge on securing power purchase agreements for export to neighboring Vietnam, Thailand, and Cambodia (as well as construction of the necessary cross-border transmission infrastructure).

Given this uncertainty, this CIA compares three renewable energy development pathways for the SRB: conservative, intermediate, and full development. The present situation in 12 active projects is also considered. The pathways have been selected to demonstrate the difference in cumulative impacts created by varying the intensity and configuration of projects.

Figure ES.3 outlines the three development pathways in terms of their power generation. Map ES.1 depicts all existing and planned hydropower projects under the full development pathway.

Table ES.2: Existing and Planned Hydropower Projects in the Sekong River Basin

Project Name	Status	Date of commercial operation	Installed capacity (MW)	Mean annual energy (GWh)	Power destination	Pathway[2]			
						Present situation	Conservative development	Intermediate development	Full development
A Luoi	Operational	2012	170	650	Vietnam	X	X	X	X
Houay Ho	Operational	1999	152	450	Thailand	X	X	X	X
Xe Kaman 3	Operational	2013	250	980	Vietnam	X	X	X	X
Xe Namnoy 6	Operational	2013	5	20	Lao PDR	X	X	X	X
Xe Namnoy 1	Operational	2014	15	80	Lao PDR	X	X	X	X
Houay Lamphan Gnai	Operational	2015	88	450	Lao PDR	X	X	X	X
Xe Kaman 1	Operational	2016	290	1,040	Vietnam	X	X	X	X
Xe Kaman Sanxay	Operational	2017	32	110	Vietnam	X	X	X	X
Nam Kong 2	Operational	2017	66	260	Lao PDR	X	X	X	X
Xe Katam 1 Xe Namnoy 2	Operational	2017	22	120	Lao PDR	X	X	X	X
Xe Pian Xe Namnoy	Construction	2020*	410	1,800	Thailand	X	X	X	X
Nam Kong 3	Construction	2020*	54	200	Lao PDR	X	X	X	X
Dakchaliou 1	Construction	2021	11	50	Unknown		X	X	X
Dakchaliou 2	Construction	2021	13	60	Unknown		X	X	X
Nam Kong 1	Construction	2022	150	560	Lao PDR		X	X	X
Nam Bi 1	PDA stage	2024	68	290	Vietnam		X	X	X
Nam Bi 2	PDA stage	2024	50	210	Vietnam		X	X	X
Nam Bi 3	PDA stage	2024	12	50	Vietnam		X	X	X
Nam Ang	PDA stage	2024	55	160	Lao PDR		X	X	X
Nam Emoun	Construction	2024	129	430	Lao PDR		X	X	X
Nam Pangou	PDA Stage	2025	33	140	Unknown		X	X	X
Xe Pian-Houysoy	PDA stage	2025	45	200	Lao PDR		X	X	X
Lower Xe Pian	FS ongoing	2030	15	60	Lao PDR		X	X	X
Xe Katam	PDA stage	2030	81	300	Lao PDR		X	X	X
Xe Kaman 2A	FS ongoing	2030	64	250	Lao PDR		X	X	X
Xe Kaman 2B	FS ongoing	2030	100	380	Lao PDR		X	X	X
Xe Kaman 4	PDA stage	2030	70	290	Vietnam		X	X	X
Xe Namnoy 5	Unknown	2030	20	90	Lao PDR		X	X	X
Sekong 5	FS completed	2030	330	1,500	Thailand			X	X
Sekong 4B	FS approved	2026	175	750	Thailand			X	X
Sekong 4A	FS approved	2025	165	780	Thailand				X
Sekong 3A	FS completed	2027	114	460	Lao PDR				X
Sekong 3B	FS completed	2028	122	400	Lao PDR				X
Sekong Downstream A	FS completed	2030	86	380	Lao PDR				X
Sekong Downstream B	FS completed	2030	50	210	Lao PDR				X

**at the time of the report preparation.*
Note: MW = megawatt; GWh = gigawatt-hour; Lao PDR = Lao People's Democratic Republic;
PDA = project development agreement; FS = feasibility study.

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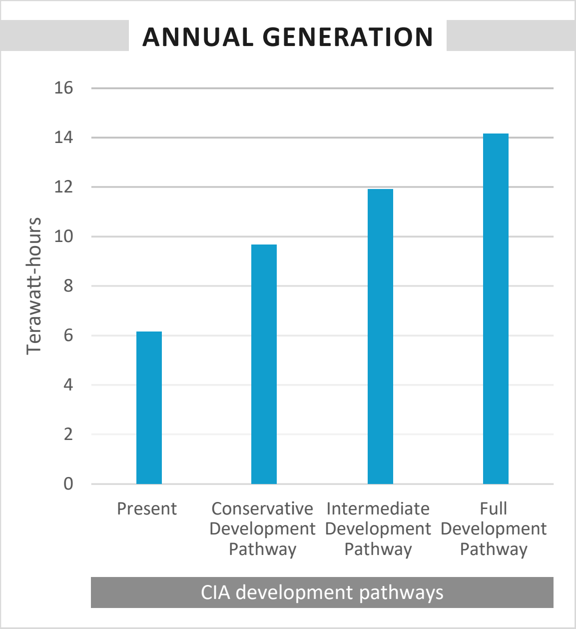
[2] Xs indicate which plants have been considered in respective pathways. If no Xs, the plant is not being considered.

Figure ES.3: **Cumulative Impact Assessment Development Pathways in the Sekong River Basin**

Conservative development pathway:
28 projects with 2,470 MW of installed capacity, including 12 existing projects. The Sekong mainstream remains unregulated to maintain fish migration routes and sediment transport downstream.

Intermediate development pathway:
30 projects with 2,975 MW of installed capacity, including 12 existing projects. Most development occurs on Sekong tributaries, except for two in the upper reaches of the Sekong mainstream. The pathway is designed based on a trade-off between power and non-power interests.

Full development pathway:
35 projects with 3,512 MW of installed capacity, including 12 existing projects and 23 projects proposed for completion by 2030.



Map ES.1: **Full Development Pathway in the Sekong River Basin—All Planned and Proposed Hydropower**

Source: Shuttle Radar Topography Mission (SRTM), Mekong River Commission (MRC), Greater Mekong Sub-Region

Step 3: Determine Baseline Conditions of the VECs

Aquatic Habitats and Biodiversity

The Sekong River is home to more than 200 fish species, of which approximately one-third are migratory. As the last major free-flowing tributary to the Mekong River, the Sekong River provides passage for migratory fish between the Mekong mainstream, the Tonle Sap Great Lake, and the Vietnam Delta. International Union for Conservation of Nature data indicate the presence of 21 endangered and critically endangered fish species in the basin, including some endemic species unique to the basin. Villagers consulted for this study report a large decline in the number of many fish species over the past 15 years, which they attribute to combined pressures of overfishing, industry, mining, agriculture, and hydropower development.

Terrestrial Habitats and Biodiversity

The SRB is rich in terrestrial biodiversity and habitats. It is home to 89 globally threatened vertebrate species classified as critically endangered, endangered, and vulnerable. Many of these species have small populations and are threatened by hunting, habitat loss, land use change, and deforestation.

Four National Protected Areas (NPAs) have been established covering 39 percent of land within the SRB. The Xe Pian NPA, in the south of the SRB, ranks second in Lao PDR and among top 10 in Asia for biodiversity. The Dong Ampham NPA, in the east, adjoins a similarly rich biodiversity area in Vietnam and is considered a regionally significant conservation corridor. The Beung Kiat Ngong Wetland, in the west, is an internationally recognized Ramsar site comprising 2,360 hectares of swamps, lakes, and marshes important for spawning fish, turtles, and birds. Parts of the Sekong floodplain contain critical habitats for freshwater birds. These protected areas function as important refuges to sustain populations of endangered species.

Forest is an important habitat for many terrestrial species in the basin. Although forest cover is relatively extensive, comprising natural deciduous and evergreen forests, it has declined over the past decade mainly due to clearance for agriculture. Conversion of forest to agriculture also affects aquatic habitats because it increases surface water runoff, erosion, turbidity, and flash floods.

Natural Resource–Dependent Livelihoods

The population of the SRB is estimated at 324,000 (across Lao PDR, Cambodia, and Vietnam). Across the SRB in Lao PDR, the population is mainly concentrated in the lowland plains and engaged in livelihoods highly dependent on terrestrial and aquatic natural resources.

Subsistence and semi-subsistence agriculture are the mainstay of rural livelihoods in the basin, with more than 80 percent of households engaged in farming. Main crops are paddy rice (in lowland areas), hill rice and swidden crops (in upland areas), and riverbank gardens (in riparian communities). Many households also keep livestock (poultry and cattle). Growing of cash crops is limited, although coffee is widely grown in the Bolaven Plateau and provides an important source of income for local communities.

Non-timber forest products (NTFPs) are a significant component of rural livelihoods. Wild plants and wildlife (for example, bamboo, fruits, edible leaves, resins, nuts, birds, and insects) are collected to eat and in some cases to sell. NTFPs are particularly important during periods of rice shortage. Forests also provide firewood and construction materials. NTFPs such as bamboo shoots and rattan are an important source of cash income for women.

After agriculture, capture fisheries provide the second largest source of income—up to 40 percent of annual household incomes in some cases. Fish are also important for food security and nutrition; consumption is estimated at nearly one kilogram per week per person, providing 80 percent of dietary protein.

Culture and Heritage

A diversity of ethnic groups with distinct cultures and beliefs populate the SRB. Ethnic Lao form the majority in some parts of the SRB (for example, in Pathoumphone District), whereas elsewhere the population is a mix of groups belonging to the Mon-Khmer language family (for example, Nya Heun, Brao, Ta-Oy, Katu, Jeh, and Kriang).

Socio-economic development within the SRB in recent decades has contributed to increasing cultural assimilation of Mon-Khmer minority ethnic groups into lowland culture. Use of ethnic languages is declining among the younger generation, particularly among men and in urban areas, as is wearing traditional clothing.

Step 4: Assess Cumulative Impacts on VECs and their significance

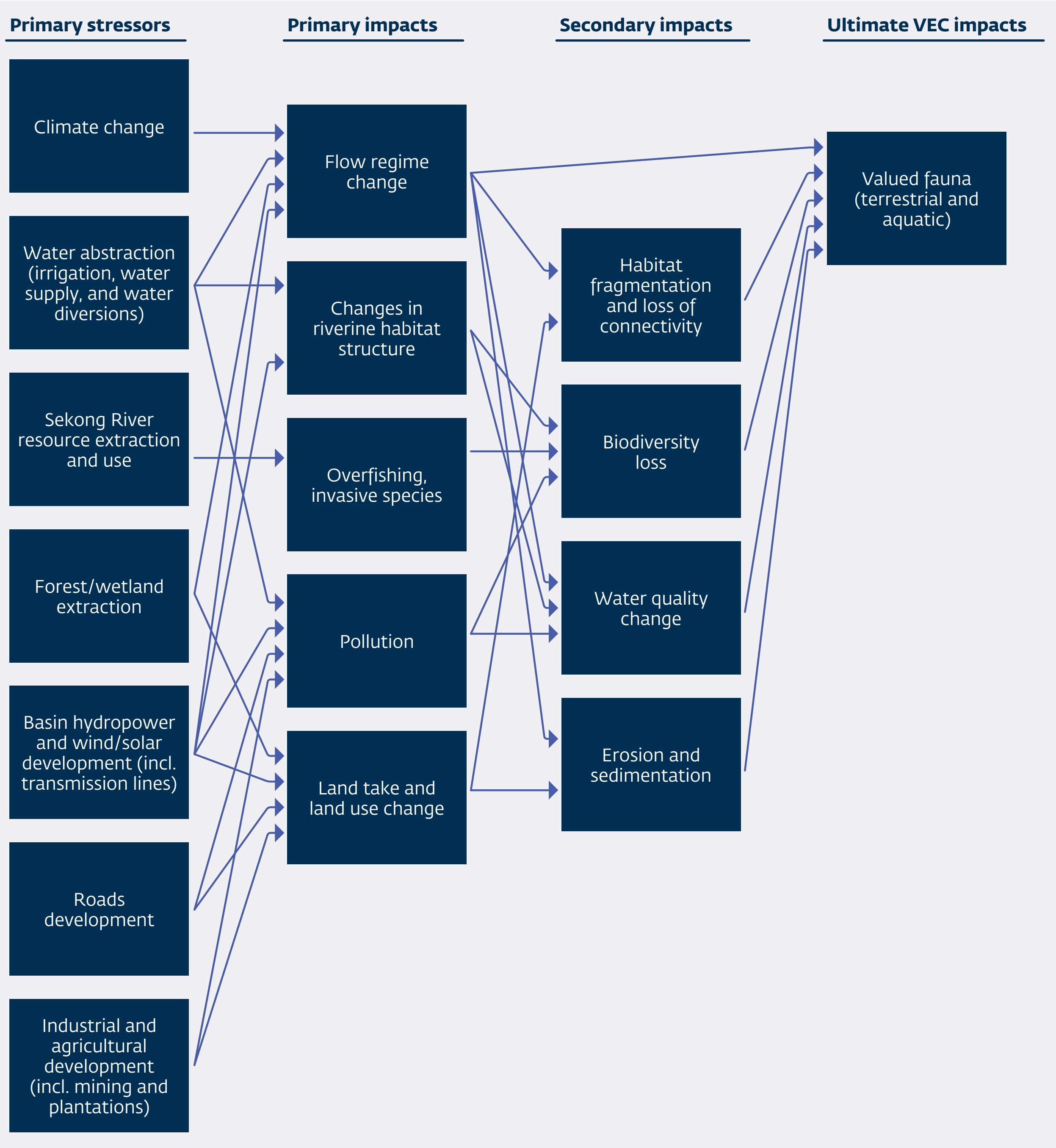
CIAs identify and evaluate multiple direct and indirect impacts on VECs that can be traced back through a chain of cause-and-effect to primary stressors (natural and human). An example of this cause-and-effect chain is illustrated in Figure ES.4. This step outlines the changes likely to occur from hydropower development in the SRB and will vary depending on the development pathway chosen for the SRB.

Flow Regime Changes

The greatest cause of flow alteration in the SRB is reservoir dams. Water extraction for irrigation has not been identified as significant, and climate change modeling predicts only small changes.

Reservoirs have been modeled using HEC-ResSim software to assess seasonal flow variations resulting from existing and planned hydropower projects. The results show a general pattern of lower wet season flows and higher dry season

Figure ES.4: **Cause-and-Effect Chain for Cumulative Impacts on Aquatic and Terrestrial Valued Fauna**



flows but with substantial variation in different sub-basins of the SRB, according to the number and scale of upstream dams.

Important flow regime changes due to hydropower development are of three types: flood frequency, dry season flows, and daily flows.

Flood Frequency

The SRB has historically experienced frequent flooding in lowland areas (due to factors including large catchment area, high rainfall, and steep topography in the upper watershed and extensive river plain). Large floods resulting in "bank full"[3] conditions (about 5,000 cubic meters per second) occur on average every 20 years; before recent hydropower development in the basin, the average time between floods was eight years.

Development of additional hydropower projects with large storage reservoirs in the SRB will tend to reduce the size and frequency of flood events (assuming reservoirs have sufficient storage capacity to accommodate inflows during flood events). The degree of modification will depend on the number and type of hydropower projects and the operational practices.

Fewer large flood events would result in less damage and disruption to riverbank settlements and riparian livelihoods but also less deposition of nutrient-rich sediment on alluvial plains, which is important for agriculture development.

Dry Season Flows

In addition to moderating wet season flows and potentially regulating floods, large storage reservoirs tend to increase dry season flows because water stored during the wet season is released to generate power over the remainder of the year.

Analysis conducted for this CIA shows that, in recent years, average flow in the Sekong River in the dry season (low flow) has nearly tripled and additional hydropower development will result in further modest increases proportionate to the number and size of reservoirs constructed.

Higher river levels during the dry season may impede access to river crossings, sand bars, and other sites of human interest along the river, although additional flow may be beneficial for river navigation and crop irrigation.

Daily Flows

Hydropower storage reservoirs operated for peak power generation tend to cause river levels downstream to vary throughout the day. The degree of variation depends on the operating rules of individual hydropower projects and the combined effect of multiple projects operating within a river system. Most storage hydropower plants in the SRB (built and planned) provide peak power to neighboring Thailand and Vietnam, and in the absence of a re-regulating dam, daily flow variations can be expected to meet power purchase agreement commitments. Rapid daily flow variations can lead to riverbank erosion, degradation of aquatic habitats, stranding of fish, damage to riverbank gardens, and—in extreme cases—community safety risks.

Changes in Sediment Transport

Reservoir dams tend to collect sediment and substantially reduce movement of sediment downstream. In a cascade of dams, the effect tends to be cumulative. Modeling conducted for this CIA indicates a 60 to 70 percent reduction in sand and courser grain sizes in the lower part of the Sekong River if all planned hydropower projects are built, although silt and clay fractions will be less affected. The significance of reduced sediment transport by the Sekong River will depend on hydropower developments elsewhere in the Lower Mekong region. The Sekong River contributes approximately 5 percent of total sediment in the Mekong River in northern Cambodia, but if all proposed dams along the Lower Mekong mainstream are built, the contribution of the Sekong River's sediment would increase to 40 percent.

Reduced sediment transport will have a variety of effects downstream. Sediment is an important conduit of nutrients important for fisheries and agriculture. Sediment also acts to maintain the geomorphology of the river system, so a reduction may lead to changes in substrate and riverbank and riverbed erosion. Transboundary problems include effects on alluvial sand extraction operations in Cambodia and stabilization of the Mekong Delta in Vietnam.

Dams can be designed with sediment-flushing mechanisms, but these tend to be of limited utility when reservoirs are large and long, as is the case of many of the proposed SRB dams. Sediment transport will decline from approximately

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[3] "Bank full" refers to the water level at which a river reaches top of its banks and any further increase would result in water spilling out into the floodplain.

5.0 million tons to 2.2 million tons per year by 2030 if all planned dams are built; sediment flushing will make only a slight difference (Figure ES.5).

Aquatic Habitats and Biodiversity

As a result of changes in flows during the dry and wet seasons, higher water levels in the dry season can harm fish because low flows support suitable habitat conditions for aquatic animals and facilitate different processes and life stages of aquatic and riparian animals. A reduction in high flows in the wet season would impede channel-floodplain connectivity, with adverse effects on species moving between these habitats.

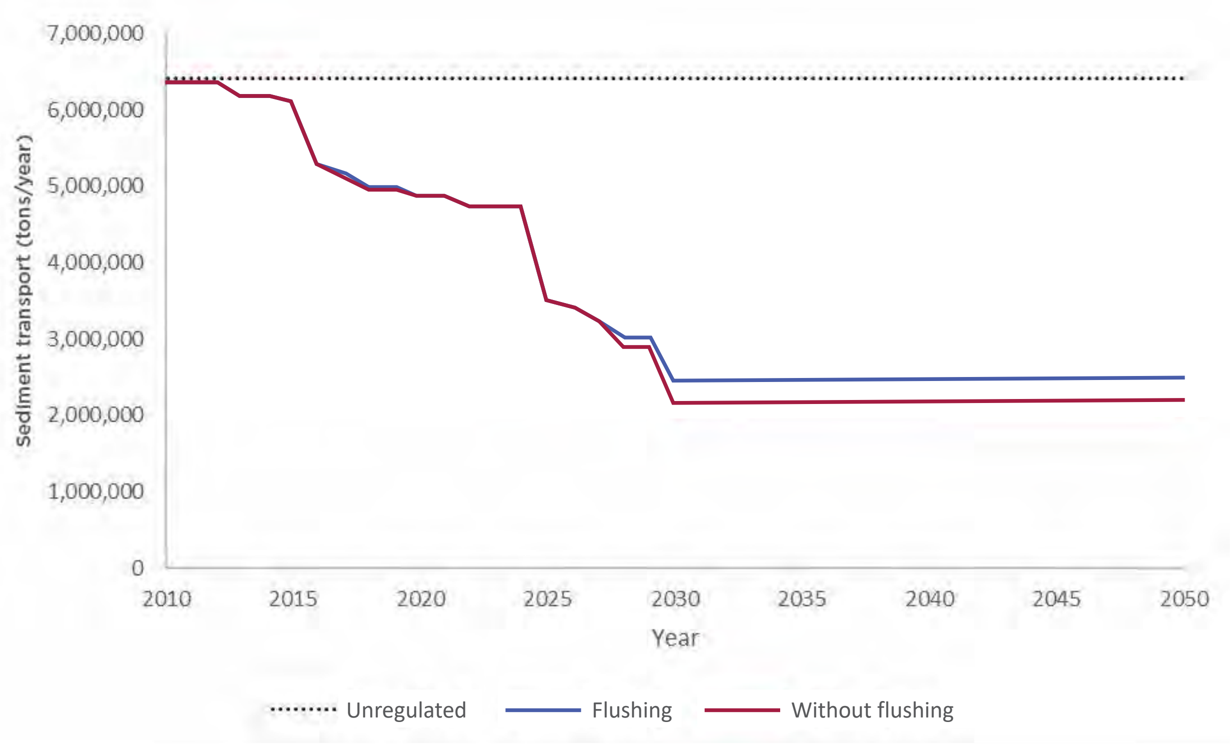
Physical blockages caused by dams and consequent modifications of aquatic habitats will fragment aquatic habitats and reduce river connectivity. Dams will decrease the length of rivers available to fish populations and fundamentally change the habitat from riparian to stagnant conditions. Substantial reductions in connectivity and fragmentation of habitats will threaten the survival of some fish species and populations if too little habitat remains available.

Terrestrial Habitats and Biodiversity

Development of reservoirs, powerhouses, worker camps, transmission lines, and access roads can reduce or affect forest habitats, conservation areas, and biodiversity directly through land conversion and indirectly through habitat fragmentation. Project access roads and transmission lines facilitate access, leading to more hunting, harvesting of forest resources, and habitat disturbance. Resettlement of communities may lead to pressures on forest resources in new locations.

For this CIA, impacts on terrestrial habitats have been assessed by measuring the extent of national biodiversity conservation areas and other conservation zones flooded by hydropower reservoirs and used for project infrastructure. Impacts on terrestrial biodiversity have been evaluated using a small number of reference species in the SRB that are globally endangered, are sensitive to large-scale infrastructure developments, and have habitat ranges that hydropower projects would affect. For each species, impacts have been estimated in terms of habitat loss (calculated as the proportion of designated conservation areas that project

Figure ES.5: **Impacts of Full Development Pathway of Flushing on Sediment Transport Downstream of the Lao People's Democratic Republic–Cambodia Border**



footprints directly affect), habitat fragmentation (due to reservoirs, transmission lines, and access roads), and proximity of projects to conservation areas (weighted according to the number of globally threatened species present).

Proposed hydropower projects on the upper reaches of the Sekong mainstream and Nam Emoun tributary are likely to cause the most impact to the biodiversity-rich forests in the Xe Xap NPA and surrounding area. Project roads and tracks associated with construction and maintenance of transmission lines will facilitate access. The shape of the reservoir, two long, narrow fingers, will enable access deep into the NPA. It is unlikely that appropriate watershed management measures that hydropower projects elsewhere in Lao PDR practice will be sufficient to prevent access, habitat disturbance, and biodiversity loss.

Hydropower development is only one factor in forest loss, habitat modification, and changes to biodiversity as these are also under pressure by other stressors such as mining, plantation agriculture, road development, hunting, and illicit logging, all of which have led to the decline of the resource base over the past few decades.

Natural Resource–Dependent Livelihoods

Fisheries

Capture fisheries are important for local livelihoods in the SRB, and construction of hydropower projects are likely to alter their composition. For example, non-migratory species that can adapt to the ecological conditions found in a lake will flourish at the expense of migratory species that depend upon faster-flowing rivers. Reservoir fisheries may offset these impacts, if managed sustainably and equitably.

To assess impacts on local livelihoods, this CIA compared the productive potential of future reservoir fisheries (fish catch) with current fish consumption of local communities. Although the results vary with different configurations of reservoirs (large mainstream reservoirs, for example, could support large fisheries), overall, reservoir fisheries cannot provide even half the amount of fish currently consumed.

Agriculture

Local communities depend on agricultural lands for food security and livelihoods. These lands tend to be concentrated in river valleys, floodplains, and surrounding hills, which are often also viable sites for storage reservoirs. Impacts on agricultural land have been quantified (in hectares) using information contained in project ESIAs augmented by spatial mapping using satellite imagery. Types of agricultural land affected by hydropower development include paddy rice fields, riverbank gardens, and swidden fields. The degree of impact depends not only on the total area of land affected, but also the amount of remaining land available to villagers who stay behind and provision of adequate land for villagers who are resettled.

Forest Products and Non-Timber Forest Products

Hydropower development in the Sekong Basin will affect community access to timber, NTFPs, game, and other forest resources. The magnitude of impact is principally a function of forest loss and forest habitat depletion (as just noted in “Terrestrial Habitats and Biodiversity”) and so varies for each development pathway.

Hydropower is only one of several determinants of forest loss in the SRB. Between 2000 and 2012, as much as 140,000 hectares (1,400 square kilometers) of forest was converted to agriculture, logging, and other activities (5.2 percent of the entire basin). Direct impacts from hydropower are moderate by comparison.

Physical Displacement and Resettlement

Numerous villages within reservoir inundation areas and immediately downstream of dams will be displaced because of hydropower developments. It is estimated that up to 11,500 people may need to be resettled depending on the scale of development. Almost half the total resettlement required is associated with two Sekong mainstream projects: Downstream A and Downstream B (about 5,000 people displaced). These two projects have the highest ratio of resettled people to megawatts of power capacity (32:1 and 47:1, respectively).

Culture and Heritage

Traditional customs, languages, belief systems, and other elements of traditional culture associated with ethnic groups in the SRB will be affected by renewable energy development through diverse and diffuse processes. Based on stakeholder consultations for this study and experiences of recent hydropower projects in other parts of Lao PDR, impacts are likely to be both positive and negative, and sometimes mixed.

- There will be interactions between communities and non-locals attached to development projects (workers, camp followers, and economic migrants), resulting in exchanges of knowledge and experience that may enhance or erode traditional values.
- It has been common in recent years for hydropower projects to result in resettlement of ethnic groups previously living in homogenous communities into mixed communities. This can be expected to further the integration of smaller ethnic groups into mainstream lowland culture. There is a potential for loss of tradition but also a chance to share beneficial new ideas and practices.
- Social development programs that hydropower projects sponsor as part of resettlement plans typically result in better education and health services for communities. It is likely that this will be beneficial to girls and women, narrowing the gender gap that is common in Mon-Khmer communities.
- Employment and other economic growth associated with project development may provide new opportunities for women, leading to a more equal role in household decision making.

Impacts of hydropower projects on VECs are summarized in Table ES.3.

Step 5: Evaluate Significance of Cumulative Impacts on VECs

The number, scale, design features, location, and configuration of hydropower development in the SRB will largely determine the significance of the cumulative impacts on the VECs described. The effects of other infrastructure developments (related, for example, to urbanization, agriculture, and mining) are likely to be less, at least during the 2030-time horizon of this assessment. Significant impacts associated with the three development pathways covered in this CIA are compared in Table ES.4.

Table ES.3: Summary of Impacts on Valued Environmental Components

VEC	Baseline conditions	Other development stressors and impacts	Hydropower-induced stresses and impacts
Aquatic habitats and biodiversity	Relatively good current conditions exist, but local communities report declining fisheries.	• Overfishing • Water abstraction • Climate change • Urbanization	• Less connectivity for fish • Habitat fragmentation • Loss of migratory fish species • Flow regime change • Changes in water quality
Terrestrial habitats and biodiversity	Substantial forest habitats remain, but there has been rapid reduction in recent years; rich biodiversity and globally endangered species are under threat from multiple stressors.	• Clearance for agriculture • Logging • Wildlife hunting • Mining and agroforestry concessions	• Habitat loss and fragmentation • Impacts on designated conservation areas • Facilitation of unsustainable exploitation of forests and wildlife caused by greater access
Natural resource–dependent livelihoods	Rural communities depend greatly on floodplain agriculture, capture fish, and non-timber forest products.	• Overexploitation • Forest clearance for agriculture, plantation forestry, and mining	• Forest loss • Loss of migratory fish species and decline in fish stocks • Physical resettlement
Society and culture	Rich ethnic cultures currently exist.	• Gradual social and economic integration into mainstream culture	• In-migration • Resettlement • Social development projects

Table ES.4: **Summary of Cumulative Effects of Valued Environmental Components for Each Pathway**

VEC	Full development	Intermediate development	Conservative development
Aquatic habitats and biodiversity	🟠 Large reduction in aquatic biodiversity due to disruption of migratory routes and inundation of riparian habitats important for spawning and feeding	🟡 Moderate impact on aquatic biodiversity because of fragmentation of Sekong tributaries; fish migration to and from Mekong supports continued connectivity along most of Sekong mainstem	🟢 Little impact on aquatic biodiversity because connectivity is maintained along the full length of the Sekong mainstem and several tributaries to support fish migration to and from the Mekong
Terrestrial habitats and biodiversity	🟡 Moderate impact on terrestrial biodiversity because of impacts on forests and protected areas	🟡 Moderate impact on terrestrial biodiversity due to impacts on forests and protected areas	🟢 Little impact on terrestrial habitats and biodiversity—important protected areas avoided
Natural resource–dependent livelihoods	🟠 Large adverse impact on livelihoods, particularly agriculture, fisheries, and resettlement	🟡 Moderate impact on livelihoods, particularly resettlement	🟢 Little impact on livelihoods overall but significant for directly affected communities
Society and culture	🟡 Moderate impact on culture and heritage, particularly because of resettlement	🟢 Mixed impact on culture and heritage—adverse and beneficial	🟢 Mixed impact on culture and heritage—adverse and beneficial

Step 6: Design and Implement Strategies to Manage Cumulative Impacts, Indicators, and Supervision Mechanisms

Effective mitigation and management of cumulative risks and impacts from renewable energy development in the SRB can be achieved at various stages of the project development process (Figure ES.6). Impact avoidance measures are more feasible in early stages, whereas later it is more realistic to focus on minimization, compensation, and offsets.

In the context of the SRB, opportunities for impact avoidance and minimization are limited for the 12 hydropower projects that are already operational or at an advanced stage of construction. Retrofitting environmental and social mitigation measures is not usually a technically or economically viable option, especially considering commitments and obligations under concession agreements and power purchase agreements; more mitigation options are available for the many projects not yet built or in earlier stages of design and feasibility study.

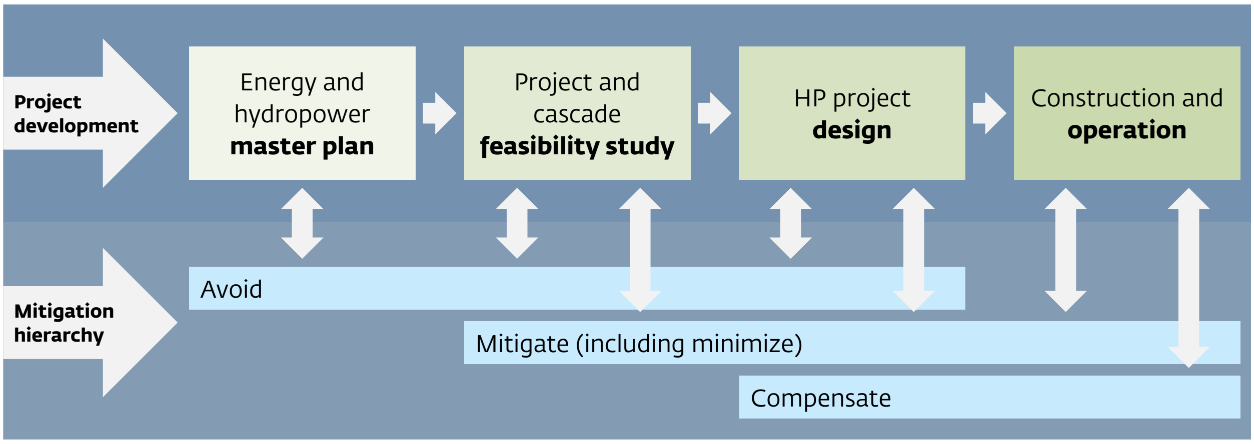
Impact management and mitigation should ideally begin with an integrated SRB power development master plan. Effective environmental mitigation and management cannot be undertaken on a project-by-project basis. It requires a basin-wide approach to address interdependencies related to energy generation and environmental and social impacts.

The SRB power development master plan would involve selection of hydropower projects through careful assessment of candidate project interactions to meet power demand while limiting environmental and social impacts. Basin-scale planning allows for coordination and optimization of hydropower projects, particularly those operating in cascades on the same reach of river.

Assessment of power development pathways in the SRB conducted for this CIA demonstrates how different project configurations result in substantially different levels of environmental and social impacts and power-generating capacity.

Power development planning should be informed by principles of integrated water resource management. Consideration of power generation alongside other uses of water resources can

Figure ES.6: **Risk and Impact Mitigation over the Development Cycle**



Source: MRC 2019a

support a robust decision-making process based on opportunities and trade-offs. Integrated water resource management can, for example, help hydropower deliver benefits such as increased water for irrigation to support agriculture, enhanced reservoirs to support fisheries, and improved river navigation to support tourism and trade.

Basin-scale power development planning also provides an opportunity to establish basin and catchment specific requirements and targets for hydropower, such as the following:

- Environmental flows (EFlows) requirements (for example, releases to sustain ecosystem dynamics, seasonal releases to trigger fish migration, and irrigation releases)
- Limits on rapid fluctuation in power generation (ramping rates)
- Water quality targets such as dissolved oxygen levels and seasonal temperature ranges
- Sediment concentration limits or targets associated with coordinated sediment flushing and sluicing operations
- Limits on lake-level operating ranges (for example, to facilitate other water uses)
- Identification and protection of ecosystem, biodiversity, and wetland hotspots
- Identification of potential intact river routes for fish migration and other water uses

During the design of individual hydropower projects and cascades, harm can be avoided by adhering to design requirements defined within basin master plans. In addition, project-specific mitigation measures related to such decisions as siting, dam height, reservoir operating rules, sediment flushing facilities, fish passages, powerhouse location, and transmission line routing can be incorporated into feasibility studies.

For operational projects, mitigation and management measures are generally defined through project specific ESIAs, which are required also to address cumulative impacts. In relation to significant impacts identified in this CIA, key operation-phase management and mitigation measures may include catchment protection, water quality monitoring, sediment flushing, maintenance of fish passages, and adherence to agreed EFlows.

Individual project-level operational measures are vital but are unlikely to be sufficient. Experience shows that mitigation and management of cumulative impacts require coordination of hydropower operations, especially for cascade operations on the same stretch of river and for clusters of projects within a sub-basin. Sediment flushing, for example, calls for coordinated action among projects so that sediment can pass from one dam to the next; failure to coordinate could cause sediment to become trapped in downstream reservoirs and reduce generating capacity. In many cases, coordination among operators is also important for fish passage, EFlows, and river navigation. To meet the need for coordination among developers, a framework for the SRB hydropower co-management platform is suggested (Figure ES.7).

This would be a voluntary, company-led initiative coordinated closely with the Ministry of Energy and Mines that would have the following core functions:

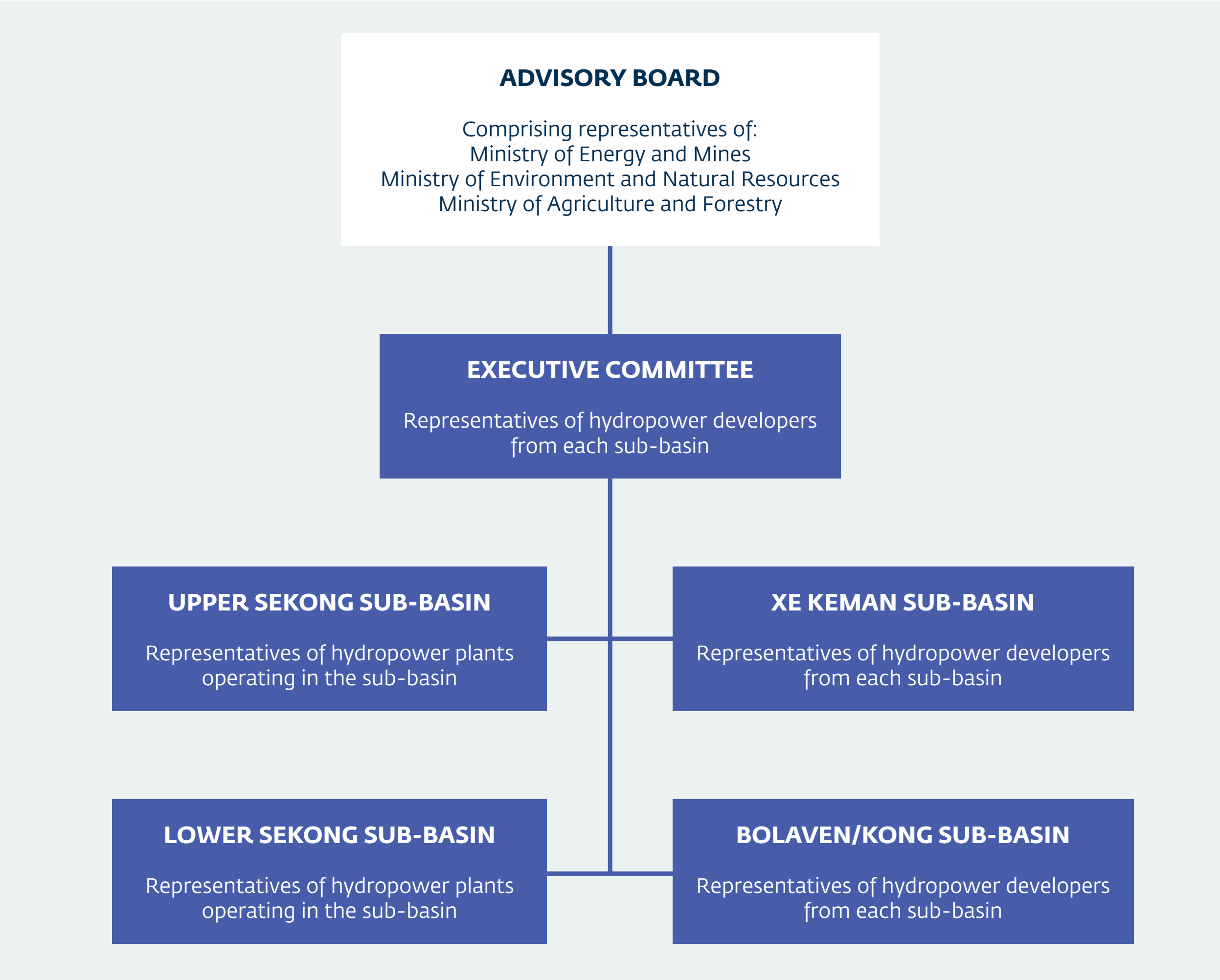
- General communication among SRB hydropower operations, particularly within the same sub-basin
- Coordination of projects on specific questions of shared relevance (for example, sediment flushing, fish passages, and EFlows)
- Sharing of selected data sets (for example, hydrometeorology and water quality) to support operational decision making and power optimization
- Pooled funding arrangements for joint-management measures where appropriate (for example, watershed management and biodiversity offsets)
- Engagement with other SRB stakeholders consistent with requirements of integrated water resource management

A basin-scale perspective also suggests that local authorities may benefit from new mechanisms to communicate and coordinate at the basin scale across administrative boundaries. The SRB, for example, spans three provinces in Lao PDR, each with separate agencies responsible for sectors such as environment, energy, and forestry of direct relevance to environmental impact mitigation. It also has transboundary implications.

Where hydropower development is highly concentrated, as in the SRB, there are also opportunities to streamline local authority regulatory oversight. For example, rather than the current approach in Lao PDR of establishing project-specific resettlement and environmental management units, it might be more efficient to establish a unified management unit in each province with pooled funding from local hydropower operations.

Pooled contributions from projects operating within the same basin or sub-basin could also be used to support integrated programs of watershed management, environmental monitoring, and biodiversity offsets.

Figure ES.7: Proposed Structure for the Sekong Basin Co-Management Platform



CIA Recommendations and Conclusions

The Sekong Basin has undergone environmental and social changes in recent years because of hydropower, other infrastructure developments, and population growth. It is a dynamic situation even in the absence of further renewable energy development over the next decade. In 2010, the Sekong Basin had a virtually undisturbed river system with no barriers to fish migration and very little flow regulation. The Houay Ho Hydropower Plant (HPP) was the only hydropower project in the entire basin. Substantial hydropower development has taken place during the past decade, and several projects are under construction, including the Xe Pian–Xe Namnoy, Nam Kong 1, and Nam Kong 3.

The present situation can be summarized as follows:

- The Sekong mainstream provides a long distance of unrestricted river flow that makes it accessible to long-distance Mekong migratory fish.
- The Sekong mainstream has no reservoirs, which enables sediment transport downstream to the Sekong floodplain and further to the Mekong.
- Since the impoundment of the Lower Sesan 2 dam and reservoir in Cambodia, sediment transport has been interrupted from the other two rivers of the 3S basin (Sesan and Srepok), which no longer make significant contributions to the Mekong.
- Apart from the trans-catchment water transfer from the A Luoi dam to the Bo River in Vietnam, no hydropower dams or reservoirs affected the main Sekong River and its northern tributaries.
- Construction of four dams and a large reservoir providing seasonal regulation of the flows passing down the Xe Kaman has heavily altered the Xe Kaman tributary basin. This has also interrupted sediment flows, with only a reduced fine silt fraction passing downstream of the Xe Kaman–Sanxay Dam, although it is still possible for migrating fish from the Sekong and Mekong to reach the Xe Xou and Nam Pa tributaries, whereas construction of several dams in cascade has fragmented the Xe Kaman mainstream and Nam Kong River.
- The Xe Pian and Xe Nam Noy tributaries have had their flows radically altered and water transferred directly to the Sekong River through new power plants. Flows along the natural courses of these tributaries have been reduced substantially, perhaps most noticeably by reduced frequency and magnitude of floods because of the high regulating volume of the Xe Namnoy and Houay Ho reservoirs.[4]
- New roads have been constructed to the uppermost dam site, Nam Kong 3, and to the various dam sites along the Xe Kaman. Roads to the new dams and diversion dams on the Bolaven Plateau have opened access to its resources, but road access north along the main Sekong River remains difficult, especially in the wet season.
- The Houay Lamphan Gnai HPP is the only Sekong Basin power project providing power exclusively to the local grid. Most existing hydropower projects are export orientated. Transmission lines have been constructed from hydropower projects in the Xe Kaman and Nam Kong sub-basins to the Vietnam border. A 220-kilovolt (kV) transmission line runs from the Xe Pian–Xe Namnoy project to Thailand.
- Forests face multiple pressures, including hydropower, new roads, agriculture, and mining. Mining is concentrated in the Xe Kaman sub-basin (Map 3.6 in page 64), but exploration permits have been issued covering most of the basin, so mining may significantly affect land use change in the future.
- There are currently no wind or solar energy projects in the basin.

The three alternative development pathways assessed were:

- *Full development pathway*, with 23 additional projects operational by 2030
- *Conservative development pathway*, with 16 additional projects by 2030
- *Intermediate development pathway*, with 18 additional projects by 2030

These three pathways will have different degrees of environmental and social impacts and risks.

The full development pathway will have large impacts on certain VECs, especially fish, livelihoods that rely on river fisheries and

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[4] Houay Ho discharges directly to the Sekong River through a tunnel, altering the Sekong River flow some 25 to 30 kilometers further upstream.

agriculture, or are affected by resettlement. Bank and bed erosion may increase in alluvial parts of the river, and less variability in river levels and smaller loads of nutrient-rich silt will restrict vegetable horticulture. Harvests from floodplain fisheries will probably fall, with some years seeing no floodplain inundation at all. The full development pathway is likely to come at the cost of loss of unique, highly valued biodiversity. Social costs will be in the form of resettlement of several thousand people.

The conservative development pathway, which excludes the seven mainstream projects, will entail hydropower development on a smaller scale and at a slower pace but will still provide a significant boost to the local and national economy. Assessment of the conservative development pathway indicates few notable additional impacts from the present situation, especially with regard to the Sekong mainstream, although local impacts will be experienced in the tributaries.

The intermediate development pathway will have more impacts on some VECs, especially as a result of the development of Sekong 4B and 5. Overall, impacts will be less than under the full development pathway but greater than the conservative development pathway. Table 9.2 (page 125) synthesizes the cumulative impacts on VECs under alternative pathways.

The findings of this study indicate the need for a Sekong Basin power development master plan incorporating renewable energy (hydropower, solar, and wind) and thermal power. Private sector interests have largely directed past developments in the basin on a first-come, first-served basis. The government should establish the trajectory of future development based on a strategic assessment of local and regional power demand and with consideration of the range of potential uses of natural resources in the basin. This approach would result in greater investment efficiency, a close match between power production and demand, and more opportunities to address adverse impacts through the full range of options available in the mitigation hierarchy. A master plan would be consistent with the 2017 Electricity Law, which requires power development planning on a five-year cycle, and the 2017 Law on Water Resources, which requires basin planning.

Important considerations for a Sekong Basin power development plan include the following:

- *Power demand*: up-to-date, realistic domestic and regional demand forecasts taking into account power development plans of neighboring countries, bilateral agreements (for example, memoranda of understanding), and a trend of rapid diversification of renewable energy solutions
- *Integrated water resources management*: incorporating integrated water resources management to ensure that needs and interests of multiple stakeholders in the basin are accommodated
- *Cumulative impacts*: environmental and social cumulative impacts as elaborated in this study
- *Avoidance by design*: reducing environmental and social impacts by modifying designs of particular projects (for example, Sekong 4A)
- *Trade-offs*: reaching a rational balance between economic benefits of power generation, adverse environmental and social impacts (particularly residual impacts and risks that cannot be fully mitigated), and opportunity costs of alternative natural resource uses foregone
- *Optimization*: achieving power generation enhancements and investment efficiencies by optimizing design and operating rules of hydropower cascades and in other circumstances where optimization benefits exist
- *Grid development*: shared transmission lines among power projects to reduce construction costs, improve grid efficiency, and reduce environmental and social impacts; co-funding by developers of transmission lines and cross-border interconnectors using this infrastructure
- *Integrating solar and wind*: identification of transmission grid and power supply and demand management improvements so that other renewable energy sources can be absorbed into the power system while maintaining balance

This master plan would provide parameters within which individual projects would be designed, assessed, and approved. Project proponents would need to integrate mitigation measures identified in the master plan into feasibility studies and environmental and social impact assessments.

This study has identified several opportunities for coordination and collaboration during the operation of renewable energy projects. A simple, practical co-management platform should be established to promote coordination among hydropower operations and to implement collaborative measures to mitigate cumulative impacts. Examples of opportunities for coordination among power developers in the

Sekong Basin include the following:

- *Coordinated environmental and social mitigation measures*: pooled funding and management arrangements for catchment protection, environmental offsets, and resettlement
- *Coordinated and joint operations*: information exchange and coordination among plant operators within the Sekong Basin, especially for dams in cascades on the same tributaries and within sub-basins to maintain EFlows and fish migration
- *Coordinated flood monitoring and warnings*: sharing hydrological data, collaborating on flood risk forecasting and preparedness, and establishing a warning system to notify local authorities and local communities of flood risks
- *Coordinated dam safety analyses*: cooperation of operators of cascading projects and pooling of resources to assess dam safety risks

Master planning and coordinated power operations will require that data and information gaps be addressed. Some priority areas for data, information, and analysis are summarized as follows:

Hydrological modeling

- Hydrological and meteorological monitoring data from existing hydropower projects should be collated and analyzed to enable precise calibration of the basin hydrological model developed for this study using satellite rainfall records.
- Meteorological and water gauging stations should be installed throughout the basin to provide a more complete set of measured data.
- Future climate change and hydrological models developed for the Sekong Basin should be made available to developers and government agencies responsible for planning, regulating, and monitoring hydropower development.

Sediment management

- The effectiveness of joint flushing and sluicing in cascades on the Sekong mainstream and tributaries should be further studied.
- Sediment load should be measured within the Sekong Basin to provide empirical data for design of effective flushing, sluicing, and other management options.

Hydropower operating rules

- Hydropower modeling of the type conducted for this study can be refined with additional information about the operating rules of individual dams, improving the accuracy of the model, and helping the effectiveness and benefits of joint operation of cascades in the tributary systems.

Fish passages

- More empirical data on the efficacy of fish passages in the Lower Mekong Region are needed. Data will soon become available from the Xayaboury HPP on the Mekong mainstream, which incorporates several fish pass design features.

EFlows

- A study to determine an appropriate EFlow regime for the entire Sekong Basin is needed.

The Sekong River Basin CIA highlights the key issues, management challenges, and trade-offs at a basin scale that are not captured through individual EIAs. It provides users opportunities to consider which pathway to develop to balance conservation and development as well as highlights the importance of the Sekong mainstream, the last free-flowing tributary in the Lower Mekong Basin.

1. Background and Introduction

1.1 Project Overview

1.1.1 Study Context

The Lao People's Democratic Republic (Lao PDR) is pursuing a strategy of expanding its renewable energy sector for domestic consumption and export to support socio-economic development targets. The power sector has grown rapidly over the past 20 years, with installed generating capacity rising from 700 megawatts (MW) in 2006 to 6,264 MW in 2016. Hydropower is the dominant energy source in the country, and the government of Lao PDR has ambitious plans to further expand hydropower generating capacity over the coming years. Some thermal energy development is also planned. Several feasibility studies for wind and solar power are underway, but these sectors are in their infancy in Lao PDR.

Although renewable energy, particularly hydropower, has the potential to help Lao PDR meet its development targets, the pace of change carries risks of significant environmental and social impacts. Individually, hydropower projects can affect the aquatic and terrestrial environment, ecosystem services, communities, and peoples' livelihoods. Cumulatively, multiple projects within the same watershed can magnify these damages by altering catchment and basin flow regimes, water quality, sediment transport, and biodiversity distribution, with subsequent effects on native biota, agriculture, navigation, and other river uses.

In recognition of these challenges, the government of Lao PDR has introduced and strengthened the policy and regulatory framework governing the renewable energy sector, as described in Section 2.1.

In recent years, IFC has spearheaded the cumulative impact assessment (CIA) approach as outlined in the *Good Practice Handbook on Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets* (IFC 2013).

IFC has assisted the Ministry of Natural Resources and Environment with developing draft CIA guidelines for Lao PDR. The project is part of IFC's Hydro Advisory Program, which is supported by the Australian Department of Foreign Affairs and Trade and the Japanese government.

The CIA guidelines have been developed in accordance with IFC's *Good Practice Handbook* and through consultations and workshops with the Ministry of Natural Resources and Environment, businesses, development partners, hydropower project proponents, and relevant stakeholders, including regional and non-governmental organizations. The objectives of the CIA guidelines are to improve and strengthen the CIA process and implementation, support studies, and promote sustainable development of natural resources while enhancing basin management planning. It is further intended to define the scope of the studies required for preparation of a CIA and to allow for consideration and subsequent decision making on the appropriateness of the construction, operation, and decommissioning or rehabilitation of hydropower projects under the Law on Environmental Protection 2012 and other relevant legislation. This CIA of the Sekong Basin aims to serve as a pilot of the draft CIA guidelines and to determine improvements required.

1.1.2 Study Objectives

To pilot the draft CIA guidelines, IFC has agreed with Lao PDR government partners to conduct a basin-wide CIA of the Sekong River Basin (this study).

The objectives of the study are threefold:

1. Plan and execute an integrated assessment of the **cumulative impacts of renewable energy development** in the Sekong River Basin, including power optimization and development scenarios.

2. Lead the participatory design of a **framework for ongoing river basin co-management** in the Sekong Basin, including collaborative environmental and social impact monitoring and management.

3. **Increase the capacity** of Sekong River Basin stakeholders to conduct CIAs and to co-manage power generation and water resources with hydropower developers and other stakeholders.

1.1.3 Scope of Work

The broad scope of work for this study comprises the following objectives and tasks:

Objective 1: Integrated Cumulative Impact and Power Optimization Assessment

- Review regulatory framework
- Scope the CIA
- Scope activities and environmental drivers for the full development pathway
- Determine present conditions of valued environmental components (VECs)
- Assess cumulative impacts of the full development pathway
- Collaborate in developing power generation scenarios for the Sekong River Basin
- Assess cumulative impacts from various scenarios
- Design cumulative impact management measures and monitoring plans
- Provide recommendations to reduce cumulative impacts and optimize power generation
- Coordinate data management and mapping

Objective 2: Design the Sekong Basin Cumulative Impact Co-Management Platform

This includes designing a framework for involving the public and private sectors in addressing identified cumulative impacts in the river basin, including collaborative environmental and social impact monitoring and management. Based on lessons learned from this and related initiatives, the work comprises facilitation of a participatory design of a framework for a Sekong River Basin Co-Management Platform.

Objective 3: Build Capacity

The objective is to increase the capacity of Sekong River Basin renewable energy stakeholders to conduct CIAs and to co-manage power generation and water resources. This has involved building the capacity of government and private developers in CIA and basin co-management through workshops and training exercises, as well as learning by doing through exposure to the study.

1.2 Approach and Methodology

1.2.1 General

This section provides a brief background for this study and how it was undertaken. As one purpose of this study was to pilot the CIA guidelines, attempts have been made to apply the approach and methodologies prescribed in the guidelines.

1.2.2 Definition of Cumulative Impacts

Cumulative impacts are those resulting “from the successive, incremental, and/or combined effects of an action, project, or activity when added to other existing, planned, and/or reasonably anticipated future ones” (IFC 2013).

Assessing cumulative impacts might require more than just adding up all impacts from individual projects or developments. Although the combined impacts of several projects may be larger than the sum of individual impacts because interactions may amplify their collective impacts, one project added to another can also lead to fewer severe cumulative impacts than the sum of the impacts of both projects.

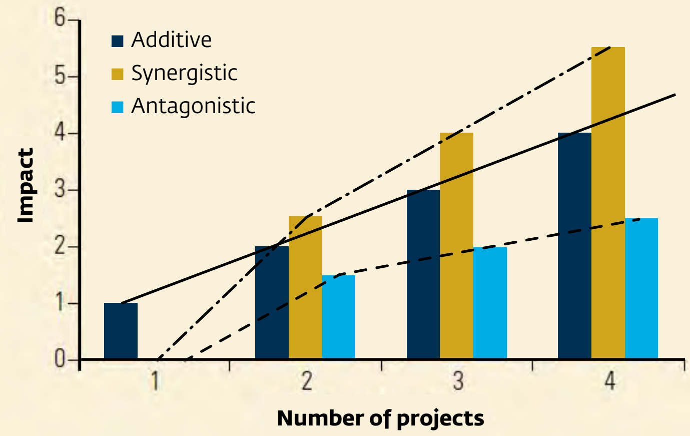
Cumulative impacts can occur through different *interactive pathways* (Bain, Irving, and Olsen 1986). Three basic interactions can be discerned among these (Figure 1.1).

1. Strictly additive: Total impact is equal to the sum of individual impacts
2. Synergistic: Total impact is more than the sum of individual impacts
3. Antagonistic: Total impact is less than the sum of individual impacts

Cumulative impacts can also be related to passing certain thresholds. For instance, some habitat loss may not have a large impact on wildlife, but when a certain threshold is passed, an entire population can be wiped out because the habitat becomes too fragmented.

In some cases, the impact of multiple small-scale projects may be greater than the impact of a single large-scale project, for example, when total impacts from a cascade of small hydropower plants exceed those that would have occurred with a single larger dam with the same power generating capacity.

Figure 1.1: Cumulative Impact Assessment Interactive Pathways



Source: World Bank 2014.

Note: The solid line denotes a strictly additive effect: the impact of two projects is twice the impact of one. The dash-dot line shows the synergistic cumulative effect: the net effect is more than the sum of its constituents. The dashed line shows an antagonistic cumulative effect.

1.2.3 Definition of Valued Environmental Components

VECs are parts of the environmental and social fabric of Lao PDR that the proponent, stakeholders, the community, environmental and social scientists, anthropologists, and government representatives involved in the assessment process consider important. Attributes of a VEC can be biological, cultural, ecological, physical, or social and include changes in the livelihoods of affected peoples, resettlement, and any other attributes of concern identified as relevant during a CIA. In some studies, VECs are defined with a narrow focus on elements of the biophysical environment (Szuster and Flaherty 2002; Bérubé 2007; Noble 2010) but are often understood to encompass social aspects (for example, Shoemaker 1994; Olangunju 2012). In this study, the broader definition of VECs is used.

1.2.4 Cumulative Impact Assessment Approach

The activities that were undertaken in each step are briefly summarized below, with additional detail presented in the appendixes. Appendix A lists the hydropower projects used in the assessment.

Step 1: Geographic boundaries and timeframes for the CIA were identified in consultation with stakeholders.

Step 2: VECs were identified in cooperation with the Ministry of Energy and Mines and in consultation with stakeholders. Identification of VECs involved collection and analysis of information from several sources and engaging with stakeholders at the local, provincial, national, and transboundary levels. Such a participatory approach provided a sound base for identification, ranking, and consideration of VECs and relevant external natural and social stressors affecting them.

Step 3: The current condition (baseline) of the VECs was assessed based on a wide range of secondary data sources.

Step 4: Cumulative impacts of alternative development pathways were assessed. Identification and selection of VECs included identifying all existing and proposed projects to be clustered into three development pathways as a basis for the CIA in this step:

1. Full development pathway
2. Conservative development pathway
3. Intermediate development pathway

Step 5: The cumulative impacts of renewable energy development on VECs by 2030 under each pathway were evaluated. The full development pathway CIA included a power generation and optimization study to explore possible benefits of coordinated operation of planned hydropower projects in the Sekong mainstream.

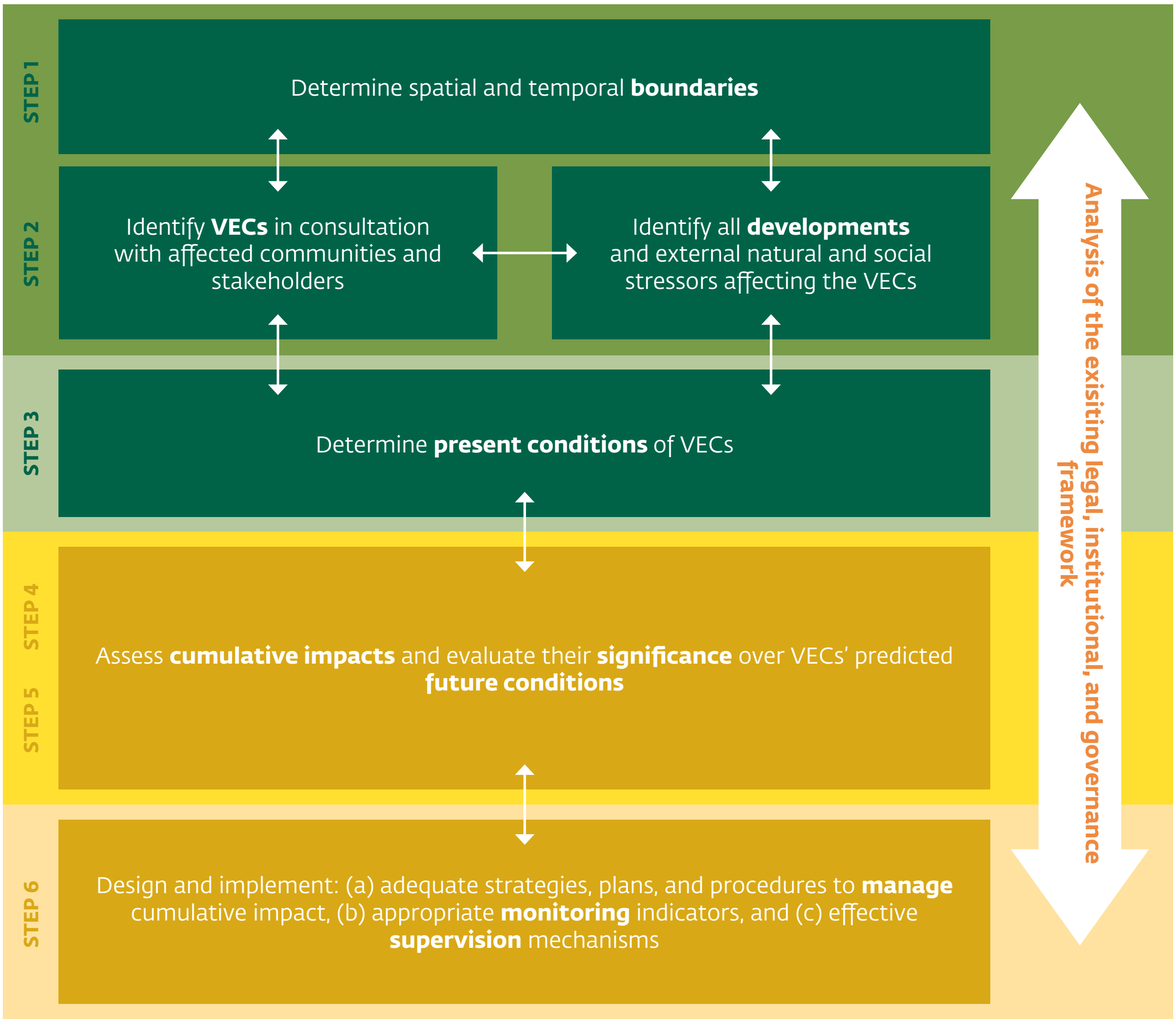
Step 6: Mitigation measures and actions for policy makers, decision makers, and planners were proposed. Institutional and operational modalities needed to ensure effective implementation of coherent mitigation measures and monitoring to minimize impacts and risks were described.

The steps followed in this study closely follow the framework stipulated in the CIA guidelines and IFC's *Good Practice Handbook* (Figure 1.2).

1.2.5 Modeling

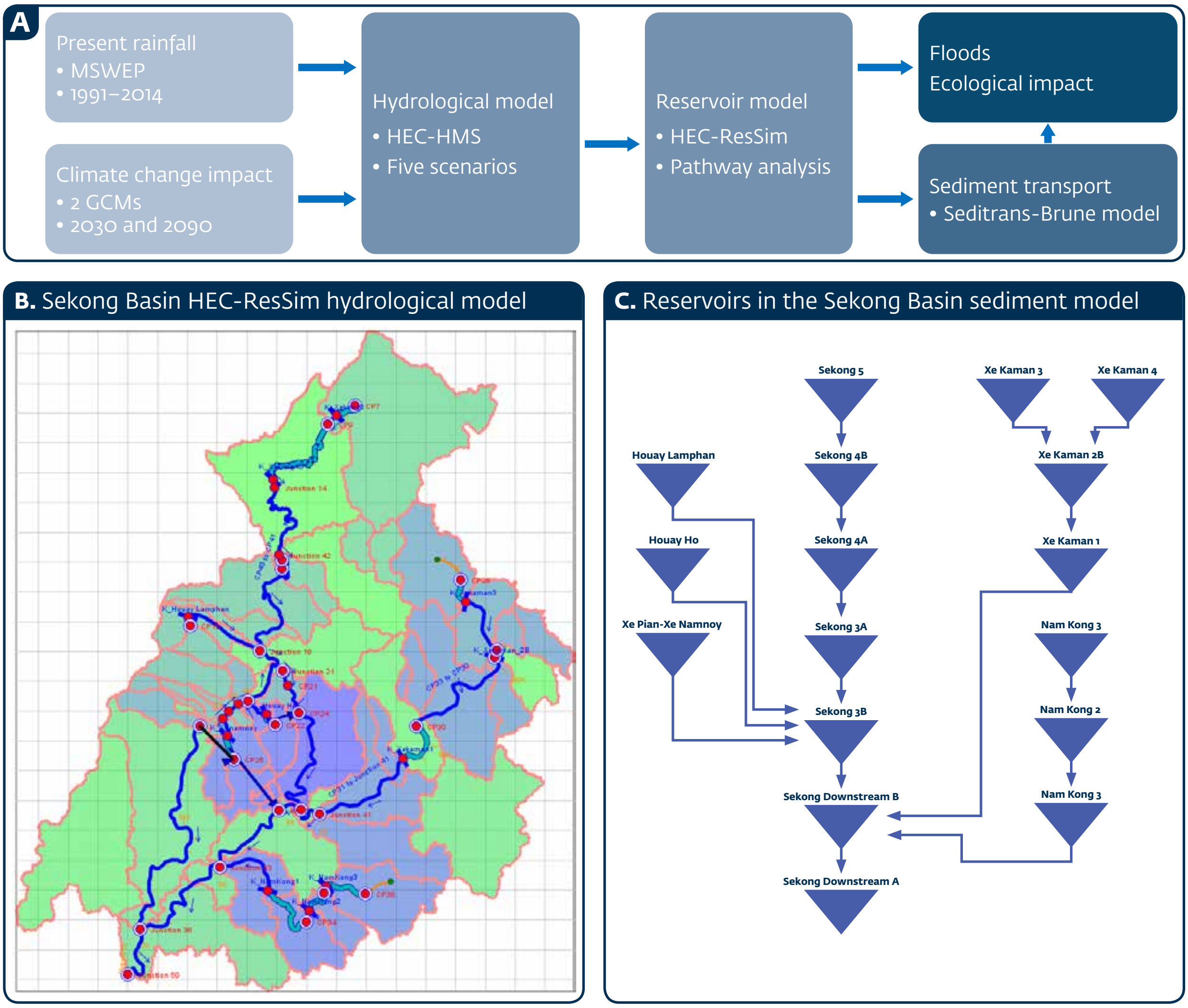
The modeling chain for impact analysis for this study is illustrated in Figure 1.3. Daily rainfall data for 24 years are entered into a hydrological model, the U.S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS), and the results of this model provide input for the Hydrologic Engineering Center, Reservoir System Simulation (HEC-ResSim) hydropower model. The latter has been used to simulate the various pathways with different configurations of hydropower plants in the Sekong Basin. The impact has been assessed in terms of such things as ecology, sediment, and floods. Appendix B presents the climate change assessment and hydrological, hydropower, and sediment modeling in detail.

Figure 1.2: IFC's Six-Step Process for Cumulative Impact Assessment



Source: IFC 2013.
Note: VEC = valued environmental component.

Figure 1.3: Modeling Chain for Impact Analysis



B. Sekong Basin HEC-ResSim hydrological model

C. Reservoirs in the Sekong Basin sediment model

Source: HEC-ResSim, U.S. Army Corps of Engineers, Hydrologic Engineering Center Reservoir System Simulation.

Note: MSWEP = multi-source weighted-ensemble precipitation; GCM = General Circulation Model; HEC-HMS = Hydrologic Engineering Center - Hydrologic Modeling System; Hec-ResSim = Hydrologic Engineering Center - Reservoir System Simulation.

1.2.6 Stakeholder Identification and Engagement

1.2.6.1 Stakeholder Identification

Engagement with multiple stakeholders at all levels is critical to the success of a CIA. Institutions and stakeholders were identified early in the study and during implementation. Stakeholders were identified in the following three categories.

1. Ministries and departments involved in the planning, assessment, and permitting process for renewable energy projects and other infrastructure projects such as roads and mining
2. International non-governmental organizations and other international and local organizations and communities involved in renewable energy projects and other projects such as biodiversity conservation
3. Private developers of renewable energy projects in the Sekong River Basin

Stakeholders were identified in consultations and workshops with the Ministry of Energy and Mines and other line ministries, the business community, development partners, hydropower project proponents, and non-governmental organizations at the national, local, regional, and transboundary levels. Stakeholders are listed in Table 1.1.

Table 1.1: Roles and Responsibilities of Relevant Institutions and Stakeholders

Institution	Roles and responsibilities
Government	
Ministry of Energy and Mines	
• Department of Energy Business	Independent power producer project development
• Department of Policy and Planning	Energy policy and power system planning
• Department of Energy Management	Energy regulation and monitoring
• Institute for Renewable Energy Promotion	Renewable energy development
• Électricité du Laos Generation Public Company	Generation, transmission and distribution
• Department of Mines	Mining sector project development and licensing
Ministry of Natural Resources and Environment • Department of Water Resources • Department of Natural Resources and Environment Policy • Natural Resources and Environment Inspection Office	Water resource management, environmental impact assessment processes and environmental permits
Ministry of Planning and Investment • Department of Planning and Cooperation	Screening and providing final approval for foreign and domestic investment projects, including energy projects; coordinating closely with Ministry of Energy and Mines and Ministry of Natural Resources and Environment
Ministry of Agriculture and Forestry • Department of Forestry • Department of Irrigation • Department of Fisheries • Living Aquatic Resources Research Center	Screening and assessing forestry and plantation projects, planning and overseeing irrigation projects and implementing fisheries law
Ministry of Public Works and Transport • Department of Roads	Planning and implementing major road projects
National University of Lao PDR • Faculty of Environment	Research on fish passage
Ministry of Industry and Trade, Vietnam • Department of Energy Efficiency and Sustainability • Planning Department	Industrial development, including hydropower development
Ministry of Natural Resources and Environment, Vietnam	Environmental protection, including environmental impact assessment studies and environmental permits
Ministry of Mines and Industry, Cambodia • Department of Energy	Industrial development, including hydropower
Ministry of Environment, Cambodia	Environmental protection, including environmental impact assessment studies and environmental permits

Ministry of Agriculture, Forestry and Fisheries, Cambodia	Freshwater fisheries and fisheries administration
Department of Foreign Affairs and Trade, Government of Australia	Mekong Region Water Resources Program
International Organizations	
Mekong River Commission Secretariat • Lao National Mekong Committee • Vietnam National Mekong Committee • Cambodian National Mekong Committee	Implementation of programs and collection of data on the Mekong River Basin
Deutsche Gesellschaft für Internationale Zusammenarbeit	Support to the Mekong River Commission program
National Heritage Institute	Studies on the Mekong River Basin and finalizing report on the Sekong River Basin
International Union for Conservation of Nature	Work on policy level regarding water resource and biodiversity challenges in the region; studies on combined Sekong, Sesan, and Srepok river basins
World Wildlife Fund	Biodiversity programs and projects in Lao PDR and the region
International Water Management Institute	Work for World Bank on the Energy-Water Nexus Project: the Nam Ou and Sekong basins
WorldFish	Non-profit organization conducting research on fish migration and fisheries in the Mekong
Consultants	
Compagnie Nationale du Rhône	Consultant for the World Bank's Energy-Water Nexus Project in Lao PDR
Developers	
Viet Lao Power JSC	Developer of Xe Kaman 1, 3, and 4; Xe Kaman–Sanxai
RATCH-Lao Services Co. Ltd.	Developer of Xe Pian–Xe Namnoy and Sekong 4A and 4B
Chaleun Sekong Energy Co.	Developer of Nam Kong 2 and 3
China International Water and Electric Corp.	Developer of Nam Kong 1 and Xe Kaman 2B
Vientiane Automation and Solution Engineering Lao PDR	Developer of Dakchaliou 1, Dakchaliou 2, Nam Pangou, and Lower Xe Pian
Construction and Investment International Co. Ltd.	Developer of Houay La Ngea

Électricité du Laos—Public Generation Company	Developer of Nam Bi 1, Nam Bi 2, and Nam Bi 3
V & H Corporation	Developer of Sekong Downstream A
Asia Investment and Development	Developer of Sekong 3A and 3B
Kaleum Wind Farm	Developer of wind farm in Sekong Province, Kaleum District
Xe-Pian Xe-Nam Noy Power Co. Ltd.	Xe-Pian–Xe-Namnoy
Inter Rao Engineering	Developer of Sekong 5
Impact Energy Asia Co. Ltd.	Developer of Monsoon Wind Farm
Financial Institutions and Donors	
IFC	Funding and overseeing implementation of cumulative impact assessment for the Sekong River Basin
World Bank	Funding and overseeing implementation of theEnergy-Water Nexus, Lao-Vietnam Interconnector, and Mekong-Integrated Water Resources Management projects
Asian Development Bank	Funding and overseeing various energy sector and transportation sector projects in Lao PDR

1.2.6.2 Stakeholder Engagement

The study team has actively engaged with stakeholders during the various stages of the study. Engagement activities have taken different forms, such as meetings and discussions with stakeholder groups to identify, analyze, and rank the VECs. Table 1.2 at the end of the chapter outlines the concerns raised by shareholders at various venues. (See Table 4.1, Chapter 4, for the final selection of VECs). Teleconferences and e-mail correspondence have also been used to reach stakeholders that are not in the region. The main meetings and workshops are the following:

- Inception period missions (2) and meetings with various ministries, developers, and other stakeholders
- Two-day inception and scoping workshop (August 23–24, 2018) at which geographic boundaries and timeframe for the CIA and VECs were jointly explored and VECs were identified
- Provincial and local consultations in the provinces of Champassak, Sekong, and Attapeu (September 24–28, 2018) to inform stakeholders at the provincial, district, and village levels about the CIA project and to inform them of the relevance and ranking of the identified VECs
- Interim workshop (October 31 to November 1, 2018)
- Consultations with key transboundary basin stakeholders (Sekong and Mekong river basins) in Vietnam and Cambodia (April 2019)
- Final CIA technical workshops (May 2019)
- Final project workshop (October 2019)

1.2.6.3 Transboundary Stakeholder Concerns

In addition to consulting national and local Sekong Basin stakeholders in Lao PDR, stakeholders in Vietnam and Cambodia were consulted to capture broad transboundary environmental and social concerns and possible effects of the proposed projects. Concerns of other riparian countries have been considered along with local concerns in selecting VECs and associated assessment parameters. Key inputs include the following:

- General concerns were expressed about flow change, river erosion, sediment transfer reduction, ecosystem degradation, deforestation, and changing cultural and livelihood conditions of communities.
- Estuarine salt intrusion into the Mekong Delta as a consequence of hydropower development in the Lower Mekong Basin is of concern.
- Sediment flow is important for riparian communities because it affects nutrient transport, bank erosion, and wetlands.
- Sediment transport from the Sekong River into the Mekong River is considered very important in Cambodia; a large reduction in sediment would be a concern.
- Water quality and flow changes from hydropower development will change the ecosystem and affect livelihoods. The reduced seasonal river flow fluctuations (runoff more evenly distributed) will affect livelihoods both positively and negatively in the Sekong Basin.
- Hydropower development will affect fish resources in the Sekong and thereby the livelihoods of people that depend on them. It will also affect endangered fish species.
- Dam safety was a concern in Cambodia in the context of a dam break in Lao PDR in 2018.
- Climate change has exacerbated cumulative effects, as extreme events (drought, salinization, flow change, and river erosion) exemplify.
- Hydropower development in Lao PDR will affect flow into the Tonle Sap.

1.3 Geographic Boundaries and Timeframe

1.3.1 Geographic Boundaries

The primary geographic boundary (study area) for the CIA is the basin boundary of the Sekong River (in Vietnam, Lao PDR, and Cambodia), from the Vietnamese highlands to the confluence with the Srepok River in Cambodia. The CIA considers downstream transboundary impacts[5] (for example, in Cambodia, along the Lower Mekong River, and as far as the Mekong Delta) beyond the boundaries of the Sekong Basin itself.

1.3.2 Timeframe

The approach sets a primary timeframe for this CIA to 2030, by when it is expected that all current development plans and practices proposed will be operational. This timeframe will also apply for alternative development scenarios, the “pathways.” A secondary timeframe has been applied for assessment of impacts of climate change and set to 2090.[6]

1.4 Study Limitations

1.4.1 Climate Change and Hydrological Modeling

Although a sophisticated method for assessment of the hydrological regime in the Sekong Basin was used, there are major uncertainties related to the impact of climate change on precipitation and to the hydrological modeling based on meteorological input. In this section, the limitations of this method are explained.

For climate change, the assessment outcome depends heavily on availability of climate change models for the region and their accuracy. There are many models, and their outcomes often deviate widely, sometimes having opposite results: that is, they may predict either a decrease or an increase in rainfall. To address this uncertainty, it was decided to use a model that represents an average of the result of several models and a worst-case outcome, which in this case meant a model that predicts a severe decrease in rainfall.

Availability of reliable rainfall data was the main limitation for hydrological modeling in this study. Data were available from only a small number of monitoring sites within the Sekong Basin over a short time span, during which there were data gaps. To decrease uncertainty related to data sparsity, it was decided to make use of global rainfall datasets spanning 24 years. The use of global data has certain limitations. Particularly for short-duration events, such as floods, the data are less reliable than using on the ground meteorological measurements because each series

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[5] For example, such impacts include potential flow regime changes and effects on sediment transport and fish migration.

[6] Selected to be a timespan that represents climate conditions and variability and interannual variability of the future time horizon. Climate datasets run until 2100, and data for 2080 to 2100 were used. This represents the conditions in 2090 more than the conditions in 2100, so 2090 was selected.

represents average rainfall over a grid cell of approximately 25 square kilometers, which means that extreme values are leveled out, resulting in missed flood events in the modeling. Nonetheless, for the purposes of water resource management and long-term hydropower simulation, it is a better alternative than the limited measured rainfall data.

1.4.2 Hydropower Data Availability

Data availability regarding existing and planned hydropower projects was a limiting factor in this study and is described in the following sections.

1.4.2.1 Technical Data

Information about the technical design of many of the built and planned hydropower projects is limited. Feasibility study summary reports were available for approximately half of the projects included in the CIA. For the remaining projects, information was sourced from power company webpages and Mekong River Commission databases. In a few cases, only megawatts and gigawatt-hours are known, with other data estimated based on knowledge of the river basin and general principles of hydropower design. The details of project components, such as gates and fish passes, are generally unknown.

1.4.2.2 Hydropower Operation and Power-Trading Data

Data related to hydropower operation and power purchase agreements are deemed commercially sensitive and so are mostly not publicly available. Rules for hydropower operation and power trading have therefore been estimated based on knowledge of the Lao PDR hydropower sector and the power system.

1.4.2.3 Sediment Data

No empirical sediment measurement data are available for the Sekong River Basin. A sediment yield of 280 tons per square kilometer per year has been applied to the entire catchment area based on data for the nearby Kon Tum massif in neighboring Vietnam (Kondolf, Rubin, and Minear 2014).

1.4.3 Data on Valued Environmental Components

1.4.3.1 Socio-Economic Data

For VECs related to social aspects of impact, such as fisheries, agriculture, and ethnic customs, gender and culture, this study was limited to information that could be extracted from past studies on the Sekong River Basin, project environmental and social impact assessments (ESIAs), and resettlement and feasibility project reports. Analysis of maps showing project locations, footprints, and layouts (for example, dam, powerhouse, reservoir, and transmission line access roads) was used to identify potential impacts in terms of physical and economic displacement. For addressing ethnic customs and gender, consultations were used to complement information obtained from ESIAs and resettlement plans. For social VECs, in particular, it was difficult to define thresholds and acceptable limits for significance of impacts on VECs and to estimate uncertainty.

1.4.3.2 Aquatic Biodiversity and Ecosystems

Information on fish ladders to be installed at planned hydropower projects on the Sekong River and its tributaries is lacking, so it is challenging to assess their potential for facilitating fish migration. Information on environmental flows (EFlows, water provided within a river or wetland to maintain ecosystems and the benefits they provide for people that depend on these ecosystems) is also limited.

1.4.3.3 Terrestrial Biodiversity and Ecosystems

Data on the presence, absence, and estimated population sizes of some of the endangered wildlife species in the basin are limited, which might lead to under- or overestimation of the impacts of basin-wide hydropower plant development. Data on workforce influx from future development that might affect wildlife are also limited.

Table 1.2: **Sekong Valued Environmental Components and Associated Stakeholder Concerns at the District and Local Levels**

VEC groups	Examples	Stakeholder concerns and messages
Natural resources important for livelihoods	• Forest and plant species and products (terrestrial, riparian, and wetlands) valued for economic, medical, food, important ecosystem function, or biodiversity reasons • Plant and tree species for food, medical, and traditional use • Timber resources including hardwood • Non-timber forest products (NTFPs) • Mainstream and tributary fisheries • Wet-rice agriculture and dry season riverbank gardens	• Livelihoods based on forest and river resources are considered the most important VEC, especially by district officials. • Villagers and district officials considered NTFPs and wildlife to be the most important VEC. • Many considered natural resources (especially forest) to be the most important VECs because of income and food from hunting and collection of NTFPs. • Timber and NTFPs are becoming scarcer, and sale of domestic animals (chickens) is replacing them as source of income for villagers. • NTFP species such as malva nuts, bamboo, and rattan shoots are collected, although they have become scarce. • Commercial hardwood tree species important for income and house construction have largely been depleted. • Hydropower development has decreased access to forest resources. • Establishment of rubber and fruit tree plantations has decreased availability of agricultural land for small-scale farming, although villagers work on plantations. • Plantations are putting pressure on resources and availability of cultivatable land for villagers. • Youth, who used to collect and sell NTFPs, now work on banana and coffee plantations.
Fish and aquatic habitats	• Fish and aquatic habitats valued for economic reasons or conservation status (threatened species) • Super-endemic fish (species only found in the Sekong) (Meynell 2014) • Endangered and critically endangered fish species • Important (economically and environmentally) migratory fish species	• River-dependent livelihoods (fish for consumption) were assessed as an important VEC. • Fish stocks are widely used for subsistence. • Women fish in smaller streams, and men fish in the Sekong. Most fish are consumed in the village. People increasingly depend on raising livestock and growing crops because fish stocks in rivers and streams are declining. • Fishing is still important for household consumption, although some important species have declined. • Villagers rely on fishing and somewhat on cultivation of vegetables in riverbank gardens for consumption and income.
Cultural and ethnic archaeology and heritage	• Gender roles, cultural diversity, traditional knowledge, social identity, and tourism	• Many consider traditional culture and customs to be a high-priority VEC (ritual ceremonies, native language, songs, and dances). • Traditional and cultural practices have changed; large livestock are no longer sacrificed, and traditional clothes are no longer worn. • Women's status, influence, and position in society have improved over the past decade; they participate in decision making.
Terrestrial habitat areas (for example, protected areas and critical habitats)	• Terrestrial habitats important for human use and for biodiversity values • Restricted protected areas • Key biodiversity areas • Endangered and critically endangered terrestrial species	• Number of wildlife species (tiger, elephant, bear, and gaur) have reportedly disappeared from the area. • Hunting is mainly done for household consumption, but wildlife populations are declining. • Wildlife and hunting (birds, wild pigs, barking deer, reptiles, and squirrel) used to be important as a source of food, but populations have declined significantly.

2. Legal, Institutional, and Governance Context

2.1 National Policy, Regulatory, and Institutional Frameworks

The government of Lao PDR has strengthened the policy and regulatory framework governing the renewable energy sector in recent years.

2.1.1 Environmental Protection Law (Revised 2013)

The Environmental Protection Law defines principles, regulations, and measures related to environmental management, including monitoring of protection, control, preservation, rehabilitation, and mitigation of impacts created naturally or by anthropogenic loads. The law aims to balance the needs of society and nature by sustaining and protecting natural resources, maintaining public health, contributing to national socio-economic development, and reducing global warming. The law stipulates requirements for basin planning, which implicitly requires consideration of cumulative effects of different water uses within a basin, supporting the use of the cumulative impact assessment (CIA).

2.1.2 Ministerial Instruction on Environmental and Social Impact Assessments (2013)

The 2013 *Ministerial Instruction on ESIA* outlines the conditions that require a CIA in addition to the standard environmental and social impact assessment. In practice, however, CIA implementation in Lao PDR has been limited. To conduct a CIA, project developers require substantial information about nearby existing and planned developments, and it is not usually readily available.

2.1.3 Policy on Sustainable Hydropower Development in Lao PDR (2015)

The Lao PDR Policy on Sustainable Hydropower Development (MEM 2015) emphasizes sustainable planning principles throughout the project lifecycle. Principles of water resource management, watershed management, and conservation are embedded in the policy, which calls for application of the mitigation hierarchy (anticipate, avoid, minimize, and compensate) as follows:

> Natural conserved habitat area losses caused by hydropower development projects shall be avoided and mitigated as much as possible. Where avoidance is not possible, the project developers must compensate for and restore lost habitats and provide funding to help manage and effectively conserve the watershed area, nearby watersheds, and other important conservation areas . . . [and] must also develop a sustainable biodiversity management plan, consider compensation, or help mitigate the impact on the local natural resources base (paragraph 5.11).

The policy also outlines revenue and benefit sharing principles.

2.1.4 Revised Law on Electricity (2018)

Under the revised Law on Electricity,[7] a comprehensive environmental and social impact assessment (ESIA) must be conducted for all developments larger than 5 MW; a less rigorous initial environmental examination must be completed for smaller developments.

Article 10 of the revised law covers integrated power sector planning and is of special relevance for this CIA and the Sekong Basin Co-Management Platform. It states:

> MEM [Ministry of Energy and Mines] shall develop an integrated power sector plan at least once every five years in consultation with other sectors such as planning and investment, finance, natural resources and environment, agriculture, and forestry. The integrated power sector plan shall, among other things, identify and prioritize projects based on criteria including . . . adherence to the principles of integrated water resources management consistent with the laws and regulations governing water resources management.

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[7] The original 1994 Law on Electricity was amended in 2008, 2011, and 2017.

2.1.5 Dam Safety Review

The government of Lao PDR has initiated a national dam safety review of existing and planned dams with the assistance of the World Bank and several other development partners. Work started in 2019 and will continue through 2020. A number of internationally funded expert advisers are assisting the Ministry of Energy and Mines with this review, and it is understood that no construction will continue unless a dam in question is found to meet the safety criteria established in this review.

2.2 Transnational Basin Governance

2.2.1 Overview

The following transnational governance instruments and bodies are relevant to this CIA:

- Mekong 1995 Agreement
- Mekong River Commission (MRC) procedures
- MRC Basin development strategy, strategic plans, and other initiatives
- National environmental impact assessment (EIA) regulations

2.2.2 Mekong 1995 Agreement

Cambodia, Lao PDR, Thailand, and Vietnam signed the Agreement on Cooperation for Sustainable Development of the Mekong River Basin on April 5, 1995. This agreement defines a set of principles and processes for pursuing a coherent regional strategy of integrated water resources management.

The agreement encourages cooperation among the Lower Mekong Basin countries to optimize the multiple uses and mutual benefits of Mekong River resources for all riparian countries while protecting the environmental and ecological balance in the basin. The 1995 agreement addresses different types of water use, including hydropower.

The vision of the Mekong 1995 agreement is for member states "to cooperate in a constructive and mutually beneficial manner for sustainable development, use, conservation, and management of the Mekong River Basin water and related resources" (MRC 1995).

2.2.3 Mekong River Commission Procedures

Five procedures were adopted for implementation in the framework of the Mekong 1995 Agreement:

1. Procedures for Notification, Prior Consultation, and Agreement (2003)
2. Procedures for Data and Information Exchange and Sharing (2001)
3. Procedures for Water Use Monitoring (2003)
4. Procedures for Maintenance Flows on the Mainstream (2006)
5. Procedures for Water Quality (2011)

These procedures are applicable to the Sekong River Basin CIA and management of renewable energy development in the basin. According to the Procedures for Notification, Prior Consultation, and Agreement, hydropower development on tributaries is subject to notification to the MRC Joint Committee, and development on the mainstream requires prior consultation among the countries. Notification requires that a country report the details of a project to the other member countries through the MRC Joint Committee before project implementation begins. The 1995 agreement also requires the countries to "make every effort to avoid, minimize, and mitigate harmful effects" (MRC 1995); in other words, to adopt the mitigation hierarchy in the planning and implementation of hydropower and other infrastructure projects.

2.2.4 MRC Basin Development Strategy, Strategic Plans, and Other Initiatives

Member countries endorsed the MRC Strategic Plan (2011–15) and the Basin Development Strategy for the Lower Mekong Basin in January 2011, which was an important step toward regional cooperation on sustainable basin-wide development, as envisaged in the 1995 agreement. The MRC Strategic Plan and the Basin Development Strategy were updated for 2016 to 2020 (MRC 2016a, 2016b). These strategies underline a growing sense of urgency among stakeholders for the need to move basin development toward sustainable outcomes that address long-term needs, including environmental protection and water, food, and energy security.

Between 2015 and 2018, MRC developed the Hydropower Mitigation Guidelines (MRC 2019a), intended as a technical guide for mitigation of risks and impacts of mainstream and tributary development in the Mekong River Basin. Central principles are the use of the mitigation hierarchy throughout a project life cycle and of basin-wide mitigation techniques (as opposed to project by project techniques) to address the risks and impacts of hydropower development. Avoidance of risk and impact in terms of planning, siting, and alternative designs of hydropower projects is highlighted in these guidelines. It may include alternative locations for projects, project design scales (for example, smaller dams), and alternative energy sources.

In 2018, MRC initiated a sustainable hydropower development strategy that considers alternative hydropower development pathways with various trade-offs among economic, social, and environmental factors. The intention is to promote balanced basin development among Lower Mekong Basin member countries. The strategy will generate input for the 2021–25 basin development plan (MRC 2019b).

MRC has developed a framework for transboundary environmental impact assessments (EIAs) to supplement existing cooperation according to the Procedures for Notification, Prior Consultation, and Agreement. A specific focus is to better understand conflict resolution in transboundary environmental matters and environmental considerations for sustainable hydropower development. Taking into consideration potential transboundary impacts of some pilot sites, member countries are learning how to manage challenges through dialogue, exchange of information, and capacity building. Experiences and procedures from the pilot projects are expected to improve the draft framework for transboundary EIAs for member states.

2.2.5 National Environmental Impact Assessment Regulations

The three countries sharing the Sekong Basin have all developed regulations for EIAs at the project level and for strategic environmental assessments and CIAs applicable to renewable energy planning and development. In Vietnam, strategic environmental assessment is required by law. Cambodia is drafting a new EIA law, the latest version of which also considers transboundary (cumulative) impacts.

2.3 International Sustainability Principles, Safeguards, and Standards

Multiple international sustainability principles have been developed over the years, including those of the World Commission on Dams (2000), the International Hydropower Association Hydropower Sustainability Protocol, the Asian Development Bank Safeguards Policy Statement, the World Bank Environmental and Social Framework, and IFC Performance Standards. Here we concentrate on IFC Performance Standards.

IFC has developed a sustainability framework to promote sound environmental and social practices, transparency, and accountability. IFC Performance Standards on Environmental and Social Sustainability (IFC 2012), which constitute a vital part of the sustainability framework, were launched in 2006, and the latest revision was introduced in 2012. The standards are recognized around the world as the benchmark for environmental and social risk management in the private sector.

There are eight performance standards addressing the main sustainability aspects of projects. The first—Assessment and Management of Environmental and Social Risks and Impacts—requires that borrowers conduct an integrated assessment to identify environmental and social impacts, risks, and opportunities related to their projects. A system to manage environmental and social performance throughout the life of a project is required. The other performance standards specify objectives and requirements to avoid and minimize impacts on workers, affected communities, and the environment and to compensate for any such impacts (in accordance with the mitigation hierarchy).

In the context of environmental impacts of hydropower development, Performance Standard 6, Biodiversity Conservation and Sustainable Management of Living Natural Resources, is one of the most important standards. It defines natural habitats as intact geographical areas composed of plant and animal species of largely native origin. The main requirement is that a project shall not significantly convert or degrade natural habitats unless no other viable alternatives exist or, where feasible, all impacts on the habitat will be mitigated so that no net loss of biodiversity occurs.

Separate guidance notes complement the performance standards, providing details of requirements under each standard. Of high relevance for hydropower development on the Sekong River are IFC's *Good Practice Note: Environmental, Health, and Safety Approaches for Hydropower Projects* (IFC 2018) and the World Bank Group's Good Practice Handbook, *Environmental Flows for Hydropower Projects: Guidance for the Private Sector in Emerging Markets* (WBG 2018).

3. Sekong Basin Profile

The current state of the basin serves as a reference for assessing cumulative impacts of future development pathways. The most extensive information on the Sekong Basin can be found in the monograph by Meynell (2014). Most information in this section is based on that publication, in addition to the *Atlas of the 3S Basins* by the International Union for Conservation of Nature (IUCN 2015). This section highlights background information on environmental conditions, natural resources, and social aspects that are relevant to assessment of impacts from renewable power development in the Sekong Basin (Map 3.1). For further details, see Appendix C.

The Sekong River is one of the few remaining major Mekong River tributaries with high biodiversity and few hydropower projects in operation. The Sekong also supports a highly diverse fish fauna. Meynell (2014) reports 213 fish species, of which 64 are migratory.

The Sekong Basin is also important for the lower Mekong (fish) migratory system (Figure 3.1) and thus the interaction between the Sekong, Sesan, and Srepok (3S) basins, Cambodian floodplains, Tonle Sap, and the Mekong Delta, with people relying on it as a source of income and food.

Map 3.1: **Sekong River Basin**

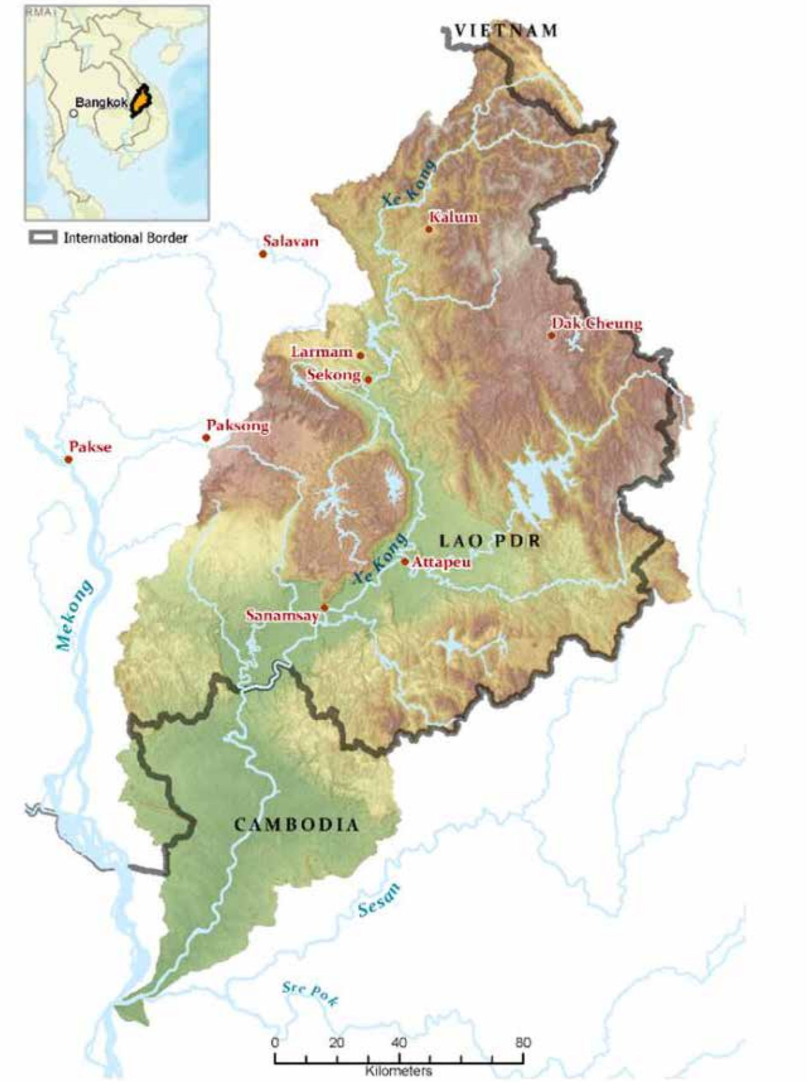
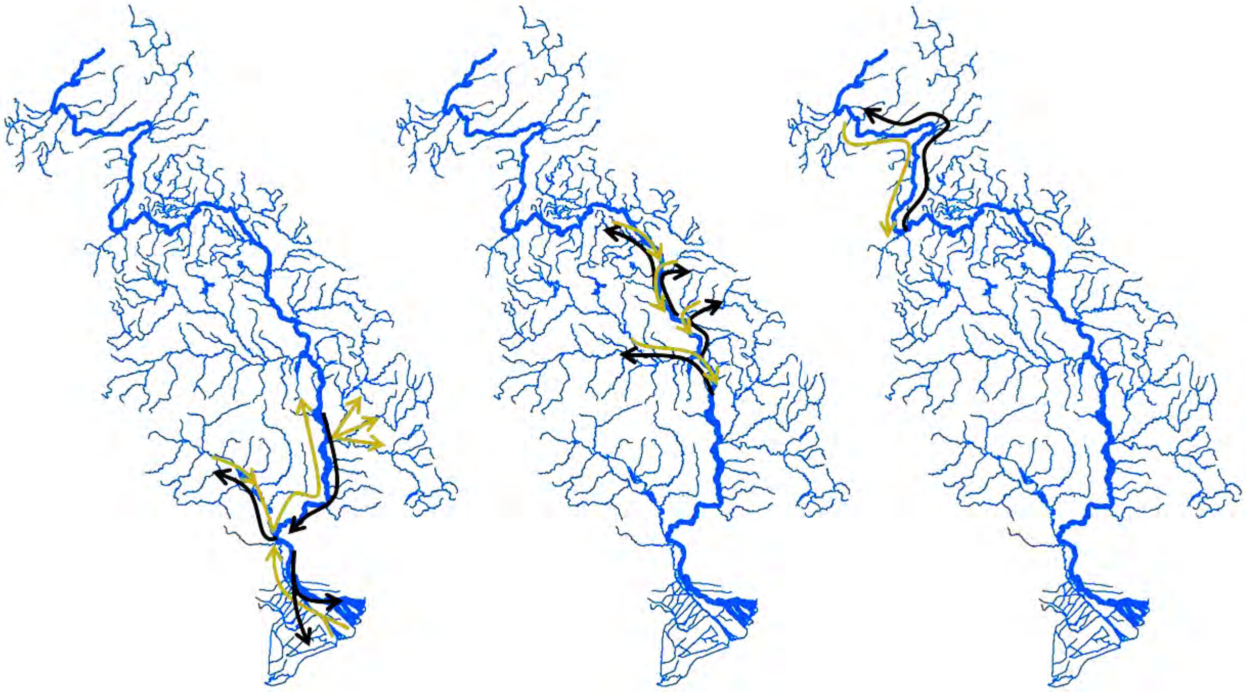


Figure 3.1: Lower, Middle, and Upper Migration Systems with Major Migration Routes in the Lower Mekong Basin



Source: MRC 2020; Schmutz and Mielach 2015, based on Poulsen et al. 2002.

Note: Black arrows indicate migrations at the beginning of wet season; gold arrows indicate migrations at the beginning of dry season.

3.1 Administrative Boundaries

The Sekong River is an important transboundary tributary of the Mekong River that rises in the central highlands of Vietnam and flows through Lao PDR and Cambodia before it joins with the Sesan and Srepok rivers approximately 7.5 kilometers upstream of the confluence with the Mekong River. The Sekong River has a catchment covering 28,414 square kilometers with 22,455 (78 percent) in Lao PDR, 5,417 (19 percent) in Cambodia, and 541 (3 percent) in Vietnam. In Lao PDR, the river overlaps with Attapeu, Champassak, Saravan, and Sekong provinces.

From the headwaters in Vietnam to the confluence with the Sesan and Srepok in Cambodia, the Sekong mainstream is 516 kilometers long (Meynell 2014). The total irrigated area is approximately 21,537 hectares, sourcing water from the Sekong mainstream and its tributaries.

3.2 Topography

Land resources and natural vegetation correlate closely with the Sekong Basin topography. Its upper parts are steep and have relatively extensive forest cover. The mountains and foothills occupy approximately one-quarter of the basin. The highly separated plateaus occupy another one-quarter and have good potential for a wide range of agricultural production, particularly perennial crops that depend on good drainage. The lowland, which occupies the remaining half of the river basin, comprises hills with moderate agricultural potential and river valleys and floodplains with potential for irrigated agriculture and hydropower development.

3.3 Hydrology and Water Resources

The 3S river basins account for approximately 23 percent of the annual flow (hydrology) and up to 25 percent of the sediment load in the Lower Mekong Basin (IUCN n.d.). Access to long-term, reliable hydrological data is crucial to the planning of hydropower investments and credible impact assessments, but detailed, accurate hydrological data are limited. Most of the gauging stations in the Sekong Basin are in the lower parts (for example, at Attapeu). Moreover, the reliability of existing hydrological data series is unclear because information about the operation and calibration of gauging stations is limited. Most of the data series are intermittent, with many missing values.

Meynell (2014) reports that mean annual rainfall in the Sekong Basin ranges from 1,400 to 2,900 millimeters (mm). Nearly 60 percent of the basin receives 1,700 to 1,900 mm per year, and 23 percent receives 2,300 to 2,700 mm. Mean annual temperature of the Sekong Basin is 21°C to 28°C. Temperatures in 56 percent of the basin are 21°C to 22°C, but approximately 33 percent of the area experiences much higher temperatures. See Map C.1 and Map C.2 in Appendix C for rainfall and temperature details.

Average monthly river flows vary greatly from low-flow—about 100 cubic meter per second (m^3/s)—to high-flow season (about 1,200 m^3/s). Historically, huge flow variations ranged from low-flow season discharges of 16 to 25 m^3/s to extreme flood situations (as in 1996) reaching nearly 4,000 m^3/s (Meynell 2014). Figure 3.2 illustrates average monthly runoff and average monthly flows at Attapeu (Meynell 2014). This is contrasted with flows in a fully regulated Sekong River in Figure C.2 panel b, Appendix C.

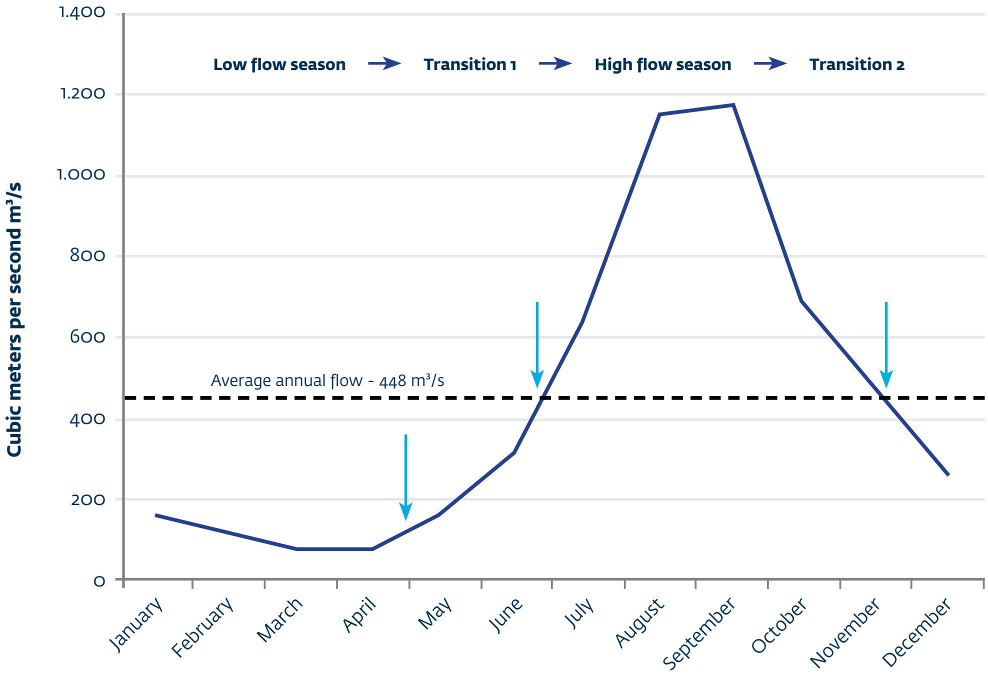
In general, water quality in the Sekong Basin is good (Freshwater Health Index 2018) but at risk of degradation (MRC 2008). Increases in agriculture, hydropower, and other infrastructure development could affect water quality.

3.4 Aquatic Biodiversity

The Sekong River is one of the few remaining major Mekong River tributaries with high biodiversity. The basin is also important for the Lower Mekong River fish migratory system (Figure 3.1), which is an important source of food and income for riparian populations. Fish migration is possible because of the absence of hydropower reservoirs along the mainstream of the river and a limited number of hydropower projects in its tributaries.

Meynell (2014) reports 14 endangered or critically endangered fish species in the 3S rivers. Data from IUCN for 2007 to 2013 suggest that 21 endangered and critically endangered fish species are present in the basin.[8] See a full list of endangered and critically endangered fish species in Table C.1, Appendix C. The list was discussed with local, provincial, and national stakeholders during stakeholder consultations and the interim

Figure 3.2: Mean Monthly Flow Distribution for the Sekong River at Attapeu, 1989–2005



Source: Meynell 2014.

Note: The arrows show the move from the low flow, dry season through to transition season 1 (May to mid-June) and to transition season 2 after the high flows (mid-June to mid-November).

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[8] See IUCN, "More Than 32,000 Species Are Threatened with Extinction," https://www.iucnredlist.org/.

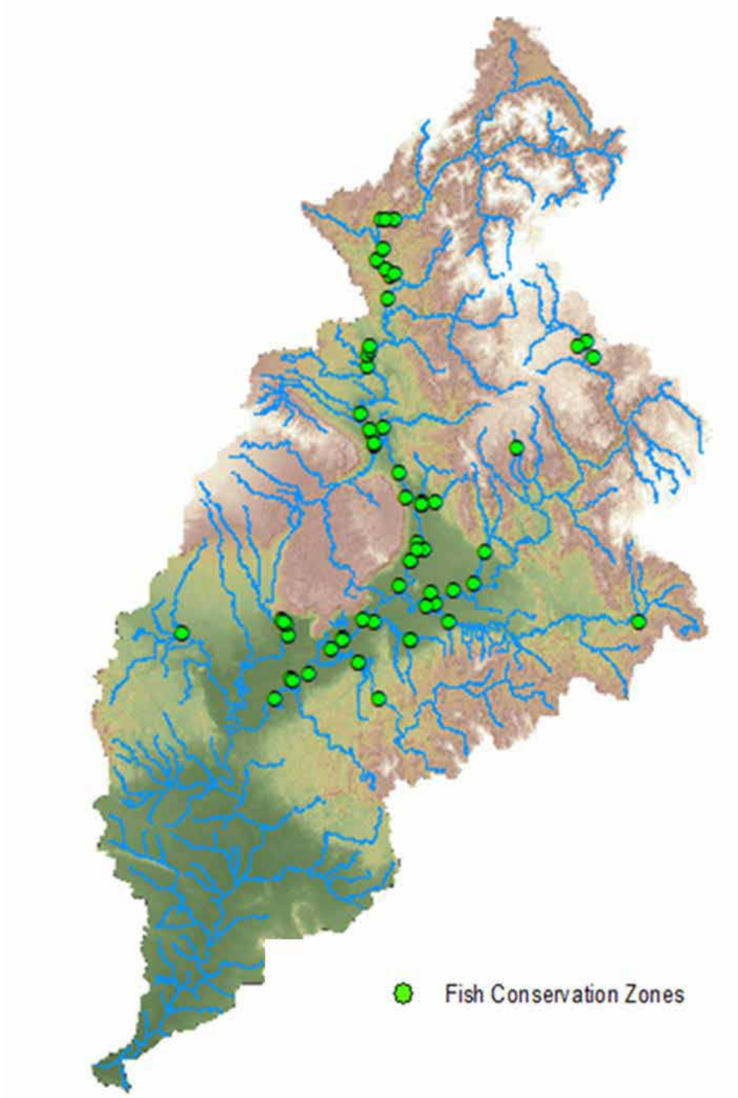
workshop. The existence of most of the species was confirmed, and several were reported to be very rare.

The consultations also revealed that fish diversity and abundance over the past 15 years have declined drastically in Champassak, Sekong, and Attapeu provinces. Stakeholders attributed this to the combined pressures of overfishing, industry, mining, agriculture, and hydropower development. Extremely large declines in total numbers of fish were noted, including important food fish species such as *Poropuntius* (barb, *Pa chat*), *Schistura* (loach, *Pa tit hin*), and *Sewillia* (river loach, no Lao name identified).

As the last major free-flowing tributary to the Mekong River, the Sekong River provides unobstructed passage for migratory fish between the Mekong mainstream, Tonle Sap Lake, and the Vietnam Delta (Lower Mekong Fish Migratory System). The Sekong River also contains a great diversity of fish, with many fish species unique to the basin and many spawning only in their unique habitats. Thirty-one of 62 fish conservation zones in Lao PDR are in the Sekong Basin (Map 3.2). Fish conservation zones are legally defined protected areas where fishing is prohibited as a means to help restore fish stock.[9] These use a community co-management framework, in which locals actively help enforce regulations.

A Sekong River with a high degree of connectivity (unrestrained mobility) is important for the Lower Mekong fish migratory system. Such uninhibited fish mobility is of immense value for conservation of fish habitats.

Map 3.2: Fish Conservation Zones in the Sekong Basin



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[9] http://www.wwf.org.la/projects/comfish/

3.5 Terrestrial Ecosystems, Biodiversity, and Protected Areas

3.5.1 Protected Areas

The Sekong Basin has among the highest proportion of protected areas (Map 3.3) and key biodiversity areas out of all Mekong River tributaries.[10] Approximately 39 percent of the basin land area lies within protected areas, and 37 percent has been identified as lying within key biodiversity areas (Meynell 2014) and important bird areas.

These are unusually high numbers and show the importance of the Sekong Basin in terms of biodiversity conservation. Several of the terrestrial valued environmental components (VECs) depend on these forest habitats for sustainable use and conservation, including hardwood timber, non-timber forest products (NTFPs), and valued terrestrial fauna. There are four National Protected Areas (NPAs) and one Ramsar site in the Sekong Basin designated as of international importance.

The north and east of the Sekong Basin contain part of the Annamite Mountain Range, where the Xe Xap and Dong Ampham NPAs

Map 3.3: **Protected Areas in the Sekong Basin**

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[10] Key biodiversity areas are sites contributing significantly to global persistence of biodiversity in terrestrial, freshwater, and marine ecosystems. Sites qualify as global key biodiversity areas if they meet one or more of 11 criteria, clustered into five categories: threatened biodiversity, geographically restricted biodiversity, ecological integrity, biological processes, and irreplaceability. The key biodiversity area criteria can be applied to species and ecosystems (IUCN 2016).

are located. This area is recognized as a regional, transboundary conservation corridor (being funded by the Asian Development Bank). The Bolaven Plateau, which reaches 1,300 meters above sea level, makes up a large portion of the west of the Sekong Basin. Temperate vegetable crops and coffee are cultivated there. The south of the basin is mainly floodplains along the Sekong River. The Xe Pian NPA, which ranks second in Lao PDR and 10th in Asia for biodiversity, is in this southern part of the basin.

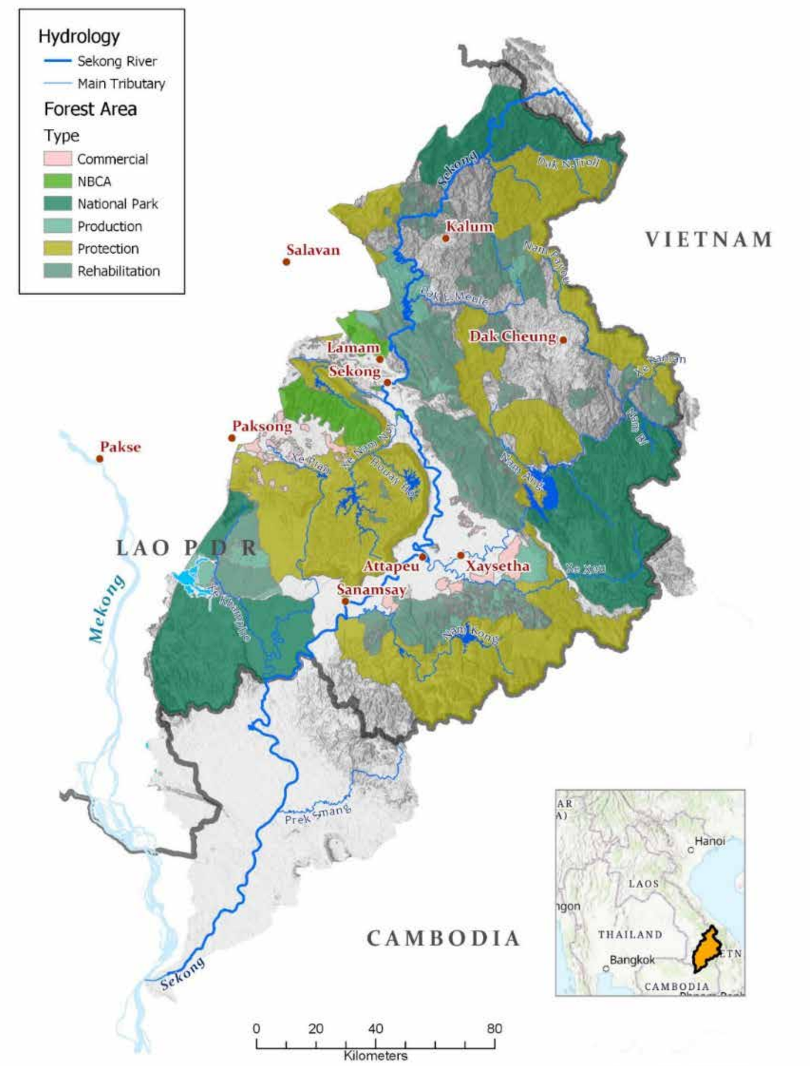
The Ramsar site is the Beung Kiat Ngong Wetland, which encompasses 2,360 hectares of swamps, lakes, and marshes important for spawning fish, turtles, and birds. It contains more than 350 species of medicinal plants and is the only place in Lao PDR where peatland can be found.

The floodplain area has a large portion of dry dipterocarp forest with wetland complexes (WWF 1997). Part of the Sekong floodplain is classified as an important bird area (BirdLife International 2020), with some critical habitats especially for water birds (Thewlis et al. 1998).

3.5.2 Forest

The various forest types and forest protected areas in the Sekong Basin are shown in Map 3.4. The forest cover is extensive (natural deciduous and evergreen forests) but has declined over the past decade, as it has been cleared for agricultural land, especially in the Lao PDR part of the basin—for crop cultivation in the west and hill rice cultivation in the north. In the south of the basin, there are extensive economic land concessions on the right bank of the Sekong River in Cambodia (Meynell 2014).

Map 3.4: **Forest Types in the Sekong Basin**



Human land and water use within a river basin can affect its geophysical processes, such as erosion and water quantity and quality (Bain and Loucks 1999). The amount and rate of change in forested areas and agricultural and other types of land can affect these processes.

Transformation of forest areas to agricultural land affects rivers by changing rainwater surface runoff. Bain and Loucks (1999) estimate that approximately 12 percent of rainfall in forest areas is surface runoff, with negligible soil loss, whereas 42 percent of rainfall on agricultural land is runoff, with high soil erosion rates.

Existing hydropower development has caused forest loss of at least 16,872 hectares (about 169 square kilometers) (Table 3.1). Approximately three-quarters of lost forest land was classified as protected forest, and nearly a quarter was conservation forest or forest within NPAs.

3.5.3 Terrestrial Wildlife

The IUCN Red List database reports many flora and fauna species in the Sekong Basin,

Table 3.1: Forest Loss Caused by Recent Development of Hydropower Projects, Including Transmission Lines

Project name	Production forest	Conservation forest or national protected area	Protected forest	Regeneration forest	Total forest
	hectares				
A Loui (Vietnam)					Unknown
Houay Ho HPP			2,758		2,758
Houay Ho transmission lines	104		319	9	432
Xe Kaman 3 HPP			564		564
Xe Kaman 3 transmission lines			116		116
Xe Namnoy 1[a]					0
Houy Lamphan Gnai HPP		109	990		1,098
Houay Lamphan Gnai transmission lines	15	19	10		44
Xe Namnoy 6[a]					0
Xe Kaman 1 HPP		3,270	33		3,304
Xe Kaman–Sanxay[a]					0
Nam Kong 2 HPP			77		77
Xe Katam 1 Xe Namnoy 2			18		18
Xe Pian–Xe Namnoy HPP			4,969		4,969
Xe Pian–Xe Namnoy transmission lines	303	10	4	109	426
Nam Kong 3 HPP			3,066		3,066
Total	**422**	**3,408**	**12,924**	**118**	**16,872**

[a] Run-of-river projects are those with no storage reservoir, so there is no significant forest loss.

Note: HPP = hydropower plant.

and according to the Integrated Biodiversity Assessment Tool (IBAT),[11] there are about 89 globally threatened vertebrate species, 21 of which are critically endangered, 32 endangered, and 36 vulnerable. The species list also contains 18 birds, 28 mammals, eight reptiles, 31 fishes, and two amphibians. Appendix C shows the number of globally threatened vertebrate species in the Sekong Basin according to IUCN.

Some prominent species under threat are the Asian elephant (endangered), banteng (endangered), gaar (vulnerable), buff-cheeked gibbon (endangered), red-shanked douc langur (endangered), Indochinese silvered leaf monkey (endangered), Siamese crocodile (critically endangered), tiger (endangered), and various bird species. More details can be found in Appendix C, which also presents the cumulative impact assessment (CIA)'s supporting analysis on terrestrial ecology.

The distribution of terrestrial wildlife in the Sekong Basin was discussed with local and national stakeholders. Many of the globally threatened species reported in the Sekong Basin have low population numbers and are threatened by hunting, habitat loss, land use change, and deforestation, although areas such as the Xe Pian NPA in the basin function as refuges for threatened species.

3.6 People and Livelihoods

3.6.1 Population and Minorities

The Sekong Basin has a low population density and a total population of approximately 324,000: 44,000 in Cambodia, 240,000 in Lao PDR, and 40,000 in Vietnam. The population is concentrated in the towns of Attapeu and Sekong in Lao PDR and in villages on the large surrounding plains.

Ethnic minority groups with distinct cultures and religious beliefs populate the Sekong River Basin (Table 3.2). The ethnic composition of the population in the Sekong Basin comprises mainly Mon-Khmer subgroups in the east and Lao in the west. In Attapeu Province, ethnic Lao is the

Table 3.2: Characteristics of Main Ethnic Groups in the Sekong Basin

Ethnic group	Language group	Characteristics
Nha Heun	Mon-Khmer Bahnaric branch	This is a small ethnic group found only in southern Lao PDR. Members live in small scattered villages in Champassak, Sekong, and Attapeu, with a concentration of villages south and east of Bolaven Plateau, in particular along the Xe Namnoy River. Previously it was a semi-nomadic group that settled at the beginning of the 20th century.
Brao	Mon-Khmer Bahnaric branch	Members are shifting cultivators in the uplands and skilled paddy farmers in the lowlands. They raise cattle and buffalo and hunt fish as well as gather non-timber forest products for supplementary livelihood. They are skilled basket makers and wood carvers and are found in Savannakhet, Salavan, Khammouan, and Sekong.
Ta-Oy	Mon-Khmer Kautic branch	Members are found in Aluoi District of Vietnam and Savannakhet, Salavan, Champassak, and Sekong provinces in Lao PDR. They are upland rice cultivators who also plant maize, sweet potatoes, and cassava.
Katu	Mon-Khmer Kautic branch	Members are found in Sekong Province along the Upper Sekong River and in Quang Nam and Thua Thien-Hue provinces of Vietnam. They are upland rice cultivators who also plant maize, sweet potatoes, beans, bananas, and vegetables. They keep mainly small domestic livestock such as pigs, chickens, and ducks. Formerly they were considered one of the most warlike ethnic groups, resisting intruders into their territories.
Yae	Mon-Khmer Bahnaric branch	Members are found in Attapeu and Sekong provinces. They make bamboo and rattan baskets and are skilled blacksmiths. Some villages also make pottery.
Kriang	Mon-Khmer Kautic branch	Members are found in Salavan, Champassak, and Sekong. They cultivate upland rice (shifting cultivation), millet, maize, and sweet potatoes. They generally do not keep large livestock but raise pigs and chickens for their own consumption. Hunting, fishing, and gathering of non-timber forest products play a large role in their livelihoods.

Source: Schliesinge 2003.

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[10] See IBAT Alliance, Integrated Biodiversity Assessment Tool, database, https://www.ibat-alliance.org/.

largest single group, accounting for more than one-third of the population, with the Brao and the Oy accounting for roughly 17 percent and 16 percent of the population, respectively (Baird and Shoemaker 2008). Smaller ethnic groups in Attapeu Province, ranging from 4 percent to 9 percent of the population, include the Trieng, Cheng, Yrou, and Harak.

In Sekong Province, Katu (24 percent) and Trieng (22 percent) are the largest groups, followed by Harak (16 percent). Ethnic Lao, who are mostly found in and around the provincial capital, make up approximately 9 percent of the total population. Other smaller groups include the Xuay, Ta Oy, and Yrou.

In Champassak Province, ethnic Lao is the dominant group, with approximately 85 percent of the population. Ethnic Lao is also the most populous group in Pathoumphone District, which forms part of the lowlands of the Sekong River Basin. The Yrou and Nhaheun ethnic groups have historically inhabited the upper parts of the basin that fall within Champassak Province, including Paksong District.

Hydropower development has led to displacement and resettlement of a number of ethnic minority villages and populations. Table 3.3 provides an overview of the groups that have been resettled.

The provincial and district consultations for this study indicated that ethnic minority groups in the Sekong River Basin are increasingly aligning with the majority Lao lowland culture. Examples of integration include adoption of Buddhist practices and the *baci su kwan* ceremony (a common lowland ceremony with animist traditions), increasing use of the Lao language instead of ethnic mother tongues, and less wearing of traditional clothing. The drivers for this change are increasing education, greater contact and interaction between ethnic groups, and dominance of Lao culture because of economic development. The faster the pace of economic development, the faster cultural integration can be expected to proceed.

Table 3.3: Overview of Ethnic Groups Affected by Present Situation Projects

Project name	Resettled households	Resettled persons	Affected ethnic groups
A Loui (Vietnam)	218	872	Not known
Houay Ho	320	1,920	Nya Heun: 12 villages moved to adjacent Lavaen villages
Xe Kaman 3	57	342	Lao, Ta Leng, De
Xe Namnoy 1	0	0	
Houy Lamphan Gnai	251	1,660	94% of all resettlers are Katu
Xe Namnoy 6	-	-	Not available
Xe Kaman 1	220	1,094	Nya Heun
Xe Kaman Sanxay			Not known
Nam Kong 2	0	0	Brao: no resettlement but indirectly affected
Xe Katam 1–Xe Namnoy 2	15	92	Nya Heun
Xe Pian-Xe Namnoy	390	2,064	Nya Heun
Nam Kong 3	21	104	All resettlers are Brao
Total present situation	**1,492**	**8,148**	

3.6.2 Agriculture

Subsistence and semi-subsistence agriculture is by far the most common livelihood system component and source of sustenance for people in the Sekong Basin, although gradually declining in importance. In 2008, more than 90 percent of households in Attapeu engaged in agriculture and livestock, and agriculture was the main occupation for 92 percent in Sekong (Baird and Shoemaker 2008). Results from the Lao Census of Agriculture 2010/11 (Epprecht et al. 2018) show a slightly smaller percentage of farming households in the two provinces (86 percent for Sekong and 84 percent for Attapeu). Percentages of farming households may have fallen further since 2011.

Various agricultural and farming practices are used in the basin. Paddy rice cultivation is the most common farming system in the Attapeu lowlands but is also found in some upland areas, where the flat valley floors provide opportunities for irrigated or rain-fed wet-rice cultivation. Paddy rice cultivation and development of new fields are being promoted to increase rice sufficiency in the Sekong Basin.

Dry season riverbank vegetable gardens are found along the riverbanks of the Sekong River and its tributaries, where fluctuation in water levels between the dry and wet seasons leaves fertile soil that is used for dry season crops. Crops cultivated include maize and tubers planted high up on the banks at the end of the rainy season and watermelons, chillies, long beans, eggplant, and tobacco planted further down later in the season. Both paddy rice farmers and upland swidden farmers cultivate riverbank gardens in the dry season. In general, farming households consume most of the produce from riverbank gardens, with surpluses sold at local markets.

Domestic livestock is important for most people in rural Lao PDR, as it is for people in the Sekong Basin, where it is one of the main sources of income for villagers, especially in remote villages with poor market access. Most families raise some kind of livestock, including cattle, buffalo, pigs, goats, and poultry. Livestock plays an important role in the local economy and tends to be regarded as a kind of savings account that can be used to obtain cash for marriage, medical care, children's education, and other major expenditures.

Swidden agriculture involves clearing secondary forest or bushland for cultivation of crops for one or two years. Upland rice varieties are the main crop cultivated on swiddens, but other crops such as maize, taro, pumpkin, watermelon, beans, and peas are often grown together with rice. In the uplands and on the Bolaven Plateau, swidden agriculture is common, but yields are low. Most families must purchase rice using money earned from collection of NTFPs, sale of coffee, and day labor on agricultural plantations.

3.6.3 Coffee Production

The Bolaven Plateau, which forms a large part of the Sekong River Basin, has fertile volcanic soil that, along with its elevation, makes it an ideal area for growing coffee, fruits, and vegetables. Coffee is one of the main sources of income for the population on the plateau, which comprises several ethnic minority groups such as the Brao and Nja Heun. Coffee has been grown since the early 1900 in smallholdings, often cultivated in a kind of agroforestry system mixed with fruit trees. The ethnic Jru people were initially the primary coffee growers, but starting in the 1970s, ethnic Lao from the lowlands cleared and planted more land to grow coffee. In the early 1990s, coffee plantations were expanded in response to rising world coffee prices. In the stakeholder consultations conducted for this study, ethnic minority villagers mentioned coffee as an important source of cash—from selling their own production or working as day laborers on coffee plantations that others owned.

3.6.4 Non-Timber Forest Products

People in the Sekong River Basin collect NTFPs for consumption and to generate income. NTFPs comprise naturally occurring plants and wildlife such as forest fruits, edible leaves, resins, nuts, birds, and insects. NTFPs constitute a significant proportion of the livelihood of people in the basin (Baird and Shoemaker 2008). Many NTFPs are collected for consumption and use, including wild vegetables, bamboo shoots, and bamboo for building huts. Wild fruits are collected for consumption and sale. The economically most important NTFPs in the Sekong Basin include dry resins, wood resin, malva nuts, wild cardamom, fern roots, yellow vine, eaglewood, rattan, wild honey and beeswax, wild mushrooms, and medicinal plants.

Quantifying the economic value and significance of NTFPs in the Sekong Basin is difficult because it varies substantially from village to village, depending on location within the basin. One study undertaken in three villages (Rosales et al. 2003) estimated the direct-use value of NTFPs to be $398 to $525 per household annually. This is relatively high, considering that the average annual household income for Sekong was estimated at only $120 at the time of the study. Nevertheless, because NTFPs that villagers collect can reduce the need for households to buy building materials, food, and medicines, it is feasible that the value of NTFPs in monetary terms could be higher than annual cash income.

3.6.5 Fisheries

After agriculture, fishing provides the second largest source of income for the Sekong Basin population. The local stakeholders underlined the important role of fisheries during the consultations and peoples' perception of it as an important natural resource.

The IUCN Sekong Basin fact sheet (IUCN n.d.) reports that fish catches contribute 35 percent to 40 percent of annual household income, and 80 percent of protein consumption in the basin. The annual consumption of fish has been estimated at nearly 50 kilograms per person.

The significance of fish for livelihoods in villages along the Sekong River and on the Bolaven Plateau was assessed in the environmental impact assessment report for the Xe Pian–Xe Namnoy hydropower project (LCG 2013). The results from the survey, which was conducted in 11 villages on the plateau and 11 along the Sekong River, indicated the following:

- Bolaven Plateau households fished four days per week on average, and villagers along the Sekong River fished six days per week.
- Average fish catch per day for one person in the dry season was 3.2 kilograms (kg) for villages on the Bolaven Plateau and along the Sekong River; catches in the wet season were 3.2 kg and 3.9 kg, respectively.
- During the upstream fish spawning migration from April to June, fish catches were considerably higher, reportedly as much as 7.5 kg per person per day.
- Bolaven Plateau villages consumed 97 percent of their fish catch, with the rest normally given to relatives and neighboring households.
- Sekong River villages consumed 70 percent to 75 percent of their catch, with the remaining fish sold (about 15 percent) or preserved (about 15 percent) by smoking, drying, and fermenting.
- The sale of fish in Sekong villages contributed about 5.2 percent of household income.

Overfishing and other unsustainable fishing practices (gill nets, electroshock, and explosives) contribute to already high fisheries pressure (MRC 2017; Baran et al. 2013). Fish catch per unit of effort has declined, and undersized fish dominate the catch (MRC 2017). During district consultations, villagers attributed the decrease in fish stocks to uncontrolled fishing and hydropower development.

Fishing pressure will probably increase in the next decade because of population growth and advances in fishing gear technology. An increasing number of people fish not only for their own consumption but also to sell (MRC 2017), which suggests fisheries demand will increase.

3.7 Development Projects in the Sekong Basin

3.7.1 Hydropower Development

Twelve projects are already operating or are at advanced stages of construction and due to become operational by 2020 (Map 3.5, Table 3.4). Together these projects will have a capacity of approximately 1,550 megawatts (MW).

Twenty-three more projects are in various stages of preparation or preliminary stages of construction and are all proposed for completion by 2030 (Table 3.5). Construction has begun on some of these projects, but most environmental and social impact assessments are not yet completed.

These projects are distributed among the tributary basins of the Sekong as well as the mainstream. All tributaries except Xe Lon will contain at least one hydropower project by 2030. The Xe Kaman and Nam Bi tributaries have a very high project density, with 13 projects.

Map 3.5: Hydropower Projects Commissioned in the Sekong Basin

Table 3.4: Commissioned Hydropower Projects in the Sekong Basin

Project dam	Status	Date of commercial operation	Installed capacity	Mean annual energy[a]	Power destination		
			MW	GWh	Lao PDR	Thailand	Vietnam
A Luoi	Operational	2012	170	650			100
Houay Ho	Operational	1999	152	450	5	95	
Xe Kaman 3	Operational	2013	250	980	10		90
Xe Namnoy 6	Operational	2013	5	20	100		
Xe Namnoy 1	Operational	2014	15	80	100		
Houay Lamphan Gnai	Operational	2015	88	450	100		
Xe Kaman 1	Operational	2016	290	1,040	20		80
Xe Kaman–Sanxay	Operational	2017	32	110	20		80
Nam Kong 2	Operational	2017	66	260	100		
Xe Katam 1–Xe Namnoy 2	Operational	2017	22	120	100		
Xe Pian–Xe Namnoy	Under construction	2020	410	1,800	10	90	
Nam Kong 3	Under construction	2020	54	200	100		
Total present situation			**1,554**	**6,160**			

Note: MW = megawatt; GWh = gigawatt hour.

[a] The mean annual energy is based on numbers from developers, with slight adjustment in some cases to fit with other technical data (for example, decreased if stated generation is above what is technically possible). All numbers have been rounded.

Table 3.5: **Status of Hydropower Projects in the Sekong Expected to be Complete by 2030**

Project dam	Status	Date of commercial operation	Installed capacity (MW)	Annual energy (GWh)	Power destination
Dakchaliou 1	Under construction	2021	11	50	Unknown
Dakchaliou 2	Under construction	2021	13	60	Unknown
Nam Kong 1	Under construction	2022	150	560	Lao PDR
Nam Bi 1	PDA stage	2024	68	290	Not confirmed, possibly Vietnam
Nam Bi 2	PDA stage	2024	50	210	
Nam Bi 3	PDA stage	2024	12	50	
Nam Ang	PDA stage	2024	55	160	Lao PDR
Nam Emoun	Under construction	2024	129	430	Lao PDR
Nam Pangou	PDA stage	2025	33	140	Unknown
Xe Pian–Houysoy	PDA stage	2025	45	200	Lao PDR
Sekong 4A	FS approved	2025	165	780	Thailand
Sekong 4B	FS approved	2026	175	750	Thailand
Sekong 3A	FS completed	2027	114	430	Lao PDR
Sekong 3B	FS completed	2028	122	400	Lao PDR
Lower Xe Pian	FS ongoing	2030	15	60	Lao PDR
Xe Katam	PDA stage	2030	81	300	Lao PDR
Xe Kaman 2A	FS ongoing	2030	64	250	Lao PDR
Xe Kaman 2B	FS ongoing	2030	100	380	Lao PDR
Xe Kaman 4	PDA stage	2030	70	290	Vietnam
Sekong 5	FS completed	2030	330	1500	Thailand
Sekong Downstream A	FS completed	2030	86	380	Lao PDR
Sekong Downstream B	FS completed	2030	50	210	Lao PDR
Xe Namnoy 5	Unknown	2030	20	90	Lao PDR

Note: PDA = project development agreement; FS = feasibility study; MW = megawatt; GWh = gigawatt hour.

3.7.2 Solar and Wind Power

Several feasibility studies for wind and solar power are under way in the basin. See Appendix C for detailed descriptions. It is assumed that some development of wind and solar photovoltaic will take place up to 2030, by which time these technologies will be more competitive. The assumption is that 600 MW of solar (land based and floating) and 600 MW of wind power are in operation, providing approximately 3 terrawatt-hour (TWh) of energy annually.

3.7.3 Grid Expansion and Other Infrastructure

Appendix C reviews power grid and transmission infrastructure. Major existing and planned national transmission systems and international grid integration have been considered. Future layout of transmission lines will influence the pace and pattern of hydropower development in the Sekong Basin.

A planned cross-border interconnection between southern Lao PDR and Vietnam is of particular relevance for this study because domestic demand in Lao PDR is low, so most Sekong Basin renewable energy projects are premised on cross-border electricity sales. When complete, there will be a considerable increase in capacity to transfer power from the Sekong Basin.

On the basis of this proposed interconnection project, it has been assumed in this study that the future grid system will allow export of all power production in the full development pathway to Vietnam, with only a small percentage of power supplied to the Lao PDR grid.

3.7.4 Power Demand and Supply

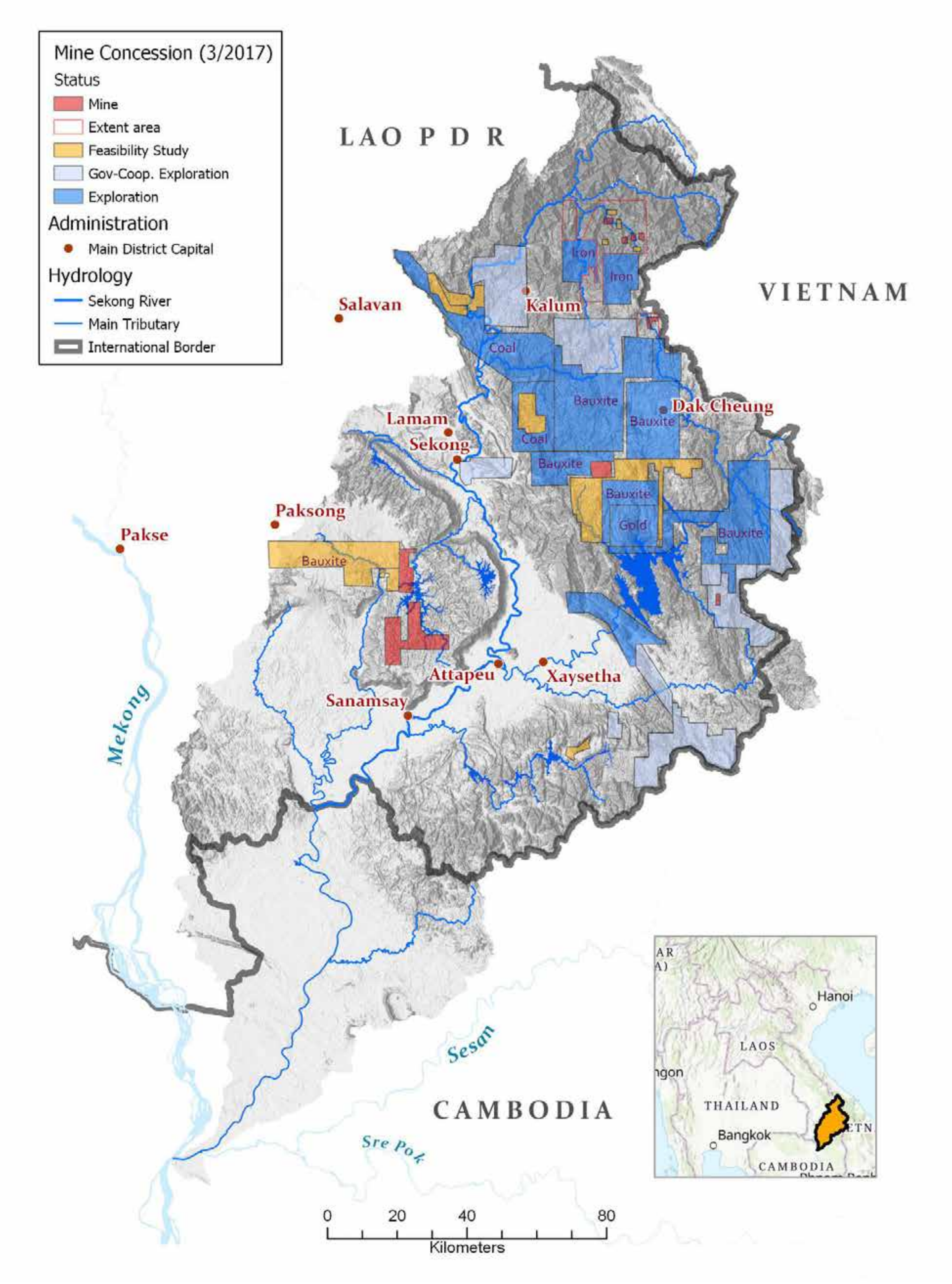
Domestic demand for additional power in Lao PDR is limited, particularly in the Sekong Basin. All proposed large hydropower projects in the Sekong Basin base their financial viability on exports through power purchase agreements with the Electricity Generating Authority of Thailand or Electricité de Vietnam. Thailand has agreed to import up to 9,000 MW from Lao PDR by 2030 (MEM 2017), and Vietnam has pledged to import 5,000 MW. Provisional information on Thailand's future power demand indicates only moderate demand for further power imports from Lao PDR (MRC 2018). In contrast, the demand forecast from Vietnam is such that Vietnam could use the majority of power generated by all 23 hydropower projects proposed for development in the Sekong Basin up to 2030. Power exports from the Sekong Basin to Vietnam and Thailand will mainly provide peak power, with thermal plants based in those countries providing baseload. Further details of the power supply and demand assessment conducted for this cumulative impact assessment (CIA) are presented in Appendix C.

3.8 Mining and Commercial Plantations

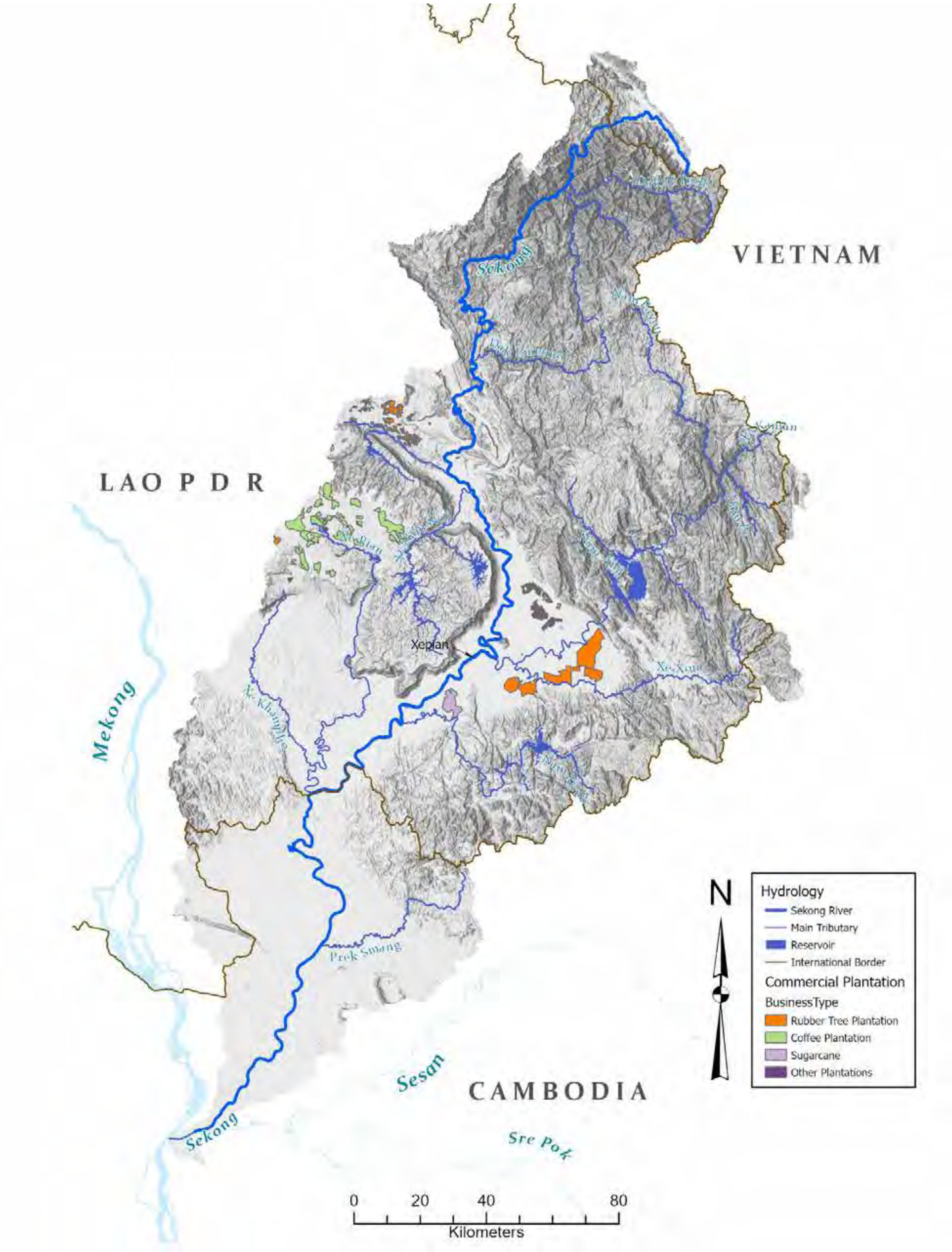
Numerous mining and exploration licenses have been issued within the Sekong Basin (Map 3.6). Active mining is concentrated in the Xe Kaman catchment. Geological exploration and feasibility studies are under way in the upper part of the Sekong Basin for bauxite and coal.

The extent of commercial plantations (mostly rubber tree plantations in the Xe Kaman sub-basin and coffee plantations in the Xe Katam sub-catchment) in the Sekong Basin is portrayed in Map 3.7. It is expected that the number of commercial plantations will continue to increase.

Map 3.6: Mining Projects in the Sekong Basin at Various Stages of Development



Map 3.7: Commercial Plantations with Land Concessions in the Sekong Basin



4. Identification of Valued Environmental Components and Existing Drivers of Change

4.1 Identification of Valued Environmental Components

Identification of valued environmental components (VECs) for this study commenced with a long list of environmental and social attributes typically relevant to hydropower development (in alphabetical order): air and noise, affected people and resettlement, cultural and ethnic archaeology and heritage, erosion and sedimentation processes, fish and aquatic habitats, natural resource–dependent livelihoods such as agriculture and forestry, terrestrial habitats (for example, protected areas and critical habitats), as well as water quality and quantity. Initial stakeholder concerns are listed in Table 1.2 (Chapter 1). Final VECs (Table 4.1) were selected based on stakeholder feedback combined with scientific research and professional judgment to estimate the appropriate scope of VECs and to analyze the limits of acceptable change.

4.2 Stressors and Drivers of Change that Affect Valued Environmental Components

4.2.1 Cause-and-Effect Chain

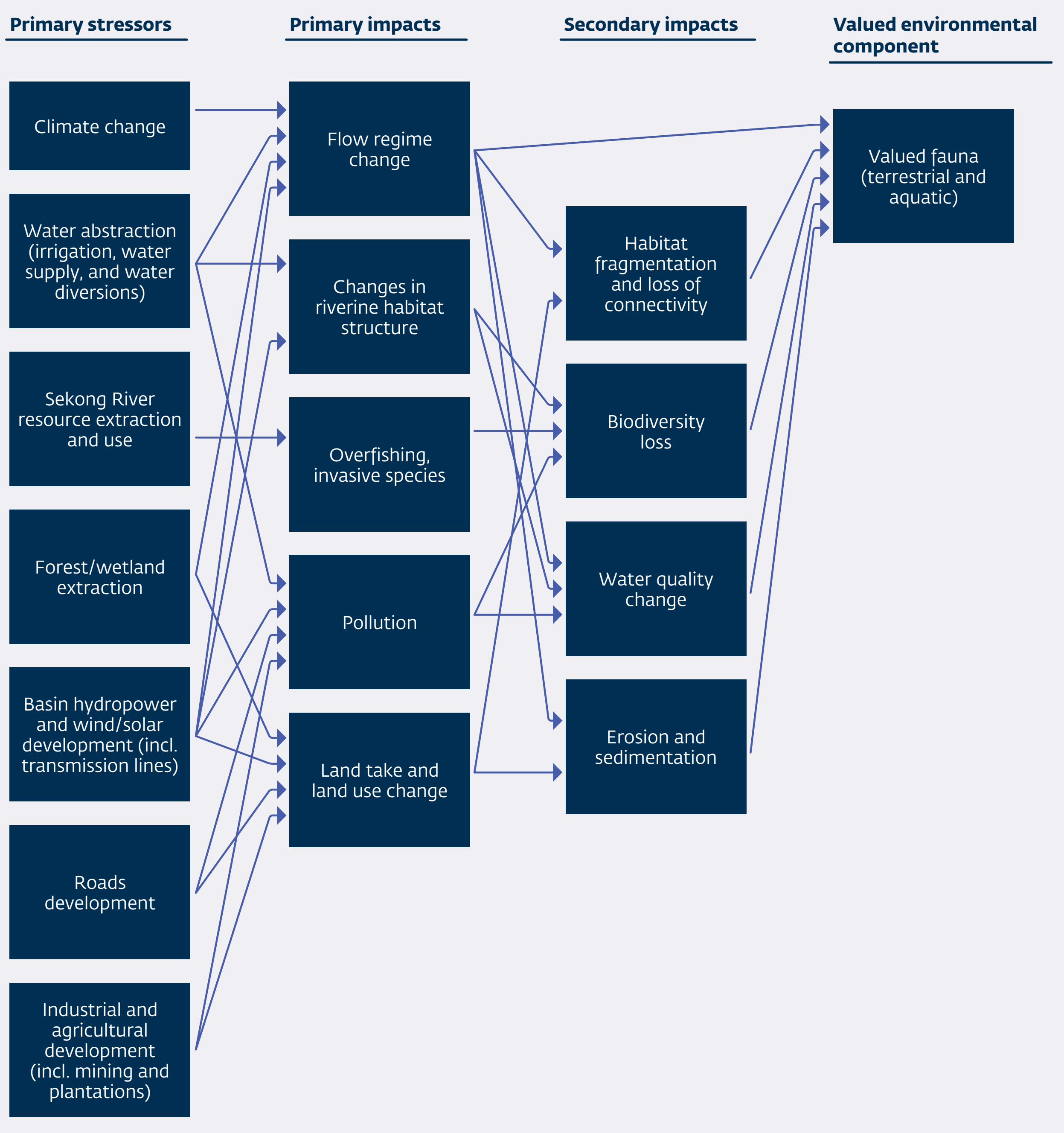
A cumulative impact assessment (CIA) is a process of analyzing potential impacts on and risks to VECs resulting from existing and proposed projects in the context of human activities and natural environmental and social external drivers over time.

The complex relationships and interactions among primary stressors, primary effects, and secondary effects that lead to cumulative impacts on VECs are illustrated in Figure 4.1. Similar cause-and-effect-impact models were developed for each VEC assessed.

Table 4.1: Selected Valued Environmental Components

Component	Description
Aquatic biodiversity and ecosystems	• Threatened or endangered aquatic habitats, flora, and fauna • Super-endemic fish (found only in the Sekong Basin) and migratory species
Terrestrial biodiversity and ecosystems	• Habitats important for biodiversity and ecosystem functions • Designated protected areas and conservation sites • Endangered and critically endangered terrestrial species
Natural resource–dependent livelihoods	• Habitats, flora, and fauna (terrestrial, riparian, and wetland) important for rural livelihoods and food security • Timber resources, including wood for construction, firewood, and charcoal • Non-timber forest products of value for food security, medicine, construction, and trade • Capture fisheries in the Sekong mainstream and tributaries • Wet-rice agriculture on river flood plains, upland fields, and dry season riverbank gardens
Community and culture	• Cohesive communities • Linguistic and cultural diversity, traditional knowledge, and ethnic identity • Gender roles and opportunities

Figure 4.1: Cause-and-Effect Chain for Cumulative Impacts on Valued Aquatic and Terrestrial Fauna



4.2.2 Anthropogenic (Human-Induced) Stressors

Human activities within the geographic boundaries covered in the CIA can be summarized as follows:

- All large and medium-sized hydropower projects, irrigation, and water supply dams along the Sekong mainstream and tributaries
- Large- and medium-scale wind and solar power generation projects in the basin
- Associated supplementary infrastructure (for example, transmission lines and roads)
- Industrial and agricultural development, including mining and plantations that will cumulatively affect VECs
- Water extraction (irrigation, water supply, and water diversions)
- River resource use (fish, sand, and gravel)
- Forest and wetlands resource use

4.2.3 Natural System Stressors

Increasing climate change will affect the hydrological regime of the Sekong Basin. There are predictions of a slight increase in flow during the wet season but a larger decrease in the dry season (Appendix B).

4.2.4 Primary and Secondary Impacts

This study has focused on the following primary and secondary impacts:

- Flow regime (hydrological) change (changes in magnitude and frequency of high and low flows)
- Changes in sediment transport (tons per year)
- Inundation, land acquisition, and change in land use (amount and percentage change in hectares)
- Overfishing and introduction of invasive species (qualitative estimate)
- Pollution and water quality change (qualitative estimate)

4.3 Impact Rating System

Determination of indicators and limits of acceptable change is a complex, multifaceted exercise. The CIA involves analysis of multiple processes of change that differ in type, scale, and other attributes. This makes it challenging to design appropriate indicators to evaluate the significance of cumulative effects on VECs.

This challenge is acknowledged in the international guidance on CIA: "Several approaches/methods are available for assessing cumulative impacts; however, there is no one single method that should always be used; nor necessarily, one type of method for specific impacts or types of actions. The appropriate method is the one that best provides an assessment of the effects on the VECs being examined" (IFC 2013). This study applied a combination of tools and drew on inputs from subject matter specialists, government authorities (for example, Ministry of Energy and Mines and Ministry of Natural Resources and Environment), and stakeholders (local, national, and transboundary). Nonetheless, constraints were faced because of limited baseline data, uncertainty about proposed project developments, and absence of a strategic regional development plan.

The approach chosen for this study was to identify appropriate indicators of impact for each VEC (Table 4.2) and apply a score from 0 to 4 to indicate the size of the impacts:

0 = Negligible

1 = Slight

2 = Moderate

3 = Large

4 = Severe

Table 4.2: Summary of Valued Environmental Components, Indicators, and Primary Sources of Impact

VEC	Indicator	Primary sources of impact
Natural resource–dependent livelihoods		
Fisheries	Fish productivity (tons per year)	Hydropower development, inundation, flow regime change, and overfishing
Agriculture	Loss of agricultural land (hectares)	Hydropower development, inundation, flow regime change, sediment transport, mining, and plantations
Settlements (villages and towns)	Resettlement (people)	Hydropower development, inundation, flow regime change, wind and solar development, mining, and plantations
Non-timber forest products	Loss of forest (hectares)	Hydropower development and transmission lines, road development, forest and wetlands extraction, mining, and plantations
Terrestrial biodiversity and ecosystems		
Timber of commercial value	Loss of forest (hectares)	Hydropower development and transmission lines, road development, forest extraction, mining, and plantations
Protected and key biodiversity areas	Loss of protected habitats (hectares) and degree of fragmentation	Industrial and agricultural development, HPP and transmission line development, road development, and forest extraction
Changes in terrestrial fauna species	Level of habitat loss for indicator species (hectares)	HPP development and transmission lines, industrial and agricultural development, forest resource extraction, and road development
Community and culture		
Ethnic customs and values	Number of people from ethnic groups affected by resettlement	Industrial, agricultural, and HPP development
Gender roles	Numbers of women and men affected	Industrial, agricultural, and HPP development
Aquatic biodiversity and ecosystems		
Fish habitat fragmentation and connectivity	Degree of connectedness and fragmentation of aquatic habitats	HPP development and inundation
Changes in fish stocks	Effect of flow regime change on aquatic ecosystems and fish stocks	HPP development, inundation, overfishing, pollution, and water quality change

Note: HPP = hydropower plant.

5. Definition of Development Pathways

This study assessed and compared the cumulative impacts of three different renewable energy development pathways in the Sekong Basin (Table 5.1 and Table 5.2) that would lead to generation capacity capable of producing 9 terawatt-hours (TWh) to 14 TWh annually (Figure 5.1).

The *full development pathway* is the expected situation in 2030 if all projects proposed in this timeframe are implemented. This pathway includes 35 hydropower projects (34 in Lao PDR and one in Vietnam): 12 already commissioned or due to be commissioned by 2020, five committed, and 18 candidate projects.

The *conservative development pathway* has been defined with a focus on maintaining the Sekong mainstream free flowing to keep it intact and ensure fish migration, whereas the tributaries will be developed as in the full development pathway. The rationale for this conservative pathway is to maintain the Sekong mainstream uninterrupted in response to concerns with fish migration, erosion and sediment transport, resettlement and land use change, and impacts on the Mekong Delta.

The *intermediate development pathway* involves the same hydropower projects as the full development pathway with the exception of the two uppermost hydropower projects (Sekong 4B and 5) on the Sekong mainstream.

All three pathways assume some development of wind and solar by 2030, by which time it is expected that these technologies will be more competitive. The assumption is that 600 megawatts (MW) of solar power (land based and floating) and 600 MW of wind power are in operation, providing approximately 3 TWh of energy. Use of reservoirs for floating solar power plants involves no alteration in land use and minimal effect on the aquatic environment.

Table 5.1: Alternative Development Pathways Assessed

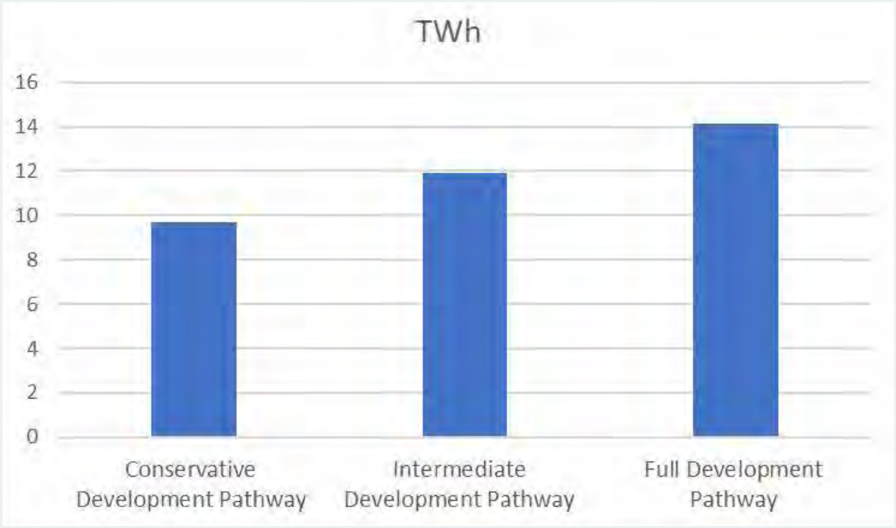
Development pathway	Time frame	Renewable energy projects
Present situation	2020	12 hydropower projects already built or under construction and due to be operational in 2020
Full development	2030	35 hydropower projects proposed to be built and commissioned in 2030 Wind and solar projects with 3 TWh of annual generation
Conservative development	2030	28 hydropower projects (as in full development pathway but omitting all seven mainstream dams) Wind and solar projects with 3 TWh of annual generation
Intermediate development	2030	30 hydropower projects (as in full development pathway but omitting five of seven mainstream dams) Wind and solar projects with 3 TWh of annual generation

Table 5.2: Existing and Planned Hydropower Projects in the Sekong Basin

Project name	Status	COD year	Installed capacity (MW)	Mean annual energy (GWh)	Power destination	Present situation	Conservative	Intermediate	Full
A Luoi	Operational	2012	170	650	Vietnam	X	X	X	X
Houay Ho	Operational	1999	152	450	Thailand	X	X	X	X
Xe Kaman 3	Operational	2013	250	980	Vietnam	X	X	X	X
Xe Namnoy 6	Operational	2013	5	20	Lao PDR	X	X	X	X
Xe Namnoy 1	Operational	2014	15	80	Lao PDR	X	X	X	X
Houay Lamphan Gnai	Operational	2015	88	450	Lao PDR	X	X	X	X
Xe Kaman 1	Operational	2016	290	1,040	Vietnam	X	X	X	X
Xe Kaman–Sanxay	Operational	2017	32	110	Vietnam	X	X	X	X
Nam Kong 2	Operational	2017	66	260	Lao PDR	X	X	X	X
Xe Katam 1 Xe Namnoy 2	Operational	2017	22	120	Lao PDR	X	X	X	X
Xe Pian Xe Namnoy	Construction	2020	410	1,800	Thailand	X	X	X	X
Nam Kong 3	Construction	2020	54	200	Lao PDR	X	X	X	X
Dakchaliou 1	Construction	2021	11	50	Unknown		X	X	X
Dakchaliou 2	Construction	2021	13	60	Unknown		X	X	X
Nam Kong 1	Construction	2022	150	560	Lao PDR		X	X	X
Nam Bi 1	PDA stage	2024	68	290	Vietnam		X	X	X
Nam Bi 2	PDA stage	2024	50	210	Vietnam		X	X	X
Nam Bi 3	PDA stage	2024	12	50	Vietnam		X	X	X
Nam Ang	PDA stage	2024	55	160	Lao PDR		X	X	X
Nam Emoun	Construction	2024	129	430	Lao PDR		X	X	X
Nam Pangou	PDA stage	2025	33	140	Unknown		X	X	X
Xe Pian-Houysoy	PDA stage	2025	45	200	Lao PDR		X	X	X
Lower Xe Pian	FS ongoing	2030	15	60	Lao PDR		X	X	X
Xe Katam	PDA stage	2030	81	300	Lao PDR		X	X	X
Xe Kaman 2A	FS ongoing	2030	64	250	Lao PDR		X	X	X
Xe Kaman 2B	FS ongoing	2030	100	380	Lao PDR		X	X	X
Xe Kaman 4	PDA stage	2030	70	290	Vietnam		X	X	X
Xe Namnoy 5	Unknown	2030	20	90	Lao PDR		X	X	X
Sekong 5	FS completed	2030	330	1,500	Thailand			X	X
Sekong 4B	FS approved	2026	175	750	Thailand			X	X
Sekong 4A	FS approved	2025	165	780	Thailand				X
Sekong 3A	FS completed	2027	114	430	Lao PDR				X
Sekong 3B	FS completed	2028	122	400	Lao PDR				X
Sekong Downstream A	FS completed	2030	86	380	Lao PDR				X
Sekong Downstream B	FS completed	2030	50	210	Lao PDR				X

Note: COD = Commercial Operation Date; MW = megawatt; GWh = gigawatt-hour; Lao PDR = Lao People's Democratic Republic; PDA = project development agreement; FS = feasibility study. No Xs means the power plant is not part of the respective pathway.

Figure 5.1: Overall Annual Electricity Generation under Various Development Pathways



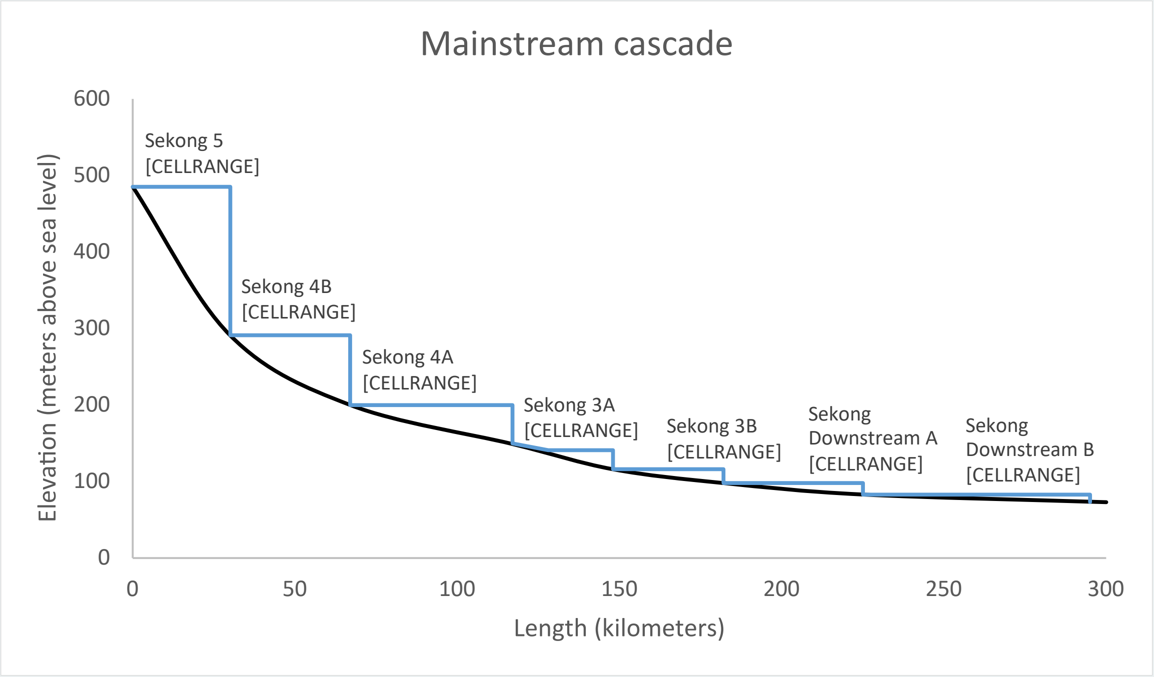
5.1 Full Development Pathway

The full development pathway (Map 5.1) comprises existing projects and all projects proposed to be constructed by 2030.

This entails full development of the entire Sekong Basin, including the mainstream and most major tributaries.

The Sekong mainstream dams will impound almost all of the river, including most rapids along the mainstream totaling more than 300 kilometers, with the exception of a short distance between the tailrace of Sekong 4A power plant and the reservoir of Sekong 3A (Figure 5.2). If a closer analysis were to be conducted, it is likely that the Sekong 3A reservoir will affect this stretch of river during flood periods.

Figure 5.2: Approximate Location and Impoundment Levels of Sekong Mainstream Reservoirs



Map 5.1: Hydropower Projects in the Full Development Pathway

Source: Shuttle Radar Topography Mission (SRTM), Mekong River Commission (MRC), Greater Mekong Sub-Region (GMS)

The Nam Emoun, Upper Xe Kaman, Xe Katam, and other mountain tributaries will also become regulated, and the only free-flowing tributaries will be the Xe Xou and Xe Kamphon, which account for only 3,217 square kilometers, or less than 13 percent of the Sekong Basin.

The uppermost two dams proposed on the Sekong mainstream have a combined head of nearly 300 meters.[12] The lower five dams have only 130 meters of head between them, meaning they are classified as low-to-medium head projects.

5.2 Conservative Development Pathway

In the conservative development pathway (Map 5.2), the Sekong mainstream remains free flowing with natural seasonal flow variations, more sediment transport downstream through Cambodia and to the Mekong Delta, and no barriers to fish migration. Maintaining a free-flowing Sekong mainstream is a basin-scale mitigation strategy for preserving fish biodiversity and sediment transport. Furthermore, this would avoid the need for large scale resettlement of communities along the Sekong mainstream.

The conservative development pathway includes 800 MW of proposed projects in the Xe Katam, Nam Emoun, Bolavan, and Nam Kong sub-basins. Most of these projects will have only a small and local impact on hydrology. The Nam Emoun project has no seasonal reservoir, large dam, or resettlement. The Xe Katam and Nam Bi projects are located above the existing Xe Katam 1 reservoir, which mitigates downstream impacts. The Nam Kong 1 project will form a barrier to fish migration and sediment, but the additional impact is likely to be minor given the existence of Nam Kong 2 and Nam Kong 3 on the same tributary.

5.3 Intermediate Development Pathway

This pathway (Map 5.3) allows for substantial hydropower development in the Sekong Basin while avoiding projects with higher environmental and social costs and lower profitability.

Because the tributary basins are already substantially developed for hydropower, discussion of what might be a balanced trade-off can be focused on the Sekong mainstream. The Upper Sekong cluster provides an amount of power from two projects similar to that of five projects in the Lower Sekong cluster (Appendix A, Table A.5, Map A.1).

Even when cost calculations are provided on a comparable basis (which is not the case at present), the five dams in the Lower Sekong cluster are likely to have higher costs per megawatt of installed capacity as low-head dams are generally more expensive because of complex river diversions, large spillways, and other required design factors. Therefore, the low-to-medium head projects will always struggle to become financially justifiable given the role of envisaged power exports to Thailand and Vietnam.

From the point of view of power system planners in Thailand and Vietnam, high-head projects (similar to Nam Theun 2, Theun Hinboun, and Xe Pian–Xe Namnoy) would be preferred to provide competitive peak power to their systems. As such, the Upper Sekong projects with 300 meters of head should be considered a more suitable, cheaper cascade than the Lower Sekong cluster of five projects to meet peak megawatt export demand in agreements already made among Lao PDR, Thailand, and Vietnam.

In terms of economic, environmental, and social efficiency, the five lower dams along the mainstream Sekong appear to be the most environmentally and socially disruptive and the most costly, so the intermediate development pathway has been defined to exclude these five downstream projects, which will result in significantly less negative cumulative impact on the Sekong mainstream than the full development pathway.

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[12] *Head* is the difference in water level between the hydro intake and the discharge point or a turbine runner. It is a vertical height measured in meters. More head means more potential energy per unit of water.

Map 5.2: Hydropower Projects in the Conservative Development Pathway

Source: SRTM, MRC, GMS.

Map 5.3: Hydropower Projects in the Intermediate Development Pathway

Source: SRTM, MRC, GMS.

6. ASSESSMENT OF PRIMARY AND SECONDARY IMPACTS—ALL PATHWAYS

6.1 Flow Regime Change

Hydropower projects can disrupt natural flows and alter the magnitude, frequency, duration, and timing of flow regimes and sediment. Because all parts of the flow regime play a role in sustaining the riparian ecosystem, altering any part can lead to physical and biological change. The more the natural flow, sediment, and water quality regimes are changed, the greater the impact on the river ecosystem (World Bank Group 2018). See detailed assessment of flow regime and water balance and modeling in Appendix C. Several important thresholds are of particular importance:

- Loss of longitudinal connectivity—preventing free movement of sediment, fish, and organic material along the system
- Loss of floods—leading to drying out of the river's floodplains and loss of lateral connectivity along the river
- Significant reduction of base flows—resulting in periodic drying out of all or part of a previously perennial channel

6.1.1 Flood Frequency

The construction of large reservoirs in the Sekong Basin affects flood conditions in the basin. The degree of impact depends greatly on the chosen pathway because of the larger impact of dams on the mainstream than of smaller dams on tributaries. Although it is beyond the scope of this study to establish the exact impact on the flood extension along the main river and its tributaries, which would require hydrodynamic modeling based on a detailed digital terrain model (for example, Lidar), it is possible to estimate based on frequency analysis of yearly maximum daily discharges at the basin outlet. For this purpose, an analysis was conducted using a three-parameter log-normal distribution, which gives adequate fit to the data points. The results are shown in Table 6.1 and Figure 6.1.

The highest flood for a chosen return period can be expected in the unregulated flow situation, whereas flood values would be dramatically lower under the full development pathway, with the largest number of hydropower reservoirs in place (for example, from 7,463 cubic meter

Table 6.1: Results of Frequency Analysis of Yearly Maximum Discharges, 1991–2014

Pathway	Return period (years)								
	2	5	10	25	50	100	250	500	1,000
	(Cubic meters per second)								
Un-regulated[a]	3,697	4,634	5,286	6,139	6,793	7,463	8,378	9,097	9,842
Present	3,142	3,914	4,440	5,119	5,634	6,156	6,863	7,414	7,980
Full development	2,807	3,394	3,765	4,216	4,542	4,862	5,279	5,592	5,906
Conservative development	3,065	3,777	4,250	4,847	5,292	5,738	6,334	6,792	7,258
Intermediate development	2,869	3,509	3,933	4,470	4,871	5,273	5,810	6,223	6,644

[a] Historical condition, with no dams.

per second (m³/s) to 4,862 m³/s for a return period of 100 years). Comparisons among the three development pathways should be made with reference to the present situation, under which there is already a substantial drop in flood frequency. The largest impact occurs for the full development pathway, with much lower, albeit still significant, impacts for the intermediate and conservative development pathways.

Figure 6.1 shows how floods of a certain size will occur less frequently as a result of hydropower reservoirs regulating the flow. A typical average flood experienced in the 1990s, when the Sekong River was unregulated (about 4,000 m³/s with a return interval of 2.3 years), now returns every five years, but under the full development pathway, the return interval is 12 to 15 years.

A larger flood of approximately 5,000 m³/s, with an original return interval of eight years, is expected to return every 20 years under the present situation, every 30 years under the conservative development pathway, and every 130 years under the full development pathway. Along many of the rivers in the floodplains of the Lower Mekong, significant flood plain inundation happens every five to 10 years.

This modeling shows that floodplain overtopping is less frequent than in the past and will become rarer under the full development pathway than under the conservative development pathway.

A decade ago, when the river was unregulated by hydropower, a flood event of 7,000 m³/s was a once-in-50-year event. Under the present situation, it has become a once-in-250-year event. Under the full development pathway, such a flood will become extremely rare, perhaps only once every 5,000 years. Fewer large flood events mean less damage and disruption to riverbank settlements and riparian livelihoods but also less deposition of nutrient-rich sediment beneficial for agriculture on alluvial plains.

6.1.2 Low-Flow Simulations Along Mainstream Sekong

More significant changes in flow can be observed during the low-flow months from January to March. Seasonal storage reservoirs to ensure reliable power year-round will result in higher river flows during the dry season (Figure 6.2).

Figure 6.1: Results of Frequency Analysis of Daily Maxima at the Sekong Outlet

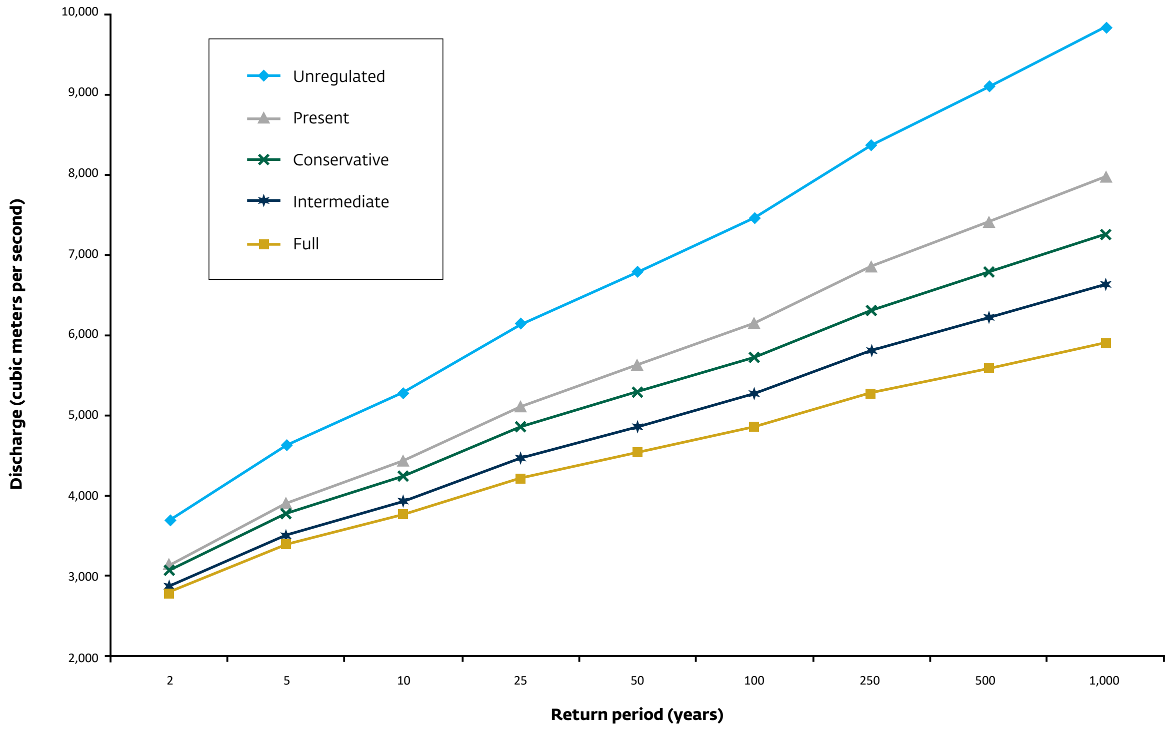
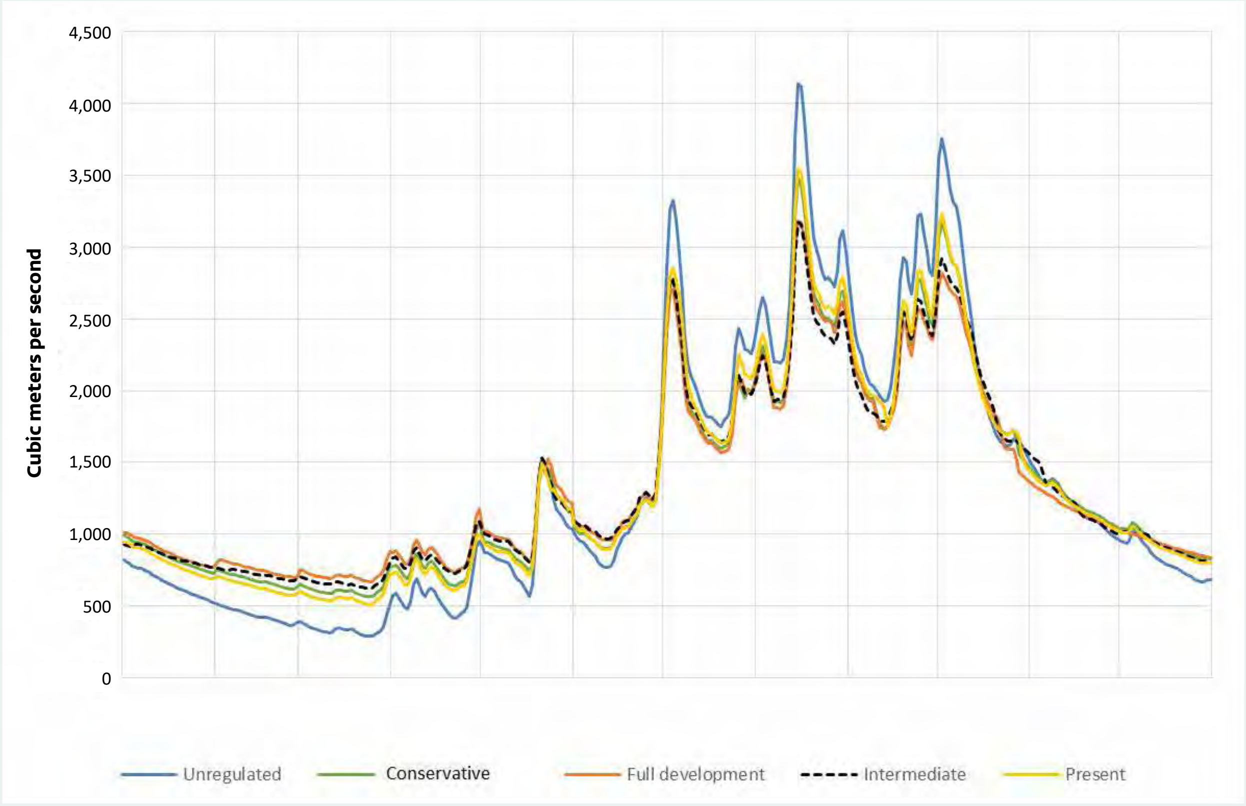


Figure 6.2: Sekong River Flow Regimes at the Lao People's Democratic Republic–Cambodian Border under Various Pathways



Previously, low flow in the Sekong below the confluence with the Nam Kong could fall to less than 150 m³/s in the dry season. In the present situation, low flow has nearly trebled and is expected to exceed 500 m³/s under all future development pathways. The increase in low flows already witnessed is because large regulating reservoirs generate power and release water during the dry season. Higher flows in the dry season mean that river crossings, sand bars, beaches, and riverbank gardens may no longer be accessible, whereas river navigation might benefit.

6.2 Changes in Sediment Transport

Hydropower reservoirs tend to capture sediment and reduce the volume transported downstream. A reduction in sediment transport will have a variety of effects downstream. Sediment is an important conduit of nutrients for fisheries and agriculture. Sediment also maintains the geomorphology of the river system, so a reduction may lead to changes in substrate, riverbank erosion, and riverbed erosion. There will also be risks to alluvial sand extraction operations in Cambodia and stabilization of the Mekong Delta.

6.2.1 Transboundary Impacts of Sediment Reductions in the Sekong Basin

The change in downstream transport of medium-sized sediment (for example, river sand) has been modeled for each development pathway using historical impoundment dates of existing hydropower projects and estimated completion dates of projects proposed up to 2030 (Figure 6.3). (For further detail, see Appendix E.)

Under the present situation in 2020, with 12 hydropower plants (HPPs), the sediment load in the Lower Sekong is approximately 24 percent lower than when the basin was in an unregulated state.

Under the full development pathway, the annual sediment load will fall 67 percent, from 6.4 million tons to 2.1 million tons (Figure 6.3).

Figure 6.3: Comparison of Effects of Pathways on Sediment Transport (Medium Fractions) Downstream of the Lao People's Democratic Republic–Cambodian Border

In the conservative development pathway, significantly more sediment would be transported because of the omission of the seven mainstream Sekong dams. The free-flowing Sekong and Xe Xou tributaries would continue to provide significant sediment to the Lower Sekong. The proposed new dams and reservoirs in the tributaries of the Nam Kong, Xe Kaman, and Xe Namnoy would have a negligible impact because of the existing large sediment-trapping reservoirs on these rivers. Consequently, total sediment transport would be only slightly less than current levels.

In the intermediate development pathway, the addition of the two Upper Sekong dams (Sekong 4B and 5) reduces sediment transport to 4.0 million tons, a reduction of 38 percent (blue line in Figure 6.3).

The size of sediment makes only a moderate difference. Modeling shows that, compared with medium-sized sediment, slightly more fine sediments and slightly less coarse sediment would be transported downstream (Figure 6.4). No matter what sediment size is considered most representative and whatever other assumptions are varied in sensitivity tests, the cumulative impact of all reservoirs is a significant reduction in sediment content passing from the Sekong Basin into the Mekong River (see background information and further detail in Appendix E.)

Figure 6.5 illustrates the limited increase in sediment transport obtained by sediment flushing through bottom outlets. The modeling assumes flushing is feasible only in the five smallest reservoirs in the Sekong Basin. It is not possible in practice to flush sediments from large reservoirs in the early years of their design life, but it is usually a good idea to include in the HPP design facilities to flush in the future.

The results of this modeling of sediment transport are clear. Each new dam and reservoir constructed will further reduce downstream sediment transport; including large sediment sluicing gates will have only a minor mitigating effect. In the full development pathway, no effective measures for preserving sediment flows nearer to a natural state are possible with so many large reservoirs in cascade along a large sediment-laden river. Omission of dams altogether is the only effective measure; in particular, omission of the dams furthest downstream on the Sekong mainstream will have the most significant effect.

Figure 6.4: **Impacts of Full Development Pathway on Transport of Fine, Medium, and Coarse Sediments Downstream of the Lao People's Democratic Republic–Cambodia Border**

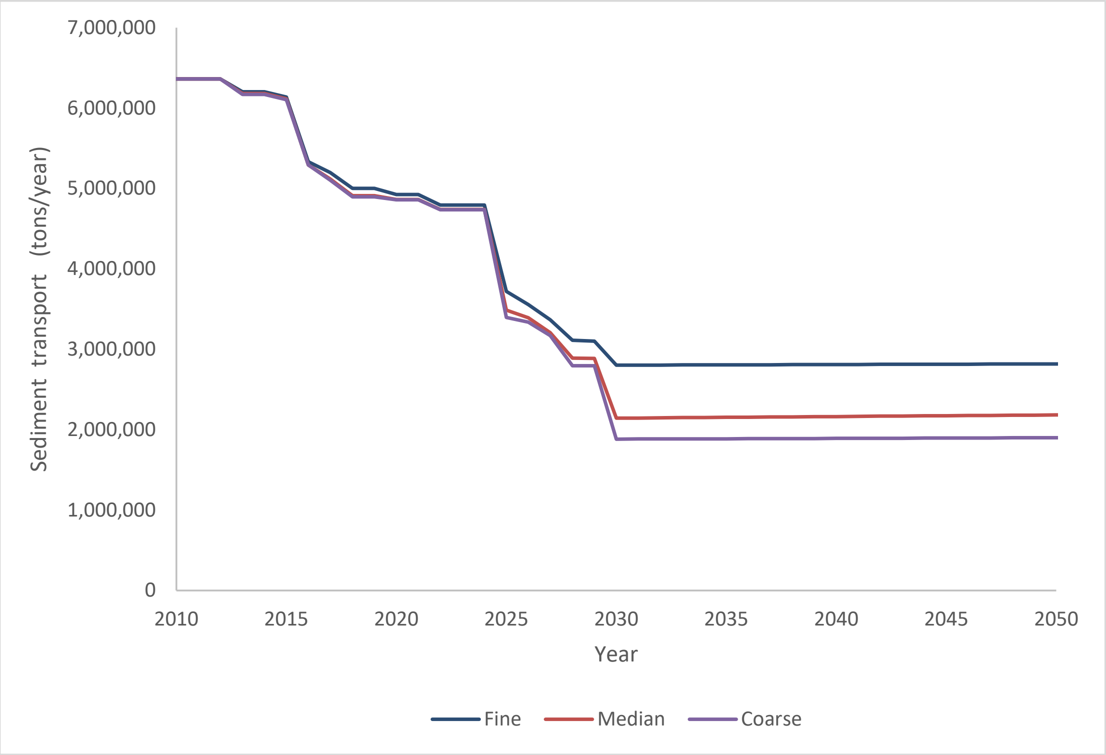


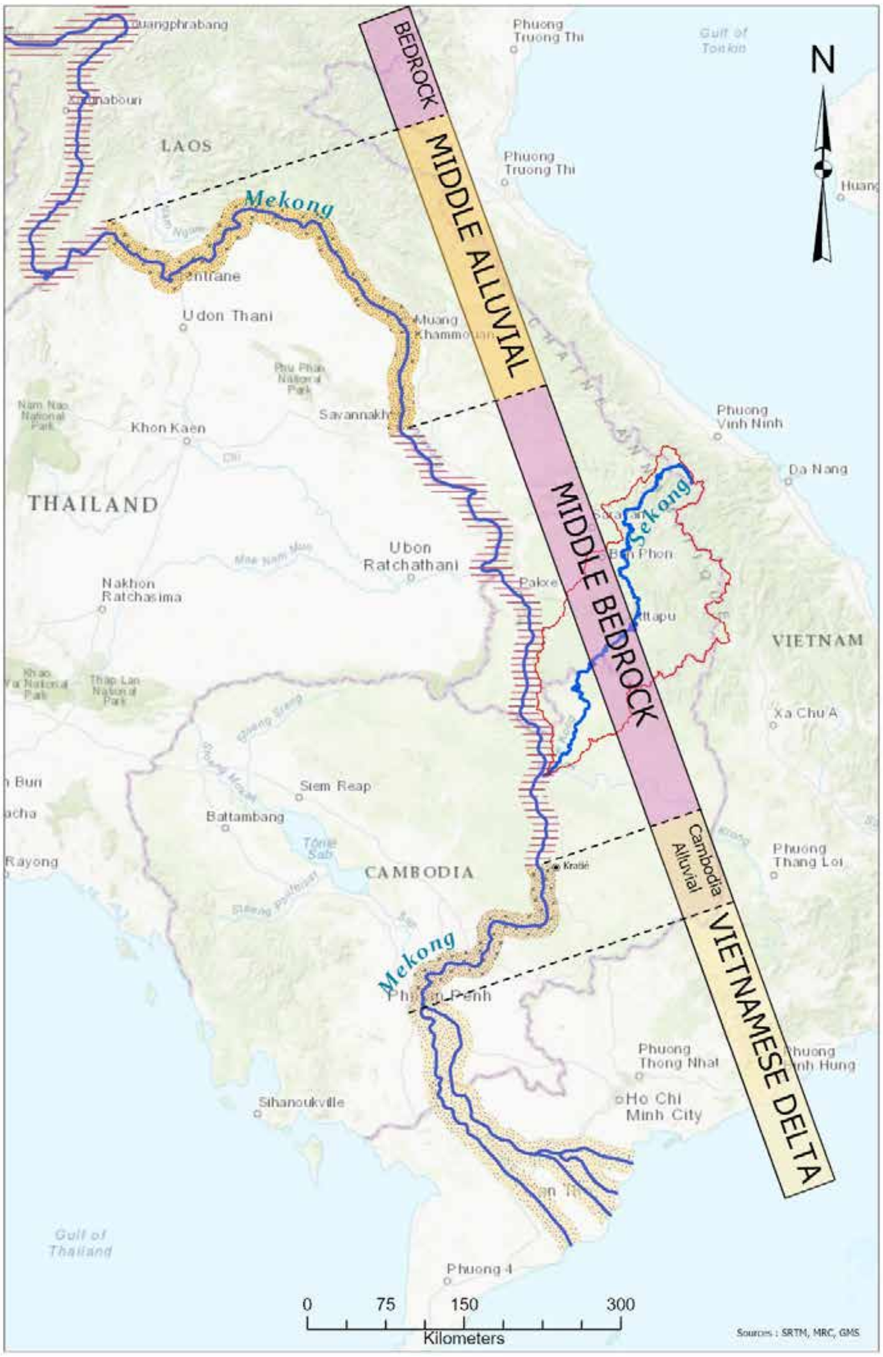
Figure 6.5: **Impacts of Full Development Pathway of Flushing on Sediment Transport Downstream of the Lao People's Democratic Republic–Cambodia Border**

6.2.2 Transboundary Impacts of Sediment Reductions for the Mekong River and Delta

Sediment transport has transboundary implications for the Mekong River and its delta. Starvation of sediment along the Mekong by many reservoirs constructed upstream has been studied (Kondolf, Rubin, and Minear 2014). If all the large reservoirs proposed on the Sekong mainstream are constructed, the alluvial stretch of the Mekong River and the Mekong Delta will experience sediment starvation (Map 6.1).

This will probably result in bank and bed erosion in reaches with alluvial deposits, fewer nutrients reaching the flood plains and delta areas, morphological changes along the Mekong, and coastline retreat in the Mekong Delta (Kondolf, Rubin, and Minear 2014).

Map 6.1: Reduction of Sediment Loads at Kratie on the Mekong River



For this cumulative impact assessment, the downstream significance of reduced sediment movement from the Sekong Basin to the Mekong River will depend on what hydropower development occurs elsewhere in the Mekong Basin. If all dams planned for Mekong tributaries are built, but none are built on the mainstream Mekong River, there will be a 67 percent reduction in historic sediment transport loads (from 144 million tons to 47 million tons) at Kratie, which is just below the confluence of the Sekong River and the Mekong River (Kondolf, Rubin, and Minear 2014).

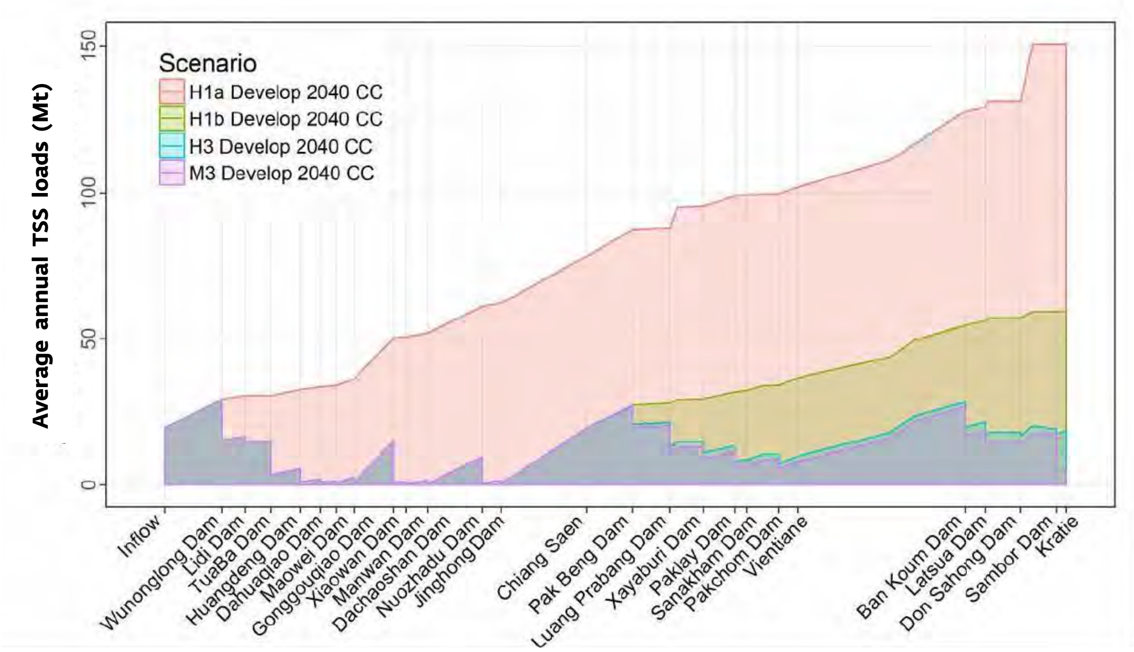
Table 6.2 compares the volume of sediment leaving the Sekong Basin under different development pathways based on sediment modeling. Sediment leaving the Sekong Basin has already been reduced from an estimated 5.2 million tons (original load) to 3.7 million tons (present situation) as a result of dams constructed so far. Sediment leaving the Sekong Basin would be reduced further in the case of the full and intermediate, but not the conservative development pathways.

Sediment capture because of hydropower development on the Mekong mainstream is shown in Figure 6.6 (MRC 2020). Dams already constructed on the Upper Mekong in China cause the largest reductions (pink area), but the proposed cascade of dams from Pak Beng to Pakchom would cause further significant reductions (green area). The proposed Sambor Dam, which has been designed without a sediment passage, results in a final sharp drop in sediment transport.

Table 6.2: Mean Annual Sediment Load (Million Tons) Generated by the Sekong Basin under Different Development Pathways

	Original load	Present 2020	Full development	Intermediate development	Conservative development
Sekong at Cambodia	5.2	3.7	1.7	2.9	3.7
Mekong at Kratie	144	47	45	46	47
Mekong Delta	160	49	47	48	49

Figure 6.6: Cumulative Sediment Capture by Dams on the Mekong River



Source: MRC 2020.

Note: M3 is the 2040 full development scenario without mitigation, and H3 is the same scenario with mitigation. H1a is a baseline scenario (no post–2007 dams), and H1b is development without mainstream dams. TSS = total suspended solids; Mt = million tons; CC: climate change.

The relative importance of sediment from the Sekong Basin for the Lower Mekong River will depend on the intensity of new Mekong mainstream hydropower development and which development pathway is chosen for the Sekong Basin. If the proposed 11 Mekong mainstream dams within Lao PDR are developed, the contribution of sediment from the Sekong Basin would be relatively large (except in the case of the full development pathway). The Sekong Basin would be among the last major contributors of sand to the Mekong River. Alternatively, if the 11 Mekong mainstream dams within Lao PDR are not developed, the contribution of the Sekong Basin to downstream sediment would be relatively small (irrespective of which development pathway is chosen). Hydropower developments downstream are also relevant. If the Sambor Dam in Cambodia is developed on the Mekong mainstream without a sediment passage, most sediment from the Sekong Basin would be captured there.

6.3 Pollution and Water Quality Change

Construction of hydropower dams can release large amounts of suspended sediment into a river. During local community consultations, this was mentioned as a past cause of fish mortality and fish decline.

During reservoir filling, when the area is inundated and massive amounts of organic material begin to decompose, algae can grow and deplete oxygen. Depending on the depth of the reservoir, stratification can occur, which leads to oxygen deprivation in the lower layers of the reservoir. Environmental and social impact assessments for the Nam Kong 2 and 3 state that no long–term water quality problems are expected (HAGL Group 2010a and 2010b), but based on the experience of other hydropower projects in Lao PDR, short–term water quality problems can be expected. This was the case with the reservoir of the Houay Ho Dam, for example, where valuable timber was selectively cleared, but a large amount of soft vegetation was present when the reservoir was inundated, resulting in poor water quality downstream (Ambasht and Ambasht 2003).

During the operational phase of a hydropower project, stagnant conditions in reservoirs can create water quality problems. Impacts are expected to increase with hydropower expansion, especially under the full development pathway, under which most of the Sekong mainstream will be converted into a cascade of reservoirs.

Additional pollution sources are mining (for example, coal and gold) and industry (for example, coffee-processing plants), which are point sources. Agriculture (for example, sugar cane, eucalyptus, fruit trees, and rubber) causes runoff pollution from fertilizer, pesticides, and nutrients. During stakeholder consultations, these issues were mentioned as a cause of reduced fish catches and occasional fish mortality events in recent years.

The flow regime of the river influences the effect of runoff pollution. Larger floods or greater flooding frequency can increase pollution loads in the river because nutrients and pesticides are washed into the water (Nguyen 2017); during the dry season, pollution loads are more concentrated. For these reasons, flow regime alterations because of climate change may create water quality problems, although dams with storage reservoirs will tend to reduce wet season floods and increase dry season flows and so dampen the effect of climate change on water quality.

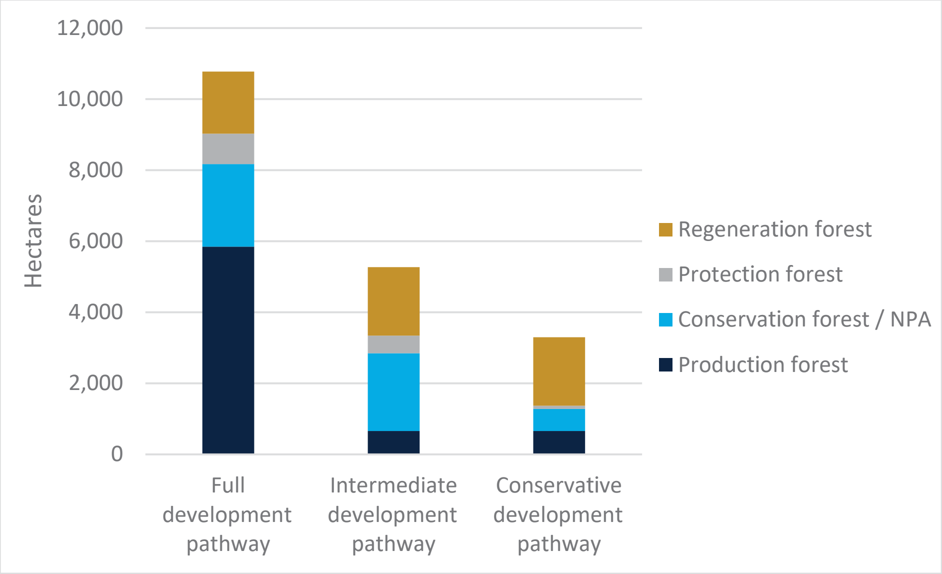
6.4 Inundation and Land Acquisition

Inundation and land acquisition are intermediate impacts relevant to two VECs in particular: valued flora (loss of forested areas) and livelihoods (loss of agricultural land).

It is estimated that 16,900 hectares of forest has already been lost because of hydropower development (present situation). Under the full development pathway, an additional 11,200 hectares of forest land would be inundated, compared with 5,300 hectares under the intermediate development pathway and 3,300 hectares under the conservative development pathway (Table C.5 in Appendix C).

Different categories of forest are affected to differing degrees under each development pathway (Figure 6.7). In the full development pathway, the area of production forest affected is much greater than in the other two pathways. The conservative development pathway affects a smaller area of conservation forests, national protected areas,, and protection forest than the other two pathways.

Figure 6.7: Forest Types Affected by Each Development Pathway



Note: NPA = National Protected Area.

7. CUMULATIVE IMPACT ASSESSMENT OF ALTERNATIVE DEVELOPMENT PATHWAYS

7.1 Aquatic Biodiversity and Ecosystems

7.1.1 Impact of Flow Regime Changes

Flow regime change because of hydropower and the effect on aquatic ecosystems have been calculated quantitatively for each development pathway using hydrological modeling and climate change models developed for this cumulative impact assessment (CIA). The assessment considered three key indicators of flow regime change—magnitude, duration, and frequency—that are ecologically relevant and sensitive to hydropower development. Magnitude refers to the amount of water under average flow, very low flow, and very high flow conditions. Duration is the length of time that low flow and high flow conditions occur. Frequency is how often there are very low and very high flow conditions. Scores for flow regime change have been calculated as percentage variation from the present situation for each of the three development pathways.

Some flow-related stressors associated with hydropower development include the following: reduced high flows (during the wet season) with effects on fish species that depend on connectivity between river channels and floodplains; greater low flows (during the dry season), which will affect fish habitats; and a delay in the flood pulse (start of wet season), which provides signals for fish migration. These stressors interact and have cumulative impacts. Studies show that any change in the three flow indicators can decrease the abundance and diversity of fish species (Poff and Zimmerman 2010).

Water extraction in the Sekong Basin affects flow regime change less than hydropower does, but the expansion of the agriculture sector together with increased domestic and industrial use of water could put pressure on water resources, particularly dry season flows.

Climate change is an additional pressure affecting the flow regime. Climate change projections for the Sekong Basin are for a slight increase in flow during the wet season and a larger decrease during the dry season (see Appendix B).

Analyses were conducted for seven indicator species present in the Sekong Basin, selected according to ecological characteristics (super-endemic, endangered, and migratory) and socio-economic characteristics (important as a source of food or otherwise important for local communities). The analyses found that dam construction will harm all fish species, with the largest effects occurring under the full development pathway and the least under the conservative development pathway. The full development pathway would most severely affect the fish species *Sphaerobelum bolavensis*, which is super-endemic and important for food.

7.1.2 Impact of Habitat Fragmentation and Reduced Connectivity

Aquatic habitat connectivity is important for many species of fish that require access to different riparian habitats at different stages of the lifecycle. Dams can reduce connectivity and increase habitat fragmentation by physically blocking a river, changing habit conditions from lentic (flowing water) to lotic (standing water), and reducing wet season flows, which prevents aquatic creatures from accessing floodplains and channels. A large reduction in connectivity and an increase in fragmentation pose a risk to fish populations supported by affected habitats.

Habitat fragmentation was calculated quantitatively for each development pathway for the seven indicator species using several indicators: longest length of continuous river providing a habitat for each species, number of habitat segments created by hydropower projects, and length of river transformed from lentic to lotic conditions. Details of the method of calculating fragmentation and connectivity are given in Appendix F. Impacts are greatest under the full development pathway (because of construction of seven mainstream projects) and less under the intermediate development pathway (with only two mainstream projects). Under the conservative development pathway, because additional hydropower development is in tributaries and sub-basins that already have dams, there would be only minor changes from the present situation.

Changes in rivers under all development pathways are illustrated in maps in Appendix F. The colors show the degree of change assessed as a combined score of average changes to flow regime, sediment transport, and fish connectivity.

7.1.3 Mitigation Options

7.1.3.1 Environmental Flows

Setting appropriate environmental flows (EFlows) for hydropower projects throughout the basin would be an important way to mitigate cumulative effects on aquatic biodiversity and ecosystem services under all three development pathways. An integrated, basin-wide approach is required, taking into account existing and planned projects. Industry good practice guidance advises that, for the Sekong Basin, this should be a detailed, high-resolution assessment because of the presence of cascading and peaking operations, habitats of high conservation value, and natural resources important for local livelihoods. The assessment would involve collection and analysis of empirical data and a consultative process involving stakeholders. The outcome would be an EFlow regime with variations between sub-basins and river sections consistent with differing environmental and social values.

Hydropower operators in the basin should be encouraged to jointly formulate and implement EFlows for several practical reasons. For example, a downstream dam without a reservoir might be unable to maintain minimum flow releases important for floodplain connectivity if an upstream storage dam were to temporarily stop discharging for maintenance or other reasons. Sediment flushing and sluicing require coordination among dams in a cascade to ensure efficient sediment transport from one dam to the next. Coordinated releases are also important to provide hydrological triggers for fish migration. A basin-scale EFlow assessment can be beneficial to project developers because it can obviate the need for such an assessment as part of the project environmental impact assessment (EIA). Global experience is that EFlows can achieve good ecological and social outcomes with little or no production losses.

EFlow requirements will vary under each of the development pathways studied. Although a detailed assessment is beyond the scope of this study, the EFlow regime for the full development pathway would need to be particularly rigorous and well-coordinated because of the higher concentration of hydropower projects in the basin and the existence of a cascade of seven dams on the Sekong mainstem. Under the intermediate development pathway, operational coordination between Sekong 5 and Sekong 4B would be a priority given the high storage capacity of these upper catchment dams. Under the conservative development pathway (and likewise the other two pathways), coordinated EFlows would be important for hydropower operations in the Bolaven, Nam Kong, and Xe Kaman sub-basins.

7.1.3.2 Sediment Flushing and Sluicing

The feasibility of sediment flushing depends on a number of factors, including the shape and size of the reservoir. Section 6.2 discusses flushing opportunities. In general, efficient sediment flushing is feasible only for very small reservoirs, with volumes up to approximately 2 percent of annual inflow. For medium-sized reservoirs, with volumes up to 20 percent of annual inflow, sediment sluicing may be feasible during periods with high sediment concentration. For larger reservoirs, sediments can be removed only using mechanical means, such as dredging. This study assessed potential for flushing and sluicing in five reservoirs with volumes up to 5 percent of annual inflow: Sekong Downstream A and B, Sekong 3A and 3B, and Nam Kong 2. The degree of sediment trapping was modeled to be 67 percent without flushing and 62 percent with flushing (see Appendix E).

Many of the proposed Sekong Basin dams have large reservoirs (for example, Sekong 4B and 5), as do several existing dams (for example, Xe Kaman 1, Nam Kong 3, Houay Ho, and Xe Pian–Xe Namnoy). Sediment sluicing or flushing will not be effective for these dams.

For the full development pathway, joint, coordinated flushing and sluicing of the four lowermost mainstream dams (Sekong Downstream A and B, Sekong 3A and B) to promote sediment transport will be important to support floodplain geomorphology and aquatic habitats.

Under the conservative development pathway, joint, coordinated cascade flushing and sluicing should be implemented in smaller reservoirs in the Xe Kaman, Bolaven, and Nam Kong sub-basins to maintain river geomorphology and aquatic habitats in these tributaries. Specifically, in the Bolaven sub-basin, flushing and sluicing should be considered for the planned Xe Katam hydropower plant (HPP), and design modifications should be explored to enable flushing and sluicing of the already commissioned Xe Namnoy 1 and 6 and Xe Namnoy 2–Xe Katam 1. Flushing and sluicing are also relevant for the Lower Xe Pian HPP. Flushing and sluicing of Nam Kong 2 and 3 are not relevant because the Nam Kong 1, already under construction downstream, will trap the majority of sediment (flushing is not feasible because of the large reservoir size). In the Xe Kaman cluster, flushing and sluicing are not feasible for the larger Xe Kaman 1 and the smaller Xe Kaman–Sanxay, although flushing and sluicing are feasible for the Xe Kaman 2A, 2B, and 4 cascade, albeit only with local and tributary sediment transport benefits.

7.1.3.3 Fish Passages

The efficacy of fish passages for mitigating the impacts of hydropower development on fish and other aquatic organisms is unproven in the Mekong region. It is likely that only some migratory fish species would benefit even if mechanisms for fish passage were optimally designed with provisions for upstream passage of fish and downstream passage of eggs, spawn, and juvenile fish. Fish passages, therefore, offer the potential for only partial mitigation of adverse impacts on fisheries, habitat fragmentation, and lack of connectivity caused by hydropower development.

Field research is needed to investigate designs, costs, and efficiencies of fish passages optimized for various endemic migratory fish species in the Sekong Basin. Engineered solutions may include fish ladders, fish locks and lifts, fish-friendly turbines, and truck and transport, although fish ladders are generally not considered economically or technically feasible for dams with an elevation greater than 40 meters. Because of this fundamental height restriction on fish passages, opportunities are limited to lower-head dams in the Sekong Basin.

Under the full development pathway, the priority would be to maximize connectivity and minimize fragmentation of the Sekong mainstream by installing fish passages on the lowest four mainstream dams (Sekong 4A and 3 and Sekong Downstream A and B). Truck and transport of fish might be an option for the large upper mainstream dams (Sekong 4B and 5) and other tributary dams, but this approach is untested in Lao PDR.

There may also be value in installing fish passages on Sekong tributaries, even on those fully developed for hydropower. Again, this would depend on researching a suitable design and would apply only to dams with lower heights, such as Lower Xe Pian, Xe Katam, Xe Namnoy 1 and 6, Xe Namnoy 2–Xe Katam 1, and the dams upstream of Xe Kaman 1 in the Xe Kaman cluster.

7.1.3.4 Fish Conservation Zones

The Sekong Basin has a high concentration of fish conservation zones that planned hydropower reservoirs will inundate (see Map 3.2, Chapter 3). It may be possible to establish new fish conservation zones in suitable river reaches, especially free-flowing reaches. These could serve as viable important—albeit altered—ecosystems to support aquatic biodiversity and local livelihoods that depend on fisheries. The focus should be on native and endemic fish species rather than introduced species that may be invasive. Consultative approaches with active participation of local communities in managing fish conservation zones would be important to achieve conservation targets. Also vital would be monitoring and enforcement to prevent illegal fishing methods and harvesting of endangered species.

7.2 Terrestrial Biodiversity and Ecosystems

Impacts on terrestrial valued environmental components (VECs) have been assessed for each development pathway, with a focus on key conservation areas within the Sekong Basin and with reference to several indicator species selected on the basis of conservation status (for example, threatened or endangered), species uniqueness, habitat requirements, and importance to local communities. The methodology is described in detail in Appendix C.

Five key conservation areas within the Sekong Basin (see Map 3.3, Chapter 3) have been assessed in this CIA:

- Dong Ampham National Protected Area (NPA)
- Nam Kong National Protected Forest (NFP)
- Xe Pian National Protected Area
- Xe Sap National Protected Area
- Bolaven National Protected Forest

Forest cover, density, and quality in the Sekong Basin have declined in recent decades partly because of hydropower but also logging, mining, and conversion to agriculture.

The future impact of hydropower on key conservation areas and forests has been estimated for each of the three development pathways, ranging from an extra 3,290 hectares of additional land acquisition under the conservative development pathway to an extra 11,196 hectares under the full development pathway. Construction of the proposed Sekong 5 HPP, which features in the intermediate and full development pathways, will result in 1,567 hectares of direct impact in the Xe Sap NPA. This is significant considering its current undisturbed condition and high biodiversity.

Hydropower development can affect key conservation areas and forest directly through land acquisition (because of reservoir inundation and construction of associated infrastructure) and indirectly through fragmentation (because of the reservoir, transmission lines, and access roads). Moreover, illicit hunting and harvesting of forest resources often increases within reservoir catchments because project roads increase access by vehicles and reservoirs improve access by boat. Resettlement of villages can increase pressure on forest resources at the resettlement site.

To capture this complexity, a composite index for key conservation areas was applied to each of the three development pathways, taking the following into consideration:

- The proportion of each conservation area directly affected (percent)
- The proximity of hydropower projects to conservation areas (kilometers)
- The degree of fragmentation because of transmission lines and access roads (percent)
- The number of globally threatened species in the conservation area

According to this analysis, the cumulative impact of hydropower development on key conservation areas is already substantial for the Dong Amphan NPA and Nam Kong and Bolaven NPFs. Further hydropower development as envisaged under the full development pathway will have only a small additional cumulative impact on most conservation areas within the Sekong Basin, except for the Xe Sap NPA (Table 7.1), where the impact will rise from none (presently) to high (intermediate and full development pathways).

The forests of the Upper Sekong Basin are largely undisturbed and relatively intact. The Xe Xap NPA forms a substantial part of these forests, but the forest is relatively undisturbed outside of the NPA as well. This is a biodiversity-rich terrestrial ecosystem that provides habitats for rare flora and fauna, possibly including the critically endangered Saola (Asian unicorn), which is found only in the Annamite Mountains of Vietnam and Lao PDR.

The planned Sekong 4B and 5 hydropower projects on the Sekong River mainstream and the planned developments on the Nam Emoun tributary will affect these unique, biodiversity-rich forested areas in the Upper Sekong Basin directly because of reservoir inundation and indirectly because of habitat fragmentation, increased hunting, and unsustainable harvesting of timber and forest products.

The species threatened most from renewable energy development projects under the full development pathway (hydropower, wind, and solar) in the Sekong Basin include the Asian elephant and gibbon.

A final composite rating for terrestrial VECs (key conservation areas, habitats, and terrestrial species) indicates that the incremental cumulative impact of the full development pathway will

Table 7.1: Cumulative Impacts on Key Conservation Areas under Full Development Pathway

Key conservation area	Number of proposed projects	Area affected (hectares)
Dong Amphan NPA	6	625
Nam Kong NPF	2	111
Xe Xap NPA	1	1,567
Bolaven Upstream NPF	4	498

Note: NPA = National Protected Area; NPF = National Protected Forest.

be moderate and slight to moderate under the intermediate and conservative development pathways, respectively. It is likely that other stressors such as mining, plantations, transmission line and road development, hunting, and forest resource extraction will have a similar impact.

Impacts of hydropower on terrestrial biodiversity and ecosystems are closely correlated with the number of projects and the size of the project footprints. Accordingly, impacts could be reduced by opting not to develop certain projects or through design modifications that reduce reservoir sizes.

For a given development pathway, the following measures would be most effective if coordinated among power developers on a basin scale.

- Catchment management protection measures, including reforestation of already degraded forestlands, especially for Sekong 5, Nam Khong 1, Nam Emoun, and Xe Kaman 2A where forest loss is greatest
- Shared transmission lines—to cut the number of transmission lines required and so reduce disturbance of forests and fragmentation of habitats
- Biological corridors—to enable wildlife migration between key conservation areas and avoid fragmentation of important habitats
- Patrols and enforcement in conservation areas—to reduce illicit logging, hunting, and harvesting of non-timber forest products (NTFPs) in conservation areas
- Community management of protected areas—to encourage sustainable resource use by local villages
- Domestic energy supply—affordable electricity and fuel-efficient wood stoves to reduce demand for fuel wood in local communities

These measures alone are unlikely to fully mitigate the impacts of hydropower development on terrestrial biodiversity and ecosystems in the Sekong Basin under the full development pathway. In particular, construction of the Sekong 5 and 4B HPPs will affect the Xe Sap NPA and surrounding area in a way that will be challenging to mitigate. There is potential to protect terrestrial habitats and ecosystems elsewhere (inside and outside of the Sekong Basin) as a means of offsetting these impacts.

7.3 Natural Resource–Dependent Livelihoods

7.3.1 Fisheries

River fisheries are critically important for the livelihoods of much of the population of the Sekong Basin, as described in Section 3.6.5. Impacts on riparian fisheries have been assessed quantitatively as far as possible (fish catch tons per year) using information in project environmental and social impact assessment (ESIA) reports and qualitatively, relying on experiences from other hydropower development projects in Lao PDR. The loss of river fisheries because of hydropower development has been compared to the potential productivity of reservoir fisheries based on experiences elsewhere in Lao PDR.

With the construction of tributary and mainstream dams in the Sekong Basin and the migration obstruction this represents, the species composition of the river system will change. Non-migratory species that can adapt to the ecological conditions in a lake (lacustrine or lentic ecosystem) will flourish at the expense of the migratory species that depend on the ecological conditions of a flowing river (lotic ecosystem). After the establishment of a reservoir, one can normally expect a sharp increase in the population and total biomass of lacustrine fish species such as common carp (*Cyprinus carpio*) and tilapia (*Oreochromis spp.*), which are introduced aquaculture species, and hampala barb (*Hampala macrolepidota*), which is a species commonly found in Southeast Asia that can tolerate flowing river and lake conditions.

Reservoirs may thus become a source of food and income for the surrounding population. How sustainable this resource can be depends to a large degree on how it is managed and on the presence of good areas for regeneration and spawning in the reservoir. There is often an initial sharp increase in lacustrine fish populations in newly impounded reservoirs because submerged vegetation provides an abundant source of aquatic food. Fish populations level off after impoundment and stabilize at a lower level if managed properly with regulated fishing and sanctuaries for spawning.

In general, the productivity of reservoir fisheries can be anticipated to be less than the existing river fisheries because there are fewer shallow fishing grounds and fish migration is obstructed. In river stretches downstream of dams, flow regulation leads to loss of diversity of habitats, fish species, and aquatic flora and invertebrates because deep pools tend to fill up, and riverbanks tend to be less productive.

The productivity of reservoirs varies greatly according to their depth and shape, with shallow reservoirs tending to be the most productive. Deep reservoirs act as nutrient sinks, and drawdowns in shallow reservoirs allow vegetation growth that serves as food for fish when the water rises again. To take one example, the Nam Ngum reservoir, which was completed in 1971, yielded 133 kilograms per hectare per year in 2007 (McCartney, Funge-Smith, and Kura 2018). This is well above the average of 74 kilograms per hectare per year of other reservoirs in the region (Kolding and van Zwieten 2006) probably because of the Nam Ngum reservoir's large drawdown zones and favorable spawning area. Because of the likely depth and shape of future Sekong Basin reservoirs, they will generally have lower fish productivity. Assuming a productivity of 100 kilograms of fish per hectare per year for future reservoirs in the Sekong Basin and multiplying this by total reservoir area for the full development pathway (15,489 hectares), the result is an estimated future reservoir productivity of 1,550 tons per year, mostly associated with Sekong mainstream projects (reservoir area 12,190 hectares, fish productivity 1,219 tons per year). Comparing these figures with the estimated current fish consumption data indicates the impacts on fish productivity and consumption that can be expected with a hydropower development following the full development pathway.

Published data on fish catches and consumption in the Sekong Basin varies. Hortle (2007) combines multiple studies and arrives at an estimate of fish consumption of 17.1 kilogram per person per year for Sekong Province. The total population of the five Sekong riparian districts (Kalum, Laman, Xaisettha, Samakkhixai, and Sanamxai) is 124,138 people, and the population of the whole Sekong Basin is estimated to be 241,670 people (Meynell 2014). Using these figures to calculate total consumption in the riparian districts and the whole basin and comparing them with reservoir productivity, one arrives at the results presented in Table 7.2.

Under the full development pathway, there is a large negative difference between reservoir productivity and fish consumption for the riparian districts and the whole Sekong River Basin. This indicates that future reservoir fisheries will be insufficient to meet present levels of fish consumption. Regulation and fragmentation of the Sekong mainstream and tributaries will significantly reduce fish catches as a source of food and earnings for the basin population. Although reservoir fisheries can make up for some of the loss of river fisheries, the total impact on food security and nutrition is likely to be negative.

Under the intermediate development pathway, impacts are slightly lower but still substantial because of blockage of fish migration in the upper reaches of the Sekong mainstream (because of Sekong 4B and 5) and full development of tributaries throughout the basin.

The conservative development pathway will keep the mainstream open for fish migration up from the Mekong and in that way maintain the potential for continued mainstream river fisheries that communities along the Sekong depend on for their livelihoods. Although new hydropower projects will affect some tributaries in the Sekong Basin under the conservative development pathway, the majority of these—including the Xe Kaman, Xe Namnoy, Nam Kong, and Xe Pian tributaries—already have commissioned dams that obstruct fish migration.

Table 7.2: **Reservoir Productivity and Calculated Fish Consumption**

Area	Population	Reservoir productivity	Calculated fish consumption	Difference
		(kilograms)		
Riparian communities	124,138	1,219,000	2,122,760	- 903,760
Sekong River Basin	241,670	1,550,000	4,132,557	- 2,582,557

7.3.2 Agriculture

Construction and operation of multiple hydropower projects in the Sekong Basin will result in the loss of important agricultural and forest areas that local people use for their livelihoods. Reservoirs inundate agricultural land and leave areas in the catchment unavailable for community use. Downstream of hydropower projects—especially during peaking operations—rapid fluctuations in river levels can cause erosion that affects riverbank gardens in riparian villages. Dams also decrease downstream sediment loads, resulting in loss of nutrient-rich sediment deposits important for subsistent agriculture.

Loss of agricultural production has been quantified (Table 7.3) using information from ESIA reports and geographic information system mapping. Where ESIA data are not available, loss of agricultural land has been estimated to be 5 percent of reservoir area. The impact on livelihoods of losing agricultural land depends on the amount of remaining land available to villages experiencing partial land loss and provision of adequate land for villagers who are resettled.

One type of agricultural land that is of crucial importance for the livelihoods of people living along tributaries and the Sekong mainstream is riverbank gardens, where important food crops are cultivated.

Table 7.3: Estimated Loss of Agricultural Land

Project name	Conservative development	Intermediate development	Full development	Total agricultural land (hectares)
Nam Kong 1	X	X	X	174
Nam Bi 1	X	X	X	n.a.
Nam Bi 2	X	X	X	n.a.
Nam Bi 3	X	X	X	n.a.
Nam Ang	X	X	X	0.2
Nam Emoun	X	X	X	84
Nam Pangou	X	X	X	n.a.
Xe Pian-Houaysoy	X	X	X	n.a.
Xe Katam	X	X	X	4
Xe Kaman 2A	X	X	X	12
Xe Kaman 2B	X	X	X	43
Xe Kaman 1	X	X	X	0
Xe Namnoy 5	X	X	X	n.a.
Sekong 5		X	X	0
Sekong 4B		X	X	65
Sekong 4A			X	1,023
Sekong 3A			X	59
Sekong 3B			X	92
Sekong Downstream A			X	70
Sekong Downstream B			X	45
Total	**317**	**382**	**1,671**	**1,671.2**

Note: n.a. = data not available in project documentation and cannot be estimated as reservoir area is unknown. If no Xs, the plant is not part of the respective scenario.

One example is the Sekong Downstream B project, for which the ESIA reports 394 affected households, of which 312 households lose riverbank gardens. The loss of riverbank gardens will mostly affect local production of vegetables for household consumption and, to a smaller degree, income from the sale of riverbank garden produce. The effect on people's livelihoods is likely to be significant.

Agricultural land loss varies between the development pathways, ranging from less than 400 hectares under the conservative and intermediate development pathways to 1,671.2 hectares under the full development pathway; this additional impact is associated with five proposed Sekong mainstream dams that are in densely populated lowland areas.

7.3.3 Timber and Forest Products

The Sekong River Basin population depends greatly on harvesting forest products, particularly NTFPs, for income and consumption. In research conducted for the CGIAR Challenge Program on Food and Water (CGIAR 2014), 11 villages that hydropower projects had affected or were expected to affect (Xe Kaman 1, Xe Kaman–Sansay, Sekong 3A) were studied and surveyed. The study results indicated that more than 95 percent of the households collected NTFPs, which constitute a substantial source of carbohydrates and green leafy vegetables. NTFPs are particularly important during rice shortages that normally occur in the rainy season. Sale of NTFPs such as bamboo shoots and rattan is also an important source of cash income for women.

NTFPs are under pressure in the Sekong Basin, and the resource base has declined in recent decades. The CGIAR study reported that women in areas affected by hydropower development are finding it increasingly difficult to collect NTFPs because of forest depletion, and as a result they have to walk further and spend more time harvesting NTFPs. District and provincial consultations in the Sekong River Basin conducted in September 2019 confirmed the same pattern of diminishing access to NTFPs.

Further hydropower development in the Sekong Basin will affect NTFP resource availability because of loss of relatively intact forest. The estimated loss of the different forest types in the present situation and under the full development pathway is shown in Table 7.4.

The greatest forest loss will occur under the full development pathway, with 11,196 hectares (about 112 square kilometers) of forested land affected, half of which is production forest, almost one-quarter is conservation forest (including areas of the Xe Sap and Dong Amphan NPAs), and the remainder is predominantly regeneration and protection forest (Table 7.5). Forest resources will be moderately affected under the intermediate development pathway and slightly affected under the conservative development pathway.

For communities, different categories of forest have different livelihood uses. Fallow swidden fields can be a rich source of NTFPs and bamboo. Production forest (forest designated for future commercial timber extraction) is also a source of NTFPs, construction timber, and fuel wood for communities.

The largest contributor to forest loss of proposed HPPs is Sekong 4A, which will affect 4,699 hectares (about 47 square kilometers) of forest largely classified as production forest (Table 7.5). The second-largest area of forest loss is associated with Sekong 5, with 1,981 hectares (20 square kilometers) of forest loss, mainly within the Xe Sap NPA.

Table 7.4: Summary of Forest Loss for Each Development Pathway

Development pathway	Production forest	Conservation forest and natural protected area	Protection forest	Regeneration forest	Total forest loss
Hectares					
Full	5,843	2,324	860	1,743	11,196
Intermediate	651	2,192	500	1,928	5,271
Conservative	651	625	86	1,928	3,290

Table 7.5: **Area of Forest Impacted by Existing and Proposed Hydropower Projects**

Project Name	Conservative development	Intermediate development	Full development	Production forest (ha)	Conservation forest and natural protected area (ha)	Protection forest (ha)	Regeneration forest (ha)	Total forest (ha)
Nam Kong 1	X	X	X	293	0	0	1,481	1,774
Nam Bi 1	X	X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Nam Bi 2	X	X	X	54	48	0	51	153
Nam Bi	X	X	X	0	29	0	0	29
Nam Ang	X	X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Nam Emoun	X	X	X	137	0	0	289	426
Xe Pian-Houaysoy	X	X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Xe Katam	X	X	X	16	0	16	0	32
Xe Kaman 2A	X	X	X	148	548	0	104	800
Xe Kaman 2B	X	X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Xe Kaman 4	X	X	X	3	0	70	3	76
Xe Namnoy 5	X	X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Sekong 5		X	X	0	1,567	414	0	1,981
Sekong 4B		X	X	n.a.	n.a.	n.a.	n.a.	n.a.
Sekong 4A			X	4,473	51	71	104	4,699
Sekong 3A			X	356	23	188		567
Sekong 3B			X		58			58
Sekong Downstream A			X	0	0	101	0	101
Sekong Downstream B			X	500	0	0	0	500
Total				**5,980**	**2,324**	**860**	**2,032**	**11,196**

Note: ha = hectare; n.a. = data not available; If no Xs, the plant is not part of the respective scenario.

Hydropower development is only one cause of forest loss and thereby of diminishing timber and NTFP resources in the Sekong River Basin. Logging and conversion of forest to agriculture and for timber plantations also play significant roles. If proposed mining concessions in the basin are approved, large areas of forest will be affected.

7.3.4 Mitigation Options

The impacts of hydropower on natural resource–dependent livelihoods are closely correlated with the number of projects and size of project footprints. Accordingly, impacts could be reduced by opting not to develop certain projects or through design modifications that reduce reservoir sizes. In the context of a given development pathway, the following measures would be most effective if coordinated among power developers on a basin scale.

- *Reservoir fisheries*: support community-managed capture and farmed fisheries in reservoirs, with exclusive focus on native species
- *Replacement agricultural land*: ensure adequate land for affected communities for agriculture and harvesting of NTFPs

- *Boost productivity*: capacity building (farmer training), infrastructure (for example, irrigation and roads), and access to finance (saving and loans) to increase productivity and access to markets
- *Alternative livelihoods*: support of off-farm income-generating activities to supplement agriculture and harvesting of forest products
- *Community forest management*: to promote sustainable use of fuel wood, timber, and NTFPs
- *Domestic energy supply*: affordable electricity and fuel-efficient wood stoves to reduce demand for fuel wood

Industry experience is that impacts of hydropower development on local livelihoods are difficult to fully mitigate. Even well-resourced HPPs in Lao PDR have struggled to meet livelihood restoration targets for resettled communities. Considering the intensity of hydropower development being planned for the Sekong Basin, the impact on livelihoods can be expected to be significant. This is especially true for the full development pathway but also for the intermediate development pathway; both include construction of Sekong 4A, which will affect approximately 47 square kilometers of forest and 10 square kilometers of agricultural land.

7.4 Community and Culture

7.4.1 Resettlement

Hydropower projects often necessitate resettlement of villages from within the project footprint to make way for the reservoir, dam, and powerhouse. Resettlement may also be required for project access roads, electricity transmission lines, and watershed management plans. Even where resettlement does not occur, villages may experience partial loss of community forest, agricultural land, and housing, with impacts on livelihoods.

Riparian communities immediately downstream from dams may need to be resettled for community health and safety reasons. For example, if water released from a dam has a strong odor that affects community well-being, or dam discharge causes rapid fluctuations in the river level that pose a hazard for fishers and other river users, riverside communities may be resettled. Flood risks from extreme weather and other events causing uncontrolled releases or dam breaches must also be assessed, which may lead to a decision to resettle communities away from the danger zone. Communities situated below a cascade of dams may be particularly vulnerable. Even if resettlement is not required, emergency preparedness plans need to be put in place.

Project-induced resettlement generally involves relocating villages to new purpose-built village settlements. This has the potential to significantly affect social cohesion and cultural integrity because it breaks traditional ties to land and place and disrupts social structures. Resettlement sites tend to be close to main roads and large towns, which can accelerate cultural integration of ethnic groups into the dominant Lao culture, which affects ethnic minority languages, customs, beliefs, and social norms. Such factors are typically considered as part of the EIA for individual projects, resulting in project-specific resettlement and social development plans designed not only to mitigate impacts but also to enhance social outcomes. The efficacy of such measures is project specific, but some residual unmitigated impacts can generally be expected. Cumulatively, development of hydropower in the Sekong Basin will amplify the effects of individual projects.

Existing hydropower development in the Sekong Basin has resulted in substantial resettlement, mostly within the past decade. At least 13,800 people have been resettled because of seven completed hydropower projects (69 percent from one project: the Xe Pian–Xe Namnoy HPP). Data are not available for five projects, so the true total is likely to be higher.

The full development pathway will lead to resettlement of an additional 12,600 people, and because data for some projects are not available, the total may be higher. Almost half of the total resettlement required for the full development pathway is associated with two Sekong mainstream projects: Downstream A and B (about 5,000 people displaced). These two projects also have the highest ratio of resettled people to gigawatt-hours of power generation (7:1 and 11:1, respectively). In comparison, the Sekong 5 HPP, which has the largest reservoir, displaces less than one person per megawatt.

By contrast, the intermediate development pathway will require resettlement of approximately 3,700 people and the conservative development pathway approximately 2,500 people. These development pathways have lower resettlement impacts because they omit some or all planned mainstream Sekong River dams, particularly in the lower reaches, where population density is higher.

In summary, the full development pathway will require the greatest resettlement, the intermediate pathway will require moderate resettlement, and the conservative pathway will require a small amount of resettlement (Tables 7.6 and 7.7).

Table 7.6: Resettled Persons per Unit of Power Generation

Pathway	Installed capacity (MW)	Reservoir area (km²)	Resettled persons	Resettled persons per annual GWh
Present situation	1,554	147	13,844	2.2
Conservative development	2,470	257	16,330	1.7
Intermediate development	2,975	303	17,578	1.5
Full development	3,512	379	26,499	1.9

Note: MW = megawatt; km² = square kilometer; GWh = gigawatt-hour.

Table 7.7: Project-Induced Resettlement in Each Development Pathway

Project Name	Present situation	Conservative development	Intermediate development	Full development	Installed capacity (MW)	Reservoir area (km²)	Resettled persons	Resettled persons/ annual GWh
A Luoi	X	X	X	X	170	8	872	1.3
Houay Ho	X	X	X	X	152	37	1,920	4.3
Xe Kaman 3	X	X	X	X	250	9	0	0
Xe Namnoy 6	X	X	X	X	5	n.a.	n.a.	n.a.
Xe Namnoy 1	X	X	X	X	15	0	n.a.	n.a.
Houay Lamphan Gnai	X	X	X	X	88	7	1,398	3.1
Xe Kaman 1	X	X	X	X	290	n.a.	n.a.	n.a.
Xe Kaman–Sanxay	X	X	X	X	32	1	n.a.	n.a.
Nam Kong 2	X	X	X	X	66	4	0	0
Xe Katam 1 Xe Namnoy 2	X	X	X	X	22	0	92	0.3
Xe Pian Xe Namnoy	X	X	X	X	410	49	9,458	5.3
Nam Kong 3	X	X	X	X	54	32	104	0.5
Dakchaliou 1		X	X	X	11	0	n.a.	n.a.
Dakchaliou 2		X	X	X	13	0	n.a.	n.a.
Nam Kong 1		X	X	X	150	22	1,612	2.9
Nam Bi 1		X	X	X	68	n.a.	n.a.	n.a.
Nam Bi 2		X	X	X	50	n.a.	n.a.	n.a.
Nam Bi 3		X	X	X	12	n.a.	n.a.	n.a.
Nam Ang		X	X	X	55	0	n.a.	n.a.
Nam Emoun		X	X	X	129	n.a.	n.a.	n.a.
Nam Pangou		X	X	X	33	n.a.	n.a.	n.a.

Xe Pian–Houysoy		X	X	X	45	n.a.	n.a.	n.a.
Lower Xe Pian		X	X	X	15	0	n.a.	n.a.
Xe Katam		X	X	X	81	0	n.a.	n.a.
Xe Kaman 2A		X	X	X	64	82	342	0.3
Xe Kaman 2B		X	X	X	100	1	98	0.3
Xe Kaman 4		X	X	X	70	5	342	1.2
Xe Namnoy 5		X	X	X	20	0	92	1
Sekong 5			X	X	330	33	440	0.3
Sekong 4B			X	X	175	13	808	1.1
Sekong 4A				X	165	23	2,494	3.2
Sekong 3A				X	114	12	1,080	2.3
Sekong 3B				X	122	18	240	0.6
Sekong Downstream A				X	86	14	2,764	7.3
Sekong Downstream B				X	50	9	2,343	11.2
Total					**3,512**	**379**	**26,499**	**1.9**
Average					**100**	**14**	**1,325**	**2.3**

Note: MW = megawatt; km² = square kilometer; GWh = gigawatt-hour; n.a. = data not available; If no Xs, the plant is not part of the respective scenario.

7.4.2 Ethnic Customs and Language and Religious Beliefs

Renewable energy development is likely to affect traditional customs, languages, belief systems, and other cultural elements associated with ethnic groups in the Sekong Basin (see Section 3.6.1) through diverse and diffuse processes. Based on stakeholder consultations for this study and experiences of recent hydropower projects in other parts of Lao PDR, the impacts are likely to be positive, negative, and sometimes mixed.

- During construction and operation of hydropower projects, there will be interactions between locals and non-locals attached to the project (workers, camp followers, and economic migrants), resulting in exchanges of knowledge and experience that may enhance or erode traditional values.

- It is common for hydropower projects to resettle ethnic groups living in homogenous communities into heterogeneous communities. This can be expected to accelerate ongoing integration and assimilation of smaller ethnic groups into mainstream lowland culture. There is a potential for loss of tradition but also a chance to benefit from new ideas and practices.

- Social development programs that hydropower projects sponsor as part of resettlement plans typically aim to improve education and health services for local communities. They can therefore help raise the socio-economic situation of ethnic groups previously lacking access to public services, utilities, and markets. Social development programs typically benefit girls and women and thus may narrow the gender gap that is common in Mon-Khmer communities.

- Employment and other economic growth associated with project development may provide new opportunities for women, leading to a more equal role in household decision making.

Impacts on ethnicity and culture are required to be assessed as part of EIAs for individual projects and mitigated through social development plans or ethnic minority development plans.

The effectiveness of these plans varies by project, but residual unmitigated impacts can be expected. Hydropower development in the Sekong Basin overall will amplify the effects of individual projects.

Hydropower development in the Sekong Basin will particularly affect communities belonging to the Mon-Khmer ethnolinguistic family (see Section 3.6.1) because most project sites are located in the upper watershed near Mon-Khmer villages (Map 7.1). Impacts on Mon-Khmer communities in terms of resettlement (both positive and negative) and economic integration (probably positive overall) are assessed as substantial and similar under all three pathways because all three include intense development of tributaries where Mon-Khmer people live.

Map 7.1: Distribution of Ethnic Groups and Hydropower Projects in the Sekong Basin

Under the full development pathway, construction of the Sekong mainstream cascade will result in substantial resettlement of ethnic Lao communities in the lowlands. Notwithstanding the challenges associated with resettlement, relocation will probably not significantly affect customs and traditional beliefs for these communities because they are already a part of the mainstream society and economy.

7.4.3 Gender

Cumulative effects of renewable energy development on gender have been evaluated with reference to gender assessments in ESIA reports (where available) and results of local government and village consultations.

Changes in gender roles in Lao PDR have been positively influenced by increased access to education, socio-economic development, and efforts of authorities and organizations to make gender relations more equitable. In this context, renewable energy development that offers employment and economic growth may provide opportunities for women, leading to a more equal role in household decision making. Social development programs that hydropower projects sponsor as part of village resettlement typically result in better education and health services for communities. It is likely that this will benefit girls and women, narrowing the gender gap that is common in Mon-Khmer communities. Power projects typically support the expansion of rural electricity networks to project-affected communities. Access to electricity in the home can help reduce some labor-intensive tasks (cooking, milling, and washing) that are performed mainly by women and girls. Conversely, renewable energy projects in rural areas may increase the risk of sexual or domestic violence for women and girls, especially if project construction draws in large numbers of migrant workers and camp followers. Nevertheless, the cumulative impact of hydropower development on gender equality is likely to be positive overall.

7.4.4 Mitigation Options

The impacts of hydropower on the aspects of community and culture reviewed are closely correlated with the number of projects and the size of project footprints. Accordingly, impacts could be reduced by opting not to develop certain projects or through design modifications that reduce reservoir sizes. In the context of a given development pathway, the following measures, which specific projects could apply, would be most effective if coordinated among power developers on a basin scale.

- Assess potential resettlement sites within the Sekong Basin—considering the need for land for housing, agriculture, and access to natural resources—to identify a maximum threshold for resettlement.
- Maintain community cohesion during resettlement—keep resettled villagers together; avoid combining different ethnic groups without consultation and consent.
- Establish funding arrangements and mechanisms to support cultural events and activities as part of resettlement and social developments plans.
- Integrate gender considerations into all resettlement and social development plans.

7.5 Summary of Impacts and Mitigation Measures for All Pathways

Tables 7.8, 7.9, and 7.10 summarize the impacts and mitigation measures for all three development pathways.

Table 7.8: Full Development Pathway

VEC category	Main impacts	Size of impact	Mitigation measures	Residual impacts
Aquatic habitats and biodiversity				
Aquatic fauna and fish populations (flow regime change)	Decrease in floodplain connectivity because of reduction in high flows in wet season	Large	Joint and coordinated EFlows especially for Sekong mainstream dams to trigger fish migration Joint coordinated flushing and sluicing of four lowermost Sekong mainstream dams to maintain floodplain geomorphology and aquatic habitats	Creation of reservoirs will change the ecosystem structure from lotic to lentic. Flushing and sluicing will be only partially effective, so floodplain geomorphology and aquatic habitat structure will still change.
Habitat fragmentation and fish connectivity	Physical blockage of river by dams and changes in the aquatic habitat, especially under the full development pathway because of seven Sekong mainstream dams	Large	Fish passages, especially on four lowermost mainstream dams if feasible For tributary and mainstream dams, research on the effectiveness, costs, and benefits of different types of fish passages (fish ladders, fish lifts, natural bypasses for dams up to 40 meters high, and truck and transport for higher dams)	Fish passages are not 100 percent effective, so migration is still partially obstructed. Creation of reservoirs will affect upstream and downstream migration triggers.
Terrestrial habitats and biodiversity				
Key conservation areas	Inundation by reservoirs and habitat fragmentation by ancillary infrastructure (e.g., transmission lines and roads)	Moderate	Creation of biodiversity offsets for inundated areas (2,324 hectares)[a] and land taken for ancillary infrastructure to ensure no net loss in biodiversity if feasible (and net gain if possible)	Biodiversity offsets may not be able to replicate original conditions of lost conservation areas.
Terrestrial species	Habitat inundation by reservoirs and obstruction of migration routes	Moderate	Creation of biodiversity offsets and ensuring biological corridors for wildlife migrations	Biodiversity offsets may not be able to replicate original conditions of lost conservation areas.
Natural resource–dependent livelihoods				
Fisheries	Decrease in fish populations and species composition, especially along the Sekong mainstream	Severe	Community-managed reservoir fisheries programs and fish cage cultures (native species)	Reservoir fisheries are unlikely to match the productivity of unregulated rivers, so total availability of fish for consumption will decrease.
Agriculture	Loss of riverbank gardens and agricultural lands (1,670 hectares), especially along the Sekong mainstream[b]	Large	Development of replacement agricultural land with equivalent productivity	Forests near resettlement villages will decline because of conversion to agricultural land.

[a] Sekong 5 and Xekaman 2A account for more than 90 percent of this loss, at 2,115 hectares (1,567 and 548 hectares, respectively).

[b] Sekong 4A constitutes more than 60 percent of this loss (1,023 hectares).

VEC category	Main impacts	Size of impact	Mitigation measures	Residual impacts
Forest and NTFP	Inundation of forests (11,196 hectares[c]) containing NTFPs	Moderate	Catchment management protection measures, including reforestation of already degraded forestlands; biggest losses from Sekong 5, Nam Khong 1, Nam Emoun, and Xe Kaman 2A	Reforestation is challenging and unlikely to be effective in replacing lost conservation and protection forests.
Physical displacement and resettlement	11,498 people resettled,[d] especially in relation to Sekong mainstream dams	Large	Basin-wide strategy for resettlement identifying suitable areas for agriculture and housing	Livelihood restoration targets will be difficult to meet because of lack of resettlement sites with sufficient land for agriculture and forest-dependent livelihoods.
Culture and heritage				
Ethnic customs and language, religious beliefs	Positive and negative impacts because of resettlement of villages	Moderate	Maintain community cohesion during village resettlement Support ethnic minority communities to maintain cultural identity through social development plans	There will be physical stress and impacts on resettled people in relation to loss of their original land.
Gender	Potential positive changes in gender roles because of socio-economic development, but some gender-related risks that have not been well studied	Slight	Community development planning that specifically addresses gender, including gender awareness training to mitigate harms and enhance benefits Gender disaggregated monitoring of resettled communities	Potential for gender-based violence, trafficking and exploitation.

[c] Sekong 4A, with total loss of 4,331 hectares of forest land, accounts for close to 40 percent of the loss, with 4,231 hectares being production forest. Sekong 5 stands at 1,981 hectares of total forest loss, with 1,567 hectares being conservation forest and 414 hectares of production forest.

[d] Sekong Downstream A and B constitute close to 45 percent of total, with more than 5,100 people resettled.

Table 7.9: Intermediate Development Pathway

VEC category	Main impacts	Size of impact	Mitigation measures	Residual impacts
Aquatic habitats and biodiversity				
Aquatic fauna and fish populations (flow regime change)	Some decrease in floodplain connectivity because of reduction in high flows in wet season from development of only the two upper mainstream dams (Sekong 4B and 5)	Slight to moderate	After initial EFlow assessment, joint and coordinated EFlow releases especially for Sekong 4B and 5 to trigger migration; joint coordinated flushing and sluicing in smaller reservoirs in tributaries, where relevant,[a] to maintain river geomorphology and aquatic habitats	Creation of reservoirs will change the ecosystem structure from lotic to lentic. Flushing and sluicing will be only partially effective, so floodplain geomorphology and aquatic habitat structure will still change.
Habitat fragmentation and fish connectivity	Physical blockage of river by dams and changes in aquatic habitat	Moderate	Consider incorporation and design of fish passages along migration routes in tributary dams not higher than 40 meters (Lower Xe Pian, Xe Katam, Xe Namnoy 1 and 6, Xe Namnoy 2—Xe Katam 1, and dams upstream of Xe Kaman 1 in the Xe Kaman cluster); truck and transport for larger dams (Sekong 4B and 5) on mainstream and larger tributary dams; research effectiveness of above	Creation of Sekong 4B and 5 reservoirs will affect upstream and downstream migration in Upper Sekong.
Terrestrial habitats and biodiversity				
Key conservation areas	Inundation by reservoir and habitat fragmentation by ancillary infrastructure (e.g., transmission lines and roads); for this pathway, relates mainly to Sekong 5 inundation of the Xe Xap NPA	Slight to moderate	Creation of biodiversity offsets for inundated areas and land taken for ancillary infrastructure, especially for Sekong 5 (will inundate 1,567 hectares of the Xe Xap NPA)	Biodiversity offsets will not necessarily reflect original conditions of lost conservation areas, but purpose is to achieve no net loss in biodiversity if feasible (and net gain if possible).
Terrestrial species	Habitat inundation and obstruction of migration routes	Slight to moderate	Creation of biodiversity offsets and ensuring biological corridors for wildlife migration, especially for Sekong 5 ancillary infrastructure (e.g., transmission lines, roads)	Biodiversity offsets will not necessarily reflect original conditions of lost conservation areas, but purpose is to achieve no net loss in biodiversity if feasible (and net gain if possible).
Natural resource–dependent livelihoods				
Fisheries	Decrease in fish production and thus catches, as well as species composition, in Upper Sekong because of Sekong 4B and 5	Moderate to large	Enable reservoir fisheries programs and fish cage cultures (native species) in Sekong 4B and 5 reservoirs and relevant tributary reservoirs	Reservoir fisheries are unlikely to match the productivity of unregulated rivers, so availability of fish for consumption will decrease, especially in Upper Sekong mainstream, because of Sekong 4B and 5.

[a] In Bolaven, flushing and sluicing should be considered in the planned Xe Katam hydropower plant (HPP) if it is possible to redesign the already commissioned Xe Namnoy 1 and 6 and Xe Namnoy 2–Xe Katam 1. Flushing and sluicing are also relevant for the Lower Xe Pian HPP. Flushing and sluicing of Nam Kong 2 and 3 are not relevant because of the large Nam Kong 1 downstream already under construction. In the Xe Kaman cluster, the larger Xe Kaman 1 (and the smaller Xe Kaman–Sanxay) has been commissioned where flushing and sluicing are not feasible, but flushing and sluicing are feasible for the Xe Kaman 2A, 2B, and 4 cascade, albeit only with local and tributary sediment transport effects.

VEC category	Main impacts	Size of impact	Mitigation measures	Residual impacts
Agriculture	Loss of riverbank gardens and agricultural lands (about 387 hectares), especially with Sekong 4B (65 hectares), Nam Kong 1 (174 hectares), Nam Emoun (84 hectares), and Xe Kaman 2A (43 hectares)	Slight to moderate	Development of new agricultural land, especially with Sekong 4B, but also planned tributary dams	Forests will decline because of conversion of agricultural land, although there will be less pressure on this along the Lower Sekong mainstream.
Forest and NTFP	Inundation of forest land (5,271 hectares total) including those with valuable NTFPs, especially along Sekong 5 (1,981 hectares)	Slight to moderate	Catchment management protection measures, including reforestation of already degraded forestlands, especially for Sekong 5, Nam Khong 1, Nam Emoun, and Xe Kaman 2A	Reforestation will not be fully effective, especially for lost conservation and protection forests.
Physical displacement and resettlement	Loss of settlements (3,300 people resettled) in inundated areas, with tributary dams constituting two-thirds of this and Sekong 4B and 5 constituting one-third	Moderate	Basin-wide guidelines for implementation of coordinated clearance of land for agriculture and building houses for resettled people to reduce residual cumulative impacts	There will be physical stress and impacts on resettled people in relation to loss of their original land.
Culture and heritage				
Ethnic customs, language, and religious beliefs	Different impacts on different ethnic groups because of development of only Sekong 4B and 5	Slight	Ensure ethnic groups are resettled to the same areas or villages; funding to support cultural events and activities as part of resettlement planning	There will be physical stress and impacts on resettled people in relation to loss of their original land.
Gender	Positive and negative impacts on gender because of exposure of ethnic minorities to mainstream society following resettlement	Slight	Community development planning that specifically addresses gender, including gender awareness training to mitigate harms and enhance benefits	Traditional gender customs will be lost (positive and negative).

Note: NPA = National Protected Area; NTFP = non-timber forest product.

Table 7.10: Conservative Development Pathway

VEC category	Main impacts	Size of impact	Mitigation measures	Residual impacts
Aquatic habitats and biodiversity				
Aquatic fauna and fish populations (flow regime change)	Minor changes from present situation	Slight	After initial EFlow assessment, joint and coordinated EFlow releases in tributaries and joint coordinated flushing and sluicing in smaller reservoirs in tributaries, where relevant,[a] to maintain river geomorphology and aquatic habitats in tributary sections	Creation of reservoirs will change the ecosystem structure from lotic to lentic. Flushing and sluicing will be only partially effective, so floodplain geomorphology and aquatic habitat structure will still change in tributaries with new HPP development.
Habitat fragmentation and fish connectivity	Minor changes from present situation; tributary systems already partially developed	Slight	Consider incorporation and design of fish passages along migration routes in tributary dams not higher than 40 meters (Lower Xe Pian, Xe Katam, Xe Namnoy 1 and 6, Xe Namnoy 2–Xe Katam 1 and dams upstream of Xe Kaman 1 in the Xe Kaman cluster); truck and transport for larger tributary dams; research on effectiveness of above	There will be minor residual impacts on fragmentation and fish connectivity only in tributary systems with more local migration because the Sekong mainstream will remain free flowing.
Terrestrial habitats and biodiversity				
Key conservation areas	Inundation by reservoir and habitat fragmentation by ancillary infrastructure (e.g., transmission lines and roads) confined to new developments in tributaries	Slight to moderate	Creation of biodiversity offsets for inundated areas (651 hectares) and land taken for ancillary infrastructure in tributaries	Biodiversity offsets will not necessarily reflect original conditions of lost conservation areas, but purpose is to achieve no net loss in biodiversity if feasible (and net gain if possible).
Terrestrial species	Habitat inundation and obstruction of migration routes confined to new developments in tributaries	Slight to moderate	Creation of biodiversity offsets and ensuring biological corridors for wildlife migrations in tributaries with new development	Biodiversity offsets will not necessarily reflect original conditions of lost conservation areas, but purpose is to achieve no net loss in biodiversity if feasible (and net gain if possible).
Natural resource–dependent livelihoods				
Fisheries	Moderate decrease in fish production and thus catches—mostly tributary fisheries—because the Sekong mainstream remains free flowing	Moderate	Enable reservoir fisheries programs and fish cage cultures (native species) in relevant tributary reservoirs	Tributary reservoir fisheries are unlikely to match the productivity of unregulated conditions, so availability of fish for consumption will decrease moderately.

[a] In Bolaven, flushing and sluicing should be considered in the planned Xe Katam hydropower plant (HPP) if it is possible to redesign the already commissioned Xe Namnoy 1 and 6 and Xe Namnoy 2–Xe Katam 1. Flushing and sluicing are also relevant for the Lower Xe Pian HPP. Flushing and sluicing of Nam Kong 2 and 3 are not relevant because of the large Nam Kong 1 downstream already under construction. In the Xe Kaman cluster, the larger Xe Kaman 1 (and the smaller Xe Kaman–Sanxay) has been commissioned where flushing and sluicing are not feasible, but flushing and sluicing are feasible for the Xe Kaman 2A, 2B, and 4 cascade, albeit only with local and tributary sediment transport effects.

Agriculture	Loss of riverbank gardens and agricultural lands (about 322 hectares) for new development in tributaries, especially Nam Kong 1 (174 hectares), Nam Emoun (84 hectares), and Xe Kaman 2A (43 hectares)	Slight	Development of new agricultural land	Forests will decline because of conversion of agricultural land, although there will be less pressure along the Sekong mainstream.
VEC category	**Main impacts**	**Size of impact**	**Mitigation measures**	**Residual impacts**
Forest and NTFP	Inundation of forest land (3,290 hectares), including that with valuable NTFPs solely in new development in tributaries	Slight	Reforestation of already degraded forestlands; catchment management protection measures; biggest losses on Nam Kong 1, Nam Emoun, and Xe Kaman 2A	Reforestation will not be fully effective, especially for lost conservation and protection forests.
Physical displacement and resettlement	Loss of households and people resettled in inundated areas (total about 2,200), with Nam Kong 1 and Nam Emoun constituting most (1,612 and 492 people resettled, respectively)	Slight	Basin-wide guidelines for implementation of coordinated clearance of land for agriculture and building houses for resettled people in tributaries to reduce residual cumulative impacts	There will be physical stress and impacts on resettled people in relation to loss of their original land.
Culture and heritage				
Ethnic customs, language, and religious beliefs	Resettlement affects different ethnic groups	Slight	Resettle ethnic groups to the same areas or villages; funding to support cultural events and activities as part of resettlement planning	There will be physical stress and impacts on resettled people in relation to loss of their original land.
Gender	Harms and benefits according to gender because of exposure of ethnic minorities to mainstream society following resettlement	Slight	Community development planning that specifically addresses gender, including gender awareness training to mitigate harms and enhance benefits	There will be loss of traditional gender customs (positive and negative).

Note: HPP = hydropower plant; NTFP = non-timber forest product.

8. MITIGATING IMPACTS AND RISKS THROUGH BASIN MANAGEMENT

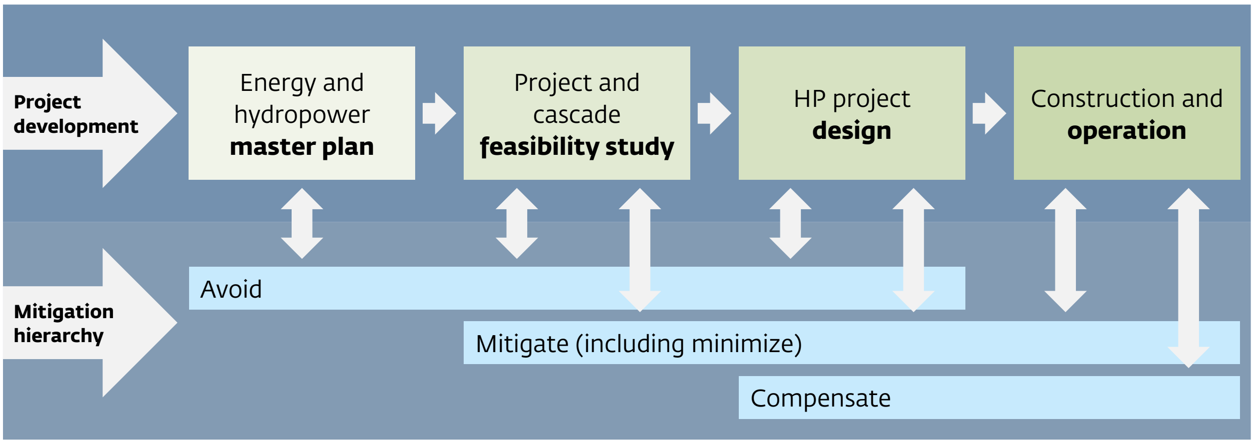
8.1 Mitigation Hierarchy Approach

Measures to mitigate impacts of hydropower development, as elaborated in Chapter 7, can include a combination of measures that may be classified into four main categories of action: avoid, minimize, restore, and offset—known as the mitigation hierarchy.

- *Avoid* through choices about project selection, location, engineering designs, and operating practices
- *Minimize* through provision of environmental flows (EFlows), fish passages, and sediment flushing facilities
- *Restore* through protection and enhancement of conservation areas and important habitats in the reservoir watershed and by restoring livelihoods and incomes of resettled communities
- *Offset* through protection of terrestrial or aquatic ecosystems with biodiversity values similar to those affected

A guiding principle of impact mitigation is that avoidance and minimization are preferred over restoration and offsetting, as opportunities to mitigate impacts and enhance benefits of hydropower are greater at earlier stages of project development (Figure 8.1). For example, impacts can be avoided during the creation of a basin, regional, or national master plan when decisions about which projects to prioritize are made. During project feasibility studies, impacts can be avoided and minimized by adjusting location, dam height, reservoir size, and other design parameters (Box 8.1). During subsequent phases (detailed design, construction, and operation), mitigation options are largely restricted to compensatory measures. Opportunities to mitigate environmental and social impacts in projects already built or under construction are limited. The main physical features of the project (dam, reservoir, powerhouse, and transmission lines) cannot be modified much. In principle, operating rules can be changed to reduce environmental and social impacts, but in practice, these rules tend to be rigidly defined in power purchase agreements. Therefore, addressing cumulative hydropower risks and impacts on the Sekong Basin requires applying the mitigation hierarchy throughout the hydropower development cycle, with a particular focus on master planning at the basin and sub-basin scale.

Figure 8.1: Risk and Impact Mitigation over the Development Cycle



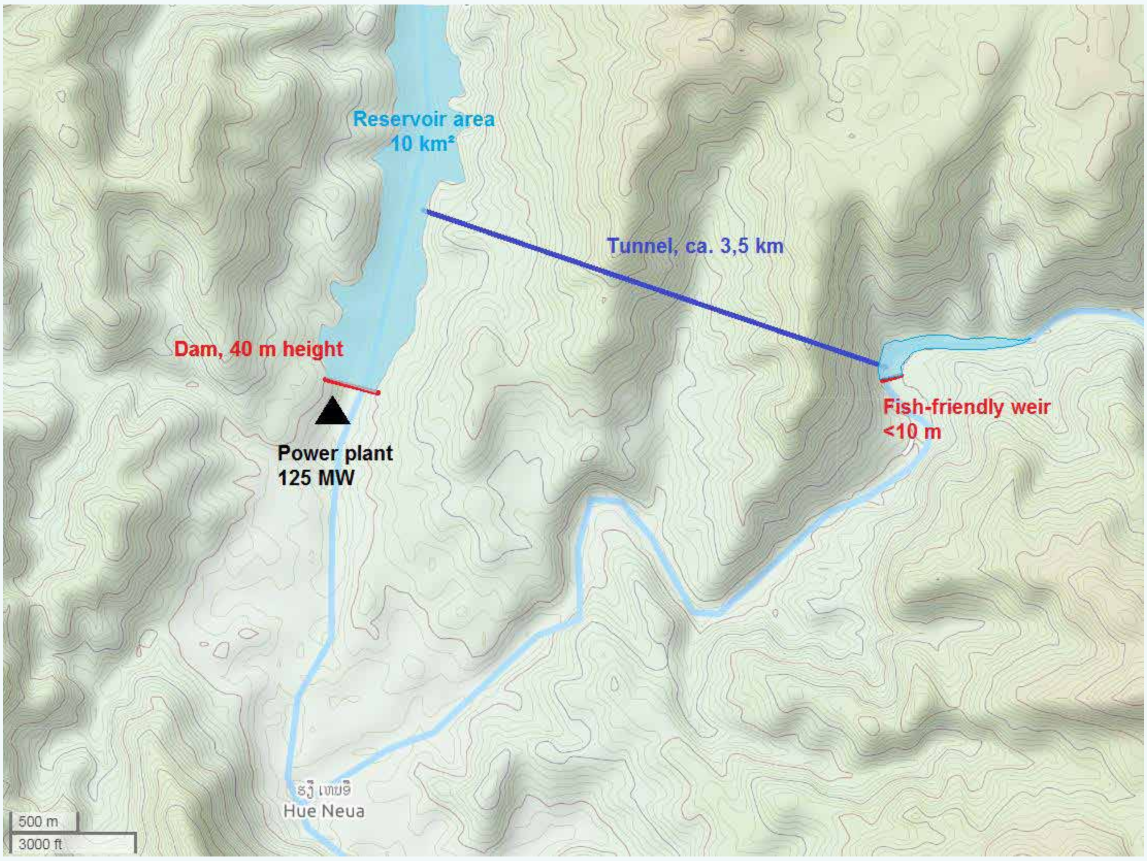
Source: MRC 2019a

BOX 1: PLANNING JOINTLY TO AVOID NEGATIVE IMPACTS

Sekong 4A will be the most expensive project in the Sekong Basin by a significant margin in terms of investment cost per megawatt installed and per annual gigawatt-hour. It will also have significant environmental and social impacts.

An alternative design for the Sekong 4A hydropower plant could reduce the cost per megawatt and the reservoir's environmental footprint. Moving the dam to a new site upstream of the confluence with the Nam Emoun (Map 8.1.1) would reduce dam height and dam volume, more than halving the area that the reservoir inundates while still having sufficient capacity to re-regulate flows released from upstream Sekong 4B when operating in peaking mode. To achieve that, an active volume of 10 million to 20 million cubic meters would be sufficient, which is 10 percent of the proposed reservoir. The power output of the revised plan would be approximately 50 megawatts less, but the investment cost and environmental footprint would also be lower. In addition, it may be technically and economically feasible to transfer water through a tunnel to the Nam Emoun River, increasing the generating capacity of the Nam Emoun hydropower plant (HPP) and offsetting some of the reduction in power that the modified Sekong 4B generates.

Map 8.1.1: Risk and Impact Mitigation over the Development Cycle



This alternative design would have several advantages in terms of environmental and social impact mitigation. First, the Nam Emoun would remain open for fish migration, assuming a small fish passage can be incorporated into the Nam Emoun dam. Second, sediment transport would be better because the flushing efficiency of the smaller Sekong 4A reservoir would be higher. Third, the area of forest lost to the reservoir would be significantly less, reducing the risk of eutrophication after impoundment and permitting continued use of the forest for non-timber forest product harvesting. Fourth, resettlement impacts would be lower. The existing design of the Sekong 4A reservoir and larger dam construction site would affect houses and some agricultural land, but the smaller reservoir in the alternative design would not.

8.2 Master Planning

Master planning enables rational decisions about which of the many possible projects in the Sekong Basin should be prioritized to meet local, national, and cross-border power generation demand while minimizing financial, environmental, and social costs (Opperman, Grill, and Hartmann 2015).

With a basin-scale perspective, it is easier to identify complementary hydropower projects that can be operationally coordinated to meet power generation needs while limiting environmental and social effects to acceptable levels. An example involving the Sekong 4A HPP and Nam Emoun HPP is presented in Box 8.1. Hydropower development in the Sekong Basin is developer driven and therefore not well coordinated to meet strategic goals. Even when three or more developers are working on the same river, there has been little observable coordination of water management and power dispatch, although there has been some cooperation in terms of access roads and transmission plans.

An integrated water resources management approach should be used during master planning to ensure that the full range of water resource uses, stakeholders, and possible trade-offs that may emerge is considered. In the Sekong Basin, this would include agriculture and forestry (using river water and ground water for irrigation), riparian communities (reliant on the river for potable water, fishing, navigation, and cultural practices), and mining and other industries (requiring river water and ground water for mineral processing and manufacturing).

A Sekong Basin master plan can establish basin- and catchment-specific requirements and targets for hydropower developments with overarching criteria such as the following:

- Environmental flow requirements (for example, minimum flows, seasonal releases, irrigation releases)
- Limits on ramping rates to minimize downstream riverbank erosion and harm to community safety
- Water quality targets such as dissolved oxygen levels and seasonal temperature ranges
- Sediment concentration limits or targets associated with coordinated sediment flushing operations
- Limits to lake-level operating ranges (for example, to support other water uses)
- Identification and protection of ecosystem, biodiversity, and wetland hotspots
- Identification of potential intact river routes for fish migration and other water uses

8.3 Power Generation Optimization

One of the benefits of master planning at a basin or sub-basin level is the possibility of optimizing power production by co-designing projects and coordinating project operations.

This is particularly relevant when multiple hydropower projects are constructed on the same river because this creates a cascade effect, with the flows released from one project affecting the generating capacity of projects downstream.

This study assessed the potential to maximize power production by optimizing operation of the seven mainstream dams planned under the full development pathway. The technical assumptions, methodology, results, and assessments are described in Appendix G.

For this assessment, three modes of operation are considered:

- *Maximization of energy output*: power plant operated mainly as run-of-river but with the reservoir used for storage in the wet season to avoid major spilling
- *Maximization of firm energy*: power plant operated at a constant output to provide as much firm power as possible
- *Dry season generation*: reservoir emptied in advance of the monsoon, and wet season inflow used to fill reservoir to generate as much power as possible in the dry season

Table 8.1 shows the dams included in the analysis and simulated power production for the Sekong mainstream dams. Differences in power generation among the three modes of operation are slight mainly because reservoirs are relatively large, and the design discharge of most HPPs is higher than the flow in the river, so there is relatively little spill, although there are some differences between the modeling results and project feasibility studies (right hand column in Table 8.1), which show higher power production for some projects. See Appendix G for more detail.

Table 8.1: Summary of Simulated Power Generation for Sekong Mainstream Dams

Hydropower project	Maximize generation	Maximize firm power	Dry season generation	Feasibility study
	(GWh per year)			
Sekong 5	1,239	1,200	1,159	1,502
Sekong 4B	736	756	757	749
Sekong 4A	734	749	752	781
Sekong 3A	368	370	371	433
Sekong 3B	307	310	310	418
Sekong Downstream B	176	180	181	206
Sekong Downstream A	423	438	439	380
Total	**3,983**	**4,003**	**3,970**	**4,469**

Note: GWh = gigawatt-hours.

There are several potential reasons for the differences in power generation between this study's model and the results of the feasibility studies. One explanation for the differences lies with the hydrological data. The power optimization model in this study uses inflows from HEC Res-Sim modeling (Section 1.2.5) that are approximately 15 percent to 20 percent lower than in the project feasibility studies. Another factor is that the production figures in the feasibility reports do not consider the upstream regulation benefits of the Sekong 5 project. This makes sense because the downstream projects cannot base their investment and financing decisions on the uncertainty that the upstream reservoir will be built and that it will operate optimally for downstream plants. Moreover, the feasibility studies do not include downstream reservoirs in their calculated tailwater level, thus overestimating the available head.

Despite these differences, overall, there is reasonable agreement between the model results in this study and the feasibility study figures for most projects, given all the uncertainties and assumptions involved in such modeling.

8.4 Coordinated Operations

Despite limited opportunity for power optimization through coordination of the Sekong mainstream cascade, there may be power optimization benefits for hydropower projects on tributaries, especially for dams in cascades on the same tributary. In particular, opportunities to coordinate cascade operations on the Xe Kaman, Nam Kong, and Xe Namnoy tributaries should be further analyzed to optimize power generation, avoid power export bottlenecks, and promote grid stability. Hydropower projects that may benefit from this analysis are the following:

- Nam Kong 1, 2, and 3 (Bolaven and Nam Kong sub-basins)
- The six dams on the Xe Namnoy tributary that divert water from Xe Pian to Xe Namnoy
- The 13 dams in the Xe Kaman sub-basin, especially the five on the Xe Kaman mainstream, but also to some degree those on its tributaries

In addition to power optimization, coordinated operations can help achieve priorities for environmental and social mitigation, management, and monitoring, including the following:

- Coordination of sediment flushing
- Synchronization of flows to trigger fish migration
- Sharing of data on biodiversity values (for example, fish species monitoring)
- Pooled financing of catchment protection and environmental offsets
- Exchange of hydrological data for power forecasting
- Coordinated flood monitoring and warnings

8.5 Institutional Arrangements

Effective planning and management of hydropower in the Sekong Basin requires appropriate institutional arrangements involving the national government, local authorities, and the private sector. Inter-ministerial coordination is particularly important because the Ministry of Environment and Natural Resources is responsible for basin planning, but the Ministry of Energy and Mines is responsible for power development planning. Integrated water resources management calls for the involvement of other ministries and agencies (for example, agriculture, forestry, industry, and tourism), communities, and other local stakeholders.

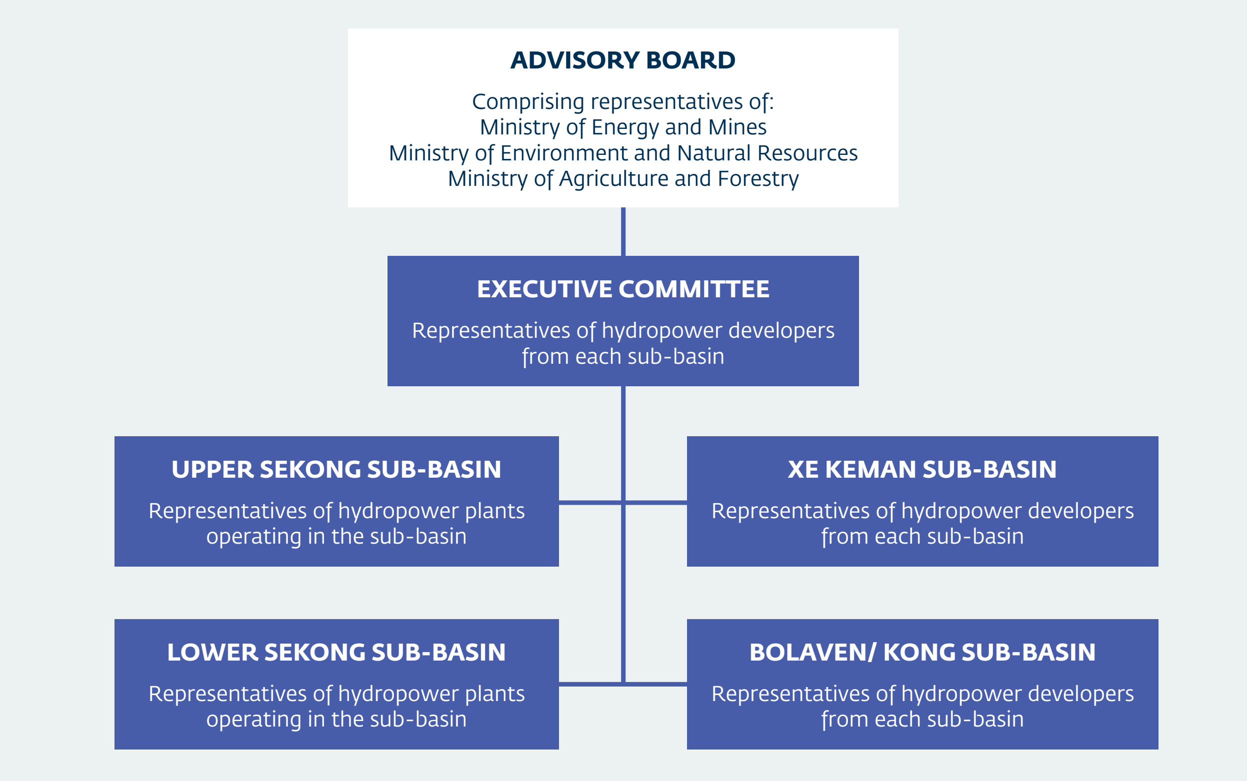
Coordination and information sharing among Sekong Basin hydropower operations could be achieved by establishing a simple co-management mechanism for the Sekong Basin organized around sub-catchments in the basin (Figure 8.2). This would be a voluntary company-led initiative coordinating closely with the Ministry of Energy and Mines that would have the following core functions:

- Communication among Sekong Basin hydropower operations, particularly within the same sub-basin
- Coordination among projects on specific matters of shared relevance (for example sediment flushing, fish passages, EFlows, and emergency procedures)
- Sharing of selected data sets (for example, hydrometeorology and water quality) to support operational decision making and power optimization
- Pooled funding arrangements for joint-management measures where appropriate (for example, watershed management and biodiversity offsets)
- Engagement with other Sekong Basin stakeholders consistent with the requirements of integrated water resource management

A co-management platform could extend to collaborative monitoring and reporting on the effectiveness of cumulative impact management mitigation. Doing so would enhance trust among participating hydropower operators and motivate closer cooperation in other areas of mutual interest.

Modest funding would be required for secretariat functions, meetings of the executive committee and sub-basin committees, and learning and information exchange events among members. To ensure long-term sustainability, the preferred funding model would be small annual contributions from hydropower operators proportionate to individual generating capacity or another simple metric, providing a surrogate indicator for a project’s contribution to cumulative environmental and social impacts. As a novel entity, the co-management platform may require seed funding from development partners to support its functions for an initial period (for example, three years). During this time, operation of the platform would be fine-tuned through a process of continuous monitoring, review, and adaptive management, culminating in an external evaluation providing guidance on future operations.

Figure 8.2: Tentative Structure of Co-Management Platform



8.6 Mitigation by Design

Hydropower project design is an iterative process moving from feasibility study to final detailed design. Project design should consider environmental design requirements and mitigation targets defined in the basin master plan (Section 8.2) as well as project-specific risks identified through an environmental and social impact assessment (ESIA). Environmental and social mitigation strategies should be identified early during the feasibility phase and refined during the detailed design phase to arrive at the final design of the project. This includes detailing of mitigation infrastructure, which might include the following:

- High- and low-level outlets to help discharge of water from different levels within the impoundment and with potential to pass sediments through the dam
- Re-regulation reservoirs to dampen downstream water level fluctuations
- Aeration weirs to increase oxygen levels in the tail water
- Fish passage addressing upstream and downstream migration
- Sediment bypass channels, tunnels, or infrastructure to promote deposition of sediment at the upstream end of reservoirs where it can be periodically harvested

To improve the design of future projects, it is recommended that the above mitigation infrastructure be considered in all HPP feasibility reports. The need for such measures is often under-emphasized in feasibility reports, or project proponents reject it as too costly; summary feasibility reports reviewed for this study contained little systematic analysis of such mitigation measures. Not all will be appropriate for all projects, but failure to assess a full range of mitigation options should be considered grounds for rejecting the feasibility study.

Evidence for the efficacy of mitigation infrastructure should be carefully reviewed. For example, whereas re-regulation dams and aeration weirs are well proven, studies show that sediment flushing and sluicing are viable for only relatively small reservoirs; regarding fish passages, data are limited on designs suitable for Mekong Basin fish species.

8.6.1 Re-regulating Reservoirs

Most of the larger hydropower plants in Lao PDR with export agreements to Thailand or Vietnam have variable prices for delivery of power during peak and off-peak periods and so tend to operate at full output during peak demand hours and conserve water during off-peak hours. Some export agreements contain clauses that provide for cross-border dispatch by the power purchaser, which means that the power purchaser can call the hydropower plant operators and instruct that the turbines be started on short notice to meet urgent power needs.

This type of peaking operation has consequences for the river downstream of the power plant tailrace. Variability in flows can be high and can change from 0 to 100 percent of the hydropower plant capacity within minutes, although such extreme peaking operation is not the norm. To operate in peaking mode, a small reservoir capacity is required, but most of the power plants in the Sekong Basin seem to be designed to include this capacity. Normally, 12 hours of storage at peak outflow is sufficient for most operation modes.

If the plant operating in such peaking mode has its outlet into or near a reservoir, the effect of flow variations is only minor—slow rises and falls of a few centimeters in the level of the downstream reservoir—but when the peaking power plant discharges into a river, the flow variations can have severe effects on downstream communities and can present a danger to anyone in the river washing, bathing, or fishing. One example of the daily variation in water levels can be seen in Photo 8.1, in which regular daily variations from full output to low output can be seen on the riverbanks.

To mitigate such rapid flow variations, it is advisable for the lowest power plant along a cascade of peaking power plants to have a re-regulating reservoir volume and to operate on a more or less constant release basis. The reservoir attached to the lowest dam does not need to be large but can function well with only a few hours of storage to capture the peak hour releases from upstream. The re-regulating reservoir is then drawn down when the upstream plants are switched off, ready for the next daily cycle of peaking operation (usually at night when power demand is lowest).

Photo 8.1: Hinboun River, Lao People's Democratic Republic, at Low Flow, Showing Regular High-Flow Water Line Two Meters Higher Corresponding to Peak Outflow from Hydropower Plant Upstream

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If no regulating reservoir has been planned, it is common to impose restrictions on the rate that power output can be increased or decreased so that changes in flow rates and river levels occur slowly. This will normally remove any life-threatening situations of rapid rises in flow without prior warning.

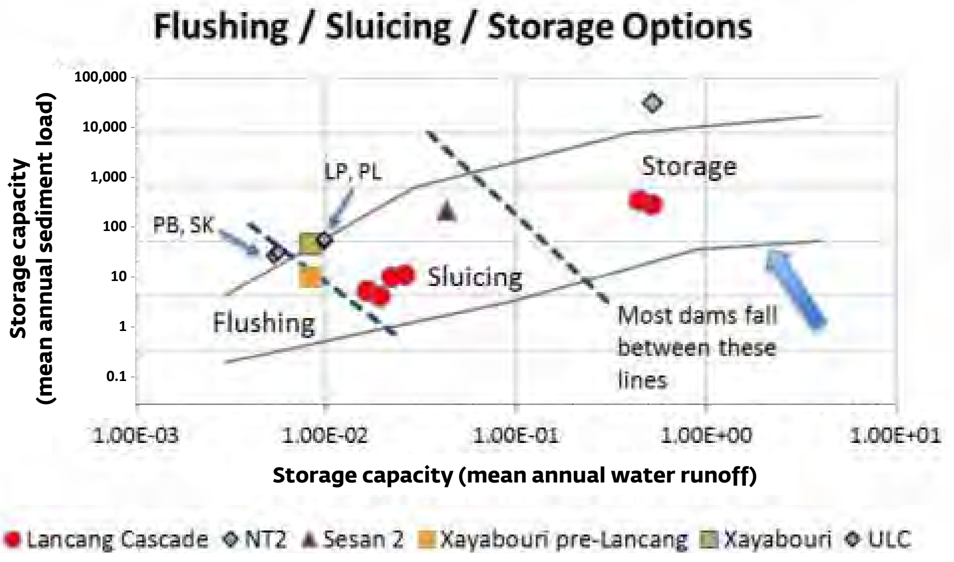
The natural laws of hydraulics will cause a dampening of such flow variations as one moves further downstream of the power plant outlet, so it is usually only the first 10 to 30 kilometers of a river exposed to peaking operation that will experience severe changes in flow and water level. One secondary effect of such flow variation is gradual erosion of riverbanks exposed to rapid river-level fluctuations. Modeling of such local downstream effects is the responsibility of each project owner and should appear in the ESIA reports for the peaking projects in question. There are no significant cumulative effects because the main effects are immediately downstream of each power plant. The study did not attempt to model such effects and did not have insight into the intended mode of operation of future hydropower plants.

8.6.2 Sediment Management Infrastructure

For very small reservoirs with a volume of less than 2 percent of mean annual inflow, sediments can be passed through the dam using low-level outlets designed for this purpose. The usual flushing procedure is to open the flushing gates fully and, if possible, draw down the reservoir level to allow erosion of sediment accumulated on the reservoir floor. Normally, only fine sand and silt can be flushed in this manner while much of the coarse sand and gravel fractions remain in the reservoir. Flushing has a cost in terms of reduced hydropower production.

Sluicing is a variation of flushing applied continually during flood inflows where incoming sediments are maintained in suspension or as rolling bed load by drawing down the reservoir as far as possible and thereby having high water velocities through the entire length of the reservoir. Because most of the incoming sediment arrives during the flood season, sluicing can be effective in maintaining sediment flows past the dam and preventing blockage of power intakes.

Figure 8.3: **Mekong Cascade Dams—Suitability of Flushing and Sluicing Sediment Management**



Source: MRC 2019c

Note: NT2 = Nam Theun 2; ULC = Upper Lao Cascade (Mekong mainstream); LP = Luang Prabang; PL = Pak Lay; PB = Pak Beng; SK = Sanakham.

Sluicing becomes less suitable as the size of the reservoir increases and becomes impractical or excessively costly after reservoir size exceeds approximately 20 percent of mean annual inflow (Figure 8.3). The effect of introducing systematic flushing operations is illustrated in the Mekong Hydropower Mitigation Guidelines (MRC 2019c), from which Figure 8.4 has been sourced. Here one sees the more precise modeling of the effect of optimal flushing procedure on the transport past a cascade of four mainstream Mekong dams, including Xayaburi, which is nearing completion in northern Lao PDR. More details of the modeling assumptions and results, including many sensitivity tests, can be found in the same report, but all four dams on the cascade have very small reservoirs in relation to annual inflow and sediment load. For such reservoirs, sluicing using bottom outlets can reduce trapping and pass sand and finer fractions past each dam.

A striking illustration of reservoir sediment trapping is seen in Photo 8.2, a satellite picture of the Sesan 2 reservoir in Cambodia showing incoming sediment from the Srepok River in February 2018, shortly before impoundment of the reservoir was completed. Incoming sediments were settling before reaching the dam. Sesan 2 is a relatively small reservoir, corresponding to 6 percent of mean annual inflow, but it has been assessed as technically not possible to flush (Annandale 2013).

Many existing and planned dams in the Sekong Basin have larger reservoirs (for example, Xe Kaman 1, Nam Kong 3, Houay Ho, and Xe Pian–Xe Namnoy) that will prevent sediment sluicing or flushing from having a significant mitigating effect.

This study assessed the potential of flushing the five reservoirs in the Sekong Basin with volumes up to 5 percent of annual inflow: Sekong Downstream A and B, Sekong 3A and 3B, and Nam Kong 2. Sediment transport increased by only 5 percent with flushing (Figure 8.4).

Figure 8.4: Transport of Medium-Sized Sediment in Sekong Downstream from the Lao People's Democratic Republic–Cambodian Border with and Without Sediment Flushing

Photo 8.2: **Satellite Picture of Lower Sesan 2 Reservoir, February 2018**

Photo credit: ©Multiconsult . Used with the permission of Multiconsult. Further permission required for reuse.

8.6.3 Minimizing Impacts on Aquatic Biodiversity

Fish passages should be considered for all dams but are likely to be feasible and effective only for small and medium-sized dams with a lower vertical head. Site-specific research is required to determine appropriate engineering designs that can support a diversity of fish species with realistic hydro-morphological properties (water depth and flow velocities) and accessibility from upstream and downstream. Because fish passages are always less effective than the natural situation, mitigation measures that reduce or re-allocate dams from the mainstream (as proposed in the conservative development pathway) are preferred over construction of dams with fish passages.

Environmental flow requirements need to be assessed for individual HPPs and for cascades, requiring analysis of all aspects of the flow (magnitude, frequency, timing, and quality) and how this can be optimized for aquatic and riparian ecosystems (World Bank 2018).

Community management and monitoring of reservoir fish stocks is important for long-term sustainability. If dam construction affects fish conservation zones (for example, when reservoirs flood them), new fish conservation sites should be established.

8.6.4 Social Impact Mitigation and Livelihood Restoration

The full development pathway will entail physical displacement and resettlement of approximately 12,600 additional people, who will, to a large degree, lose the land that has provided them with their livelihoods. Section 7.4 describes the extent of resettlement and displacement entailed by hydropower (and other) energy development.

One measure that could help mitigate social risks, including livelihood outcomes for resettlers and effects of in-migration on local communities, would be establishment of resettlement management units at the provincial government level. Present practice is for district government authorities to establish such units separately for each project in its jurisdiction. A permanent unit at the provincial level managing all large-scale infrastructure projects in the province and retaining a permanent staff would be better placed to mitigate cumulative social impacts that multiple projects in a basin or sub-basin would cause. Provincial resettlement committees could be mandated to monitor the livelihoods and food security status of resettled communities from all development projects within the province. Such a committee could also study availability of agricultural land for resettlement within the province to determine whether it is feasible to find good-quality resettlement land for the resettled people required to relocate under the full development pathway.

8.6.5 Environmental Offsets

If, despite appropriate mitigation measures, there are significant residual environmental effects, then offset measures should be identified and implemented. The principle is that protection of equivalent environmental values elsewhere may counterbalance unavoidable loss of environmental values. The Sekong Basin has rich forest habitats in the upper catchment that could be a focus for such an offset plan.

One approach could be to establish a joint fund for forest protection with financial contributions from all downstream hydropower projects. Contributions could be distributed based on agreed-on models (for example, per megawatt installed, per kilowatt-hour of electricity produced annually, per reservoir area lost to impoundment, or per annual inflow volume), but contributions should be mandatory and ring-fenced specifically for the protected area.

8.7 Mitigation During Construction and Operation

Construction sites in remote areas have effects that can be reduced but not avoided. Environmental mitigation measures during construction include requiring the contractor to finalize, submit, and implement the environmental monitoring and management plan drafted during the detailed design phase.

To achieve a consistent approach, the government should impose environmental monitoring and management plan standards through the concession agreement. This plan should be required to include the following:

- Erosion and sediment control plan
- Spoil disposal plan
- Quarry management plan
- Water quality monitoring plan
- Chemical waste and spillage management plan
- Emergency plan for hazardous materials
- Emissions and dust control plan
- Noise control plan
- Physical cultural resources plan
- Landscaping and revegetation plan
- Vegetation clearing plan
- Waste management plan
- Reservoir impoundment management plan
- Environmental training for construction workers plan
- On-site traffic and access management plan
- Explosive ordnance survey and disposal plan
- Construction work camp and spontaneous settlement area plan

The operational phase of a hydropower project is the longest period of the project lifecycle but is often given too little attention in feasibility reports, ESIA reports, and detailed designs. During operations, the hydropower operator needs to be actively involved in catchment management activities, including those to minimize cumulative effects. Catchment management goals should include minimization of upstream or downstream changes that might affect (joint) HPP operations. The operator needs to be aware of risks associated with new developments that might be linked to the creation of impoundment, such as water quality risks associated with increased runoff from agricultural or industrial discharges or *in situ* activities such as aquaculture. Catchment management also needs to include development and maintenance of communication systems to alert communities regarding potential for extreme flows or other unusual events (for example, sediment flushing).

Over the decades, operations will need to adapt to changing conditions associated with climate change and changes to electrical transmission systems or energy markets. Development of upstream, downstream, or tributary hydropower projects can also lead to the need for altering operations. These future unknowns highlight the need for ongoing monitoring flexibility with respect to environmental mitigation measures.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 A Dynamic Baseline: the Present Situation

The Sekong Basin has undergone environmental and social changes in recent years because of hydropower, other infrastructure developments, and population growth. It is a dynamic situation even in the absence of further renewable energy development that is proposed over the next decade. In 2010, the Sekong Basin had a virtually undisturbed river system with no barriers to fish migration and very little flow regulation. The Houay Ho hydropower plant (HPP) was the only one in the entire basin. Substantial hydropower development has taken place during the past decade, and several projects are under construction, including the Xe Pian–Xe Namnoy, Nam Kong 1, and Nam Kong 3.

The present situation can be summarized as follows:

- The Sekong mainstream provides a long distance of unrestricted river flow that makes it accessible to long-distance Mekong migratory fish.
- The Sekong mainstream has no reservoirs, which enables sediment transport downstream to the Sekong floodplain and further to the Mekong.
- Since the impoundment of the Lower Sesan 2 dam and reservoir in Cambodia, sediment transport has been interrupted from the other two rivers (Sesan and Srepok) of the Sekong, Sesan, and Srepok (3S) basin. The two rivers no longer make significant contributions to the Mekong.
- Apart from the trans-catchment water transfer from the A Luoi dam to the Bo River in Vietnam, no hydropower dams or reservoirs affected the mainstream Sekong River and its northern tributaries.
- Construction of four dams and a large reservoir providing seasonal regulation of the flows passing down the Xe Kaman has heavily altered the Xe Kaman tributary basin. This has also interrupted sediment flows, with only a reduced fine silt fraction passing downstream of the Xe Kaman–Sanxay Dam, although it is still possible for migrating fish from the Sekong and the Mekong to reach the Xe Xou and Nam Pa tributaries, whereas construction of several dams in cascade has fragmented the Xe Kaman mainstream and Nam Kong River.
- The Xe Pian and Xe Nam Noy tributaries have had their flows radically altered and water transferred directly to the Sekong River through new power plants. Flows along the natural courses of these tributaries have been reduced substantially, perhaps most noticeably by reduced frequency and magnitude of floods because of the high regulating volume of the Xe Namnoy and Houay Ho reservoirs.
- New roads have been constructed to the uppermost dam site, Nam Kong 3, and to the various dam sites along the Xe Kaman. Roads to the new dams and diversion dams on the Bolaven Plateau have opened access to its resources, but road access north along the main Sekong River remains difficult, especially in the wet season.
- The Houay Lamphan Gnai HPP is the only Sekong Basin power project providing power exclusively to the local grid. Most existing hydropower projects are export orientated. Transmission lines have been constructed from hydropower projects in the Xe Kaman and Nam Kong sub-basins to the Vietnam border. A 220-kilovolt transmission line runs from the Xe Pian–Xe Namnoy project to Thailand.
- Forests face multiple pressures, including hydropower, new roads, agriculture, and mining. Mining is concentrated in the Xe Kaman sub-basin (Map 3.6), but exploration permits have been issued covering most of the basin, so mining may significantly affect land use change in the future.
- The basin has no wind or solar energy projects.

9.2 Alternative Development Pathways

This study has assessed three alternative development pathways:

- *Full development pathway*, with 23 additional projects operational by 2030
- *Conservative development pathway*, with 18 additional projects by 2030
- *Intermediate development pathway*, with 23 additional projects by 2030

Table 9.1 summarizes the characteristics of the three development pathways assessed in this report, including some key parameters relevant to assessment of cumulative impacts. Figure 9.1 illustrates the difference in power-generating capacity of each development pathway.

9.3 Power Generation and Revenue Forecasts

The conservative development pathway would generate approximately 9.7 terawatt-hours (TWh) of power annually (57 percent more than the present situation) (Figure 9.1), the intermediate development pathway would generate 11.9 TWh (94 percent more annually), and the full development pathway would generate 14 TWh (129 percent more) a year.

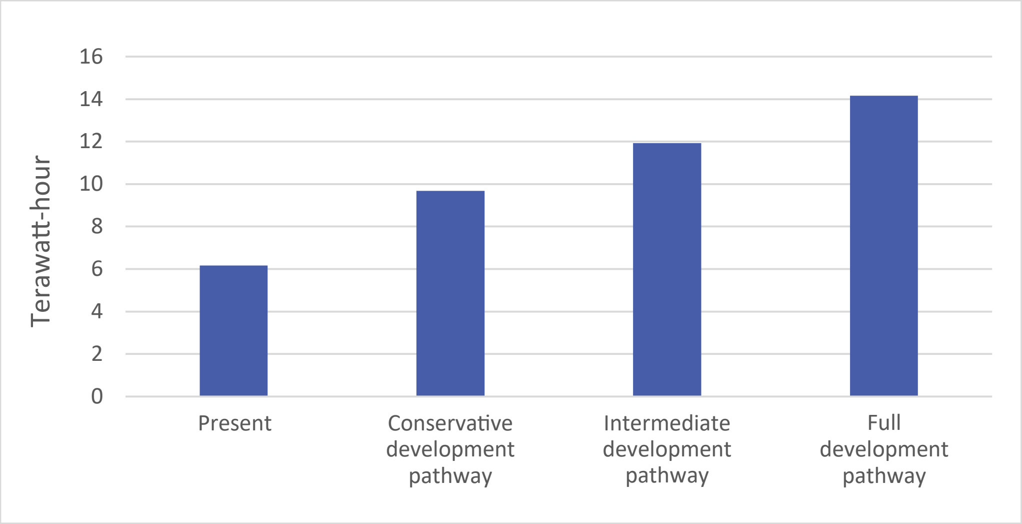
Table 9.1: Summary of Characteristics of Alternative Pathways

Development pathway	Active reservoir volume (hm³)	Installed capacity (MW)	Annual generation (TWh)[a]	Total reservoir area (km²)	Population resettled persons	Sediment load into Cambodia (tons/y)	2006 peak flood into Cambodia (m³/s)	Number of dams on Sekong mainstem	Km of free run to headwater of Sekong
Present	3,928	1,554	6.16	224	14,500	3.7	3,453	0	410
Conservative	4,985	2,470	9.68	260	16,700	3.7	3,380	0	410
Intermediate	6,310	2,975	11.93	306	18,000	2.9	3,130	2	306
Full	6,881	3,512	14.13	382	26,900	1.7	3,084	7	68

Note: hm³ = million cubic meters; MW = megawatts; TWh = terawatt-hours; km² = square kilometers; tons/y = tons per year; m³/s = cubic meters per second; km = kilometer.

[a] The full development, conservative, and intermediate pathways also include an estimated additional 3.0 TWh per year of solar and wind energy.

Figure 9.1: Annual Electricity Generation Under Different Development Pathways



In Lao PDR, most hydropower projects are private investments built on a 30-year build-operate-transfer model, after which project ownership is transferred to the state. In the longer term, Sekong Basin hydropower projects will become valuable assets for the Lao PDR government and continue to generate revenue for their operational life. In the short term, projects contribute to government revenue through royalties on electricity sales, taxes, and government equity shares.

9.4 Cumulative Impacts

The three pathways will have different degrees of environmental and social impacts and risks.

The full development pathway will have large impacts on certain valued environmental components (VECs), especially fish, livelihoods that rely on river fisheries and agriculture, or are affected by resettlement. Bank and bed erosion may increase in alluvial parts of the river, and less variability in river levels and smaller loads of nutrient-rich silt will restrict vegetable horticulture. Harvests from floodplain fisheries will probably fall, with some years seeing no floodplain inundation at all. The full development pathway is likely to come at the cost of loss of unique, highly valued biodiversity. Social costs will be in the form of resettlement of several thousand people.

The conservative development pathway, which excludes the seven mainstream projects, will entail hydropower development on a smaller scale and at a slower pace but will still provide a significant boost to the local and national economy. Assessment of the conservative development pathway indicates few notable additional impacts from the present situation, especially with regard to the Sekong mainstream, although local impacts will be experienced in the tributaries.

The intermediate development pathway will have more impacts on some VECs, especially as a result of development of Sekong 4B and 5. Overall, impacts will be less than under the full development pathway but greater than the conservative development pathway. Table 9.2 synthesizes the cumulative impacts on VECs under alternative pathways.

Table 9.2: Summary of Cumulative Impacts on Valued Environmental Components for Each Pathway

VEC	Full development	Intermediate development	Conservative development
Aquatic habitats and biodiversity	🟠 Large reduction in aquatic biodiversity due to disruption of migratory routes and inundation of riparian habitats important for spawning and feeding	🟡 Moderate impact on aquatic biodiversity because of fragmentation of Sekong tributaries; fish migration to and from the Mekong supports continued connectivity along most of the Sekong mainstem	🟢 Little impact on aquatic biodiversity because connectivity is maintained along the full length of the Sekong mainstem and several tributaries to support fish migration to and from the Mekong
Terrestrial habitats and biodiversity	🟡 Moderate impact on terrestrial biodiversity because of impacts on forests and protected areas	🟡 Moderate impact on terrestrial biodiversity due to impacts on forests and protected areas	🟢 Little impact on terrestrial habitats and biodiversity—important protected areas avoided
Natural resource–dependent livelihoods	🟠 Large adverse impact on livelihoods, particularly agriculture, fisheries, and resettlement	🟡 Moderate impact on livelihoods, particularly resettlement	🟢 Little impact on livelihoods overall but significant for directly affected communities
Society and culture	🟡 Moderate impact on culture and heritage, particularly because of resettlement	🟢 Mixed impact on culture and heritage—adverse and beneficial	🟢 Mixed impact on culture and heritage—adverse and beneficial

9.5 Mitigation

Mitigation measures discussed here refer to future hydropower projects rather than projects already built. There is generally limited scope to modify hydropower projects after they have been built or even after detailed designs have been completed; the technical challenges and financial costs involved tend to be prohibitive.

All three development pathways require similar mitigation measures, although the magnitude of the interventions will vary in proportion to the intensity of the development. Key measures (as detailed in Section 7.5) include the following:

- Engineering design features, including gates at different levels and regulating ponds
- Joint and coordinated management of environmental flows (EFlows) and sediment flushing
- Incorporation of fish passages on main migration routes where technically feasible
- Reservoir fisheries programs (native species) that prioritize benefits for affected communities
- Catchment protection measures including reforestation and patrols to prevent illicit harvesting of forest products
- Creation of biodiversity offsets focused on support for protected areas with equivalent conservation values and biological corridors for wildlife migrations
- Carefully designed and fully resourced resettlement plans and community developments, considering risks and opportunities related to gender and ethnicity
- Livelihood restoration through the provision of replacement agricultural land and introduction of new income-generating activities, including off-farm activities

9.6 Recommendations

The findings of this study indicate the need for a Sekong Basin power development master plan incorporating renewable energy (hydropower, solar, and wind) as well as thermal power. Private sector interests have largely directed past developments in the basin on a first-come, first-served basis. The government should establish the trajectory of future development based on a strategic assessment of local and regional power demand and with consideration of the range of potential uses of natural resources in the basin. This approach would result in greater investment efficiency, a close match between power production and demand, and more opportunities to address adverse impacts through the full range of options available in the mitigation hierarchy. A master plan would be consistent with the 2017 Electricity Law, which requires power development planning on a five-year cycle, and the 2017 Law on Water Resources, which requires basin planning.

Important considerations for a Sekong Basin power development plan include the following:

- *Power demand*: up-to-date, realistic domestic and regional demand forecasts taking into account power development plans of neighboring countries, bilateral agreements (for example, memoranda of understanding), and a trend of rapid diversification of renewable energy solutions
- *Integrated water resources management*: incorporating integrated water resources management to ensure that needs and interests of multiple stakeholders in the basin are accommodated
- *Cumulative impacts*: environmental and social cumulative impacts as elaborated in this study
- *Avoidance by design*: reducing environmental and social impacts by modifying designs of particular projects (for example, Sekong 4A)
- *Trade-offs*: reaching a rational balance between economic benefits of power generation, adverse environmental and social impacts (particularly residual impacts and risks that cannot be fully mitigated), and opportunity costs of alternative natural resource uses foregone
- *Optimization*: achieving power generation enhancements and investment efficiencies by optimizing design and operating rules of hydropower cascades and in other circumstances where optimization benefits exist
- *Grid development*: shared transmission lines among power projects to reduce construction costs, improve grid efficiency, and reduce environmental and social impacts; co-funding by developers of transmission lines and cross-border interconnectors using this infrastructure
- *Integrating solar and wind*: identification of transmission grid and power supply and demand management improvements so that other renewable energy sources can

be absorbed into the power system while maintaining balance

This master plan would provide parameters within which individual projects would be designed, assessed, and approved. Project proponents would need to integrate mitigation measures identified in the master plan into feasibility studies and environmental and social impact assessments.

This study has identified several opportunities for coordination and collaboration during the operation of renewable energy projects. A simple, practical co-management platform should be established to promote coordination among hydropower operations and to implement collaborative measures to mitigate cumulative impacts. Examples of opportunities for coordination among power developers in the Sekong Basin include the following:

- *Coordinated environmental and social mitigation measures*: pooled funding and management arrangements for catchment protection, environmental offsets, and resettlement
- *Coordinated and joint operations*: information exchange and coordination among plant operators within the Sekong Basin, especially for dams in cascades on the same tributaries and within sub-basins to maintain EFlows and fish migration
- *Coordinated flood monitoring and warnings*: sharing hydrological data, collaborating on flood risk forecasting and preparedness, and establishing a warning system to notify local authorities and local communities of flood risks
- *Coordinated dam safety analyses*: cooperation of operators of cascading projects and pooling of resources to assess dam safety risks

Master planning and coordinated power operations will require that data and information gaps be addressed. Some priority areas for data, information, and analysis are summarized as follows:

Hydrological modeling

- Hydrological and meteorological monitoring data from existing hydropower projects should be collated and analyzed to enable precise calibration of the basin hydrological model developed for this study using satellite rainfall records.
- Meteorological and water gauging stations should be installed throughout the basin to provide a more complete set of measured data.
- Future climate change and hydrological models developed for the Sekong Basin should be made available to developers and government agencies responsible for planning, regulating, and monitoring hydropower development.

Sediment management

- The effectiveness of joint flushing and sluicing in cascades on the Sekong mainstream and tributaries should be further studied.
- Sediment load should be measured within the Sekong Basin to provide empirical data for the design of effective flushing, sluicing, and other management options.

Hydropower operating rules

- Hydropower modeling of the type conducted for this study can be refined with additional information about the operating rules of individual dams, improving the accuracy of the model, and enhancing the effectiveness and benefits of joint operation of cascades in the tributary systems.

Fish passages

- More empirical data on the efficacy of fish passages in the Lower Mekong Region are needed. Data will soon become available from the Xayaboury HPP on the Mekong mainstream, which incorporates several fish passage design features.

EFlows

- A study to determine an appropriate EFlow regime for the entire Sekong Basin is needed.

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APPENDIXES ON SUPPORTING ANALYSIS

TABLE OF CONTENTS

APPENDIX A
DATA ON DAMS AND HYDROPOWER PLANT PROJECTS, SCREENING, AND MULTICRITERIA ANALYSIS

A.1 List of Projects

Table A.1 lists all hydropower projects used in the cumulative impact assessment with the most important data. Twelve projects are completed, and five are under construction. It is believed that the remaining 18 projects are not committed yet.

Table A.1: Hydropower Projects in Cumulative Impact Assessment

Developer	Project name	Status	Date of commercial operation	Capacity (MW)	Annual energy (GWh)	Active storage (m^3)
Not known	A Luoi	Commissioned	2012	170	650	60
Not known	Houay Ho	Commissioned	1999	152	450	527
Vietnam-Laos Power Joint Stock Company	Xe Kaman 3	Commissioned	2013	250	980	109
Chaleun Sekong Energy Co. Ltd.	Xe Namnoy 6	Commissioned	2013	5	20	0
Chaleun Sekong Energy Co. Ltd.	Xe Namnoy 1	Commissioned	2014	15	80	0
Électricité du Laos	Houay Lamphan Gnai	Commissioned	2015	88	450	141
Vietnam-Laos Power Joint Stock Company	Xe Kaman 1	Commissioned	2016	290	1,040	1,683
Vietnam-Laos Power Joint Stock Company	Xe Kaman–Sanxay	Commissioned	2017	32	110	0
Chaleun Sekong Energy Co. Ltd.	Nam Kong 2	Commissioned	2017	66	260	29
B. Grimm Power Public Company Ltd.	Xe Namnoy 2–Xe Katam 1	Commissioned	2017	22	120	0
Xe-Pian Xe-Namnoy Power Co., Ltd.	Xe Pian–Xe Namnoy	Commissioned	2019	410	1,800	908

Developer	Project name	Status	Date of commercial operation	Capacity (MW)	Annual energy (GWh)	Active storage (m^3)
Chaleun Sekong Energy Co. Ltd.	Nam Kong 3	Commissioned	2020	54	200	471
Chaleun Sekong Energy Co. Ltd.	Nam Emoun	Committed	2022	129	430	1
Électricité du Laos (	Nam Bi 1	Committed	2024	68	290	unknown
Électricité du Laos	Nam Bi 2	Committed	2024	50	210	unknown
Électricité du Laos	Nam Bi 3	Committed	2024	12	50	unknown
Chaleun Sekong Energy Co. Ltd.	Nam Ang	Candidate	2024	55	160	0
Électricité du Laos	Xe Kaman 2A	Candidate	2030	64	250	4
Électricité du Laos	Xe Kaman 2B	Candidate	2030	100	380	217
Vietnam-Laos Power Joint Stock Company	Xe Kaman 4A	Candidate	2030	70	290	14
Vientiane Automation and Solution Engineering	Nam Pangou	Candidate	2025	33	140	20
Vientiane Automation and Solution Engineering	Dakchaliou 1	Committed	2021	11	50	0
Vientiane Automation and Solution Engineering	Dakchaliou 2	Committed	2021	13	60	0
RAO	Sekong 5	Candidate	2030	330	1,500	1,145
Ratch Lao	Sekong 4B	Candidate	2026	175	750	180
Ratch Lao	Sekong 4A	Candidate	2025	165	780	460
AICS	Sekong 3A	Candidate	2027	114	460	12
AICS	Sekong 3B	Candidate	2028	122	400	55
V&H Corporation (Lao) Ltd.	Sekong Downstream B	Candidate	2030	50	210	9
V&H Corporation (Lao) Ltd.	Sekong Downstream A	Candidate	2030	86	380	35

Developer	Project name	Status	Date of commercial operation	Capacity (MW)	Annual energy (GWh)	Active storage (m^3)
China International Water & Electric Co.	Nam Kong 1	Committed	2022	150	560	505
Not known	Xe Namnoy 5	Candidate	2030	20	90	10
Not known	Xe Pian–Houaysoy	Candidate	2025	45	200	285
Not known	Xe Katam	Candidate	2030	81	300	0
Vientiane Automation and Solution Engineering	Lower Xe Pian	Candidate	2030	15	60	0
			TOTAL:	**3,512**	**14,160**	**>6,880**

Note: MW = megawatt; GWh = gigawatt-hour; m^3 = cubic meters.

Information about each hydropower project was sourced mainly from feasibility studies and environmental impact assessment reports (Table A.2). As-built project specifications may vary slightly because there are often alterations in parameters during negotiations for power purchase agreements, licenses, and financing.

Small hydropower projects planned for the Sekong Basin are not included in the analysis because they are mostly run-of-river projects that cause little if any alteration in flows downstream.

Table A.2: List of Sources of Information about Hydropower Projects in the Sekong River Basin

Hydropower project	Main sources of information
Nam Emoun	Company webpage https://csenergy.la/our-business/hydropower-plants/power-plants-under-construction/nam-emoun/?lang=en
Houay Lamphan Gnai	Company webpage http://www.edlgen.com.la/project/houaylamphanhgnai-hydro-power-plant
Nam Kong 1	Feasibility study summary report (2010)
Nam Kong 2	Company webpage https://csenergy.la/our-business/hydropower-plants/power-plants-in-operation/nam-kong-2/?lang=en
Nam Kong 3	Company webpage https://csenergy.la/our-business/hydropower-plants/power-plants-in-operation/nam-kong-3/?lang=en
Nam Bi 1	No information available

Hydropower project	Main sources of information
Nam Bi 2	No information available
Nam Bi 3	No information available
Nam Ang	Company webpage https://csenergy.la/our-business/hydropower-plants/power-plants-under-development/nam-ang/?lang=en
Xe Kaman 1	Xe Kaman 1-4 feasibility study summary (no date)
Xe Kaman 2A	Xe Kaman 1-4 feasibility study summary (no date)
Xe Kaman 2B	Xe Kaman 1-4 feasibility study summary (no date)
Xe Kaman 3	Xe Kaman 1-4 feasibility study summary (no date)
Xe Kaman 4	Feasibility study summary report (2017)
Xe Kaman–Sanxay	Xe Kaman 1-4 feasibility study summary (no date)
Nam Pangou	Company webpage http://vaselaos.com/nampangou.htm
Dakchaliou 1	Company webpage http://vaselaos.com/dakchaliou1.htm
Dakchaliou 2	Company webpage http://vaselaos.com/dakchaliou2.htm
Houay Ho	Feasibility study summary report (2011)
Xe Namnoy 1	Company webpage https://csenergy.la/our-business/hydropower-plants/power-plants-in-operation/xe-nam-noy-1/?lang=en
Xe Namnoy 2–Xe Katam 1	Turbine manufacturer's webpage https://www.global-hydro.eu/en/news/press/
Xe Namnoy 6	Project Design Document version 05.0
Xe Katam	Executive summary Xe Katam Hydropower Project, Design Option No 2 (2015)
Xe Pian–Xe Namnoy	Environment and social impact assessment summary report (2011) Feasibility study (2007) Company webpage http://www.pnpclaos.com/index.php/en/project
Lower Xe Pian	Company webpage http://vaselaos.com/lower-xepian.htm
Sekong Downstream A	Feasibility study summary report (2011) HPP summary table, Ministry of Energy and Mines (10/29/2018)
Sekong Downstream B	Feasibility study summary report (2013) HPP summary table, Ministry of Energy and Mines (10/29/2018)
Sekong 3B	Feasibility study summary report (2017) HPP summary table, Ministry of Energy and Mines (10/29/2018)

Hydropower project	Main sources of information
Sekong 3A	Feasibility study summary report (2017) HPP summary table, Ministry of Energy and Mines (10/29/2018)
Sekong 4A	Feasibility study 4A & 4B summary report (2017) HPP summary table, Ministry of Energy and Mines (10/29/2018)
Sekong 4B	Feasibility study 4A&4B summary report (2017) HPP summary table, Ministry of Energy and Mines (10/29/2018)
Sekong 5	Feasibility study summary report (2016) HPP summary table, Ministry of Energy and Mines (10/29/2018)
A Luoi	http://icon.com.vn/en-s83-98943-576/Speed-up-progress-rate-of-A-Luoi-hydropower-project.aspx
Xe Namnoy 5	No information available
Xe Pian-Houaysoy	No information available

Note: HPP = hydropower project

A.2 Project Data Screening

To ensure that the study used realistic figures for key parameters in the analysis, project data were screened; the results are summarized in Table A.3 and Table A.4. This screening is based on rules of thumb for parameters such as installed capacity, plant-use factor, energy output compared with annual inflow, and reservoir size. The cost of each project was also compared with the costs of other projects and construction costs in the Mekong region.

The results of this screening show relatively consistent planning and design principles. For example, because projects have been designed independently of each other without coordinated and integrated reservoir operation strategies, the preference has been for seasonal reservoirs in most projects, rather than a cascade of dams with a large upstream reservoir providing seasonal regulation for power plants downstream. In addition, the larger projects are optimized for maximization of income from power exports according to power purchase agreements with Thailand and Vietnam. The destination power systems in Thailand and Vietnam require hydropower to meet periods of peak demand (for example, weekday evenings). Such agreements also define “firm energy,” which is a guaranteed supply from the developer. If this is not supplied as agreed, there is a heavy financial penalty, which leads each developer to build large reservoirs to ensure that each has sufficient seasonal storage to guarantee firm energy commitment through the dry season in a dry year.

The government’s dam safety review, which was ongoing when this report was being drafted, is not expected to materially affect the pathway descriptions or cumulative impact assessment analysis results in this study, but they may affect project cost. The extra cost of bringing certain projects to standard, for example, in providing extra spillway gates and larger capacity for future floods, may make some already marginally economical projects less economical, possibly resulting in a few projects being redesigned, delayed a few years, or even shelved indefinitely.

Table A.3: Key Technical and Hydrologic Data for Each Project

Project name	Date of completion	Catchment area (km²)	Mean annual inflow (m³/s)	Design flow (m³/s)	Percentage of average flow	Median head (m)	Active reservoir volume (m³)	Installed capacity (MW)	Percentage of theoretical capacity[a]	Generation (GWh per year)	Percentage of theoretical generation[a]
Nam Emoun	2022	462	21	37	**179**	397	1	129	**103**	430	**68**
Houay Lamphan Gnai	2015	237	11	19	**170**	529	122	88	**100**	450	**99**
Nam Kong 1	2022	1,250	42	88	**210**	190	505	150	**105**	560	**89**
Nam Kong 2	2017	861	37	76	**208**	99	31	66	**103**	260	**94**
Nam Kong 3	2020	646	29	61	**210**	101	471	54	**103**	200	**89**
Nam Bi 1	2024	285	11	23	**200**	285		68	**97**	290	**97**
Nam Bi 2	2024	105	9	17	**200**	105		50	**100**	210	**96**
Nam Bi 3	2024	111	4	9	**200**	111		12	**99**	50	**95**
Nam Ang	2024	200	9	19	**209**	338	0	55	**103**	160	**69**
Xe Kaman 1	2016	3,580	149	337	**226**	104	1,683	290	**97**	1040	**93**
Xe Kaman 2A	2030	1,970	78	172	**222**	49	4	64	**89**	250	**99**
Xe Kaman 2B	2030	1,740	68	153	**224**	82	217	100	**94**	380	**97**
Xe Kaman 3	2013	712	30	62.3	**211**	450	109	250	**104**	980	**94**
Xe Kaman 4	2030	216	10	20	**202**	431	14	70	**97**	290	**96**
Xe Kaman-Sanxay	2017	3,740	152	378	**249**	10	0	32	**99**	110	**98**
Nam Pangou	2025	446	20	37	**184**	104	20	33	**100**	140	**89**
Dakchaliou 1	2021	170	7	14	**196**	95	0	11	**97**	50	**102**
Dakchaliou 2	2021	125	5	10	**190**	150	0	13	**102**	60	**100**
Houay Ho	1999	192	10	22	**232**	748	527	152	**108**	450	**78**
Xe Namnoy 1	2014	436	20	24	**122**	75	0	15	**96**	80	**75**
Xe Namnoy 2–Xe Katam 1	2017	256	40	12	**104**	200	0	22	**107**	120	**65**
Xe Namnoy 6	2013	82	1.6	3	**198**	180	0	5	**102**	20	**90**
Xe Katam	2030	263	12	20	**168**	458	0	81	**104**	300	**71**
Xe Pian–Xe Namnoy	2019	820	40	80	**199**	630	908	410	**95**	1,800	**100**
Lower Xe Pian	2030	789	32	70	**190**	25	0	15	**99**	60	**103**
Sekong Downstream A	2030	18,960	796	1,105	**139**	9	35	86	**101**	380	**70**
Sekong Downstream B	2030	9,594	399	688	**173**	8	9	50	**103**	210	**83**
Sekong 3A	2027	5,860	247	532	**216**	25	12	114	**100**	460	**100**
Sekong 3B	2028	8,700	335	900	**269**	16	55	122	**100**	400	**101**

Project name	Date of completion	Catchment area (km^2)	Mean annual inflow (m^3/s)	Design flow (m^3/s)	Percentage of average flow	Median head (m)	Active reservoir volume (m^3)	Installed capacity (MW)	Percentage of theoretical capacity[a]	Generation (GWh per year)	Percentage of theoretical generation[a]
Sekong 4A	2025	5,182	227	385	**170**	50	460	165	**100**	780	**92**
Sekong 4B	2026	3,211	132	220	**167**	94	180	175	**99**	750	**82**
Sekong 5	2030	2,518	125	204	**163**	193	1,145	330	**98**	1,500	**85**
A Luoi	2012	331	20	40	**202**	486	60	170	**102**	650	**88**

[a] Should be about 100 percent.

Note: m = meter; m^3 = cubic meter; km^2 = square kilometer; m^3/s = cubic meter per second; MW = megawatt; GWh = gigawatt-hour.

Table A.4: Other Information for Estimating Environmental and Social Footprint of Projects

Project name	Transmission voltage (kV)	Transmission line length (km)	Project cost ($ million)	Cost per GWh ($ million per annual GWh)	Reservoir area (km^2)	Resettlement number of persons	Persons resettled per annual energy generation (GWh)
Nam Emoun	230	51	142	0.33	0	0	0.0
Houay Lamphan Gnai	115	9	206	0.46	7	1,398	3.7
Nam Kong 1	230	41	178	0.32	22	1,612	2.9
Nam Kong 2	115	36	70	0.27	4	0	0.0
Nam Kong 3	115	14.5	68	0.34	32	104	0.5
Nam Bi 1			146	0.51		0	0.0
Nam Bi 2			108	0.51		0	0.0
Nam Bi 3			26	0.52		0	0.0
Nam Ang	115	25			0	0	0.0
Xe Kaman 1			539	0.52	82	342	0.3
Xe Kaman 2A			119	0.48	1	98	0.4
Xe Kaman 2B			158	0.42	9	0	0.0
Xe Kaman 3			311	0.32	5	342	0.3
Xe Kaman 4	115	12	153	0.53	1	0	0.0
Xe Kaman-Sanxay				0.36		0	0.0
Houay Ho	230	160	166	0.37	37	1,920	4.3
Xe Namnoy 1	115	32			0	0	0.0

Project name	Transmission voltage (kV)	Transmission line length (km)	Project cost ($ million)	Cost per GWh ($ million per annual GWh)	Reservoir area (km²)	Resettlement number of persons	Persons resettled per annual energy generation (GWh)
Xe Namnoy 2–Xe Katam 1					12	92	0.8
Xe Namnoy 6	115	12			0	0	0.0
Xe Katam	115	45	120	0.40	0	0	0.0
Xe Pian–Xe Namnoy	230	167	1,020	0.57	49	9,458	5.3
Sekong Downstream A					14	2,764	7.3
Sekong Downstream B	115	10	82	0.39	9	2,343	11.2
Sekong 3A	115	9	218	0.47	12	1,080	2.3
Sekong 3B	115	9	233	0.58	18	240	0.6
Sekong 4A	230	35	471	0.60	23	2,494	3.2
Sekong 4B	230	136	335	0.45	13	808	1.1
Sekong 5	230	60	765	0.51	33	440	0.3
A Luoi	230		202	0.31	8	872	1.3

Note: kV = kilovolt; km = kilometer; GWh = gigawatt-hour; km² = square kilometer.

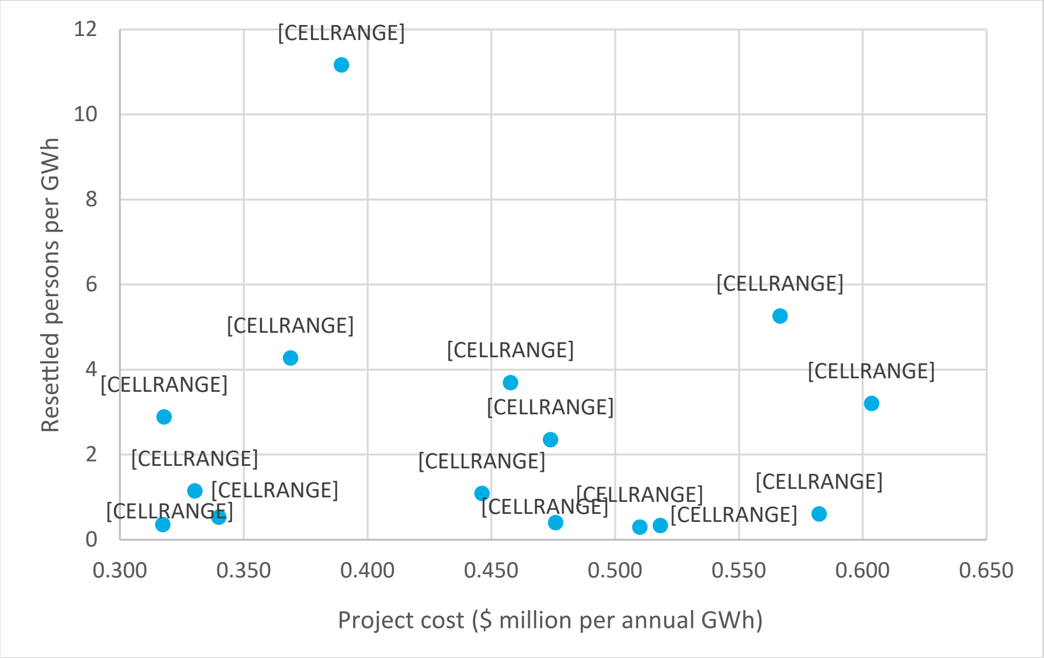
A.3 Multi-Criterion Ranking of Projects

A multi-criterion analysis was conducted to assess the technical and economic characteristics of each project and its environmental and social footprint. Such analysis was limited to available data and was therefore relatively simple. Figures A.1, A.2, and A.3 compare each project's footprint in terms of parameters such as land take and numbers of relocated people with the annual cost per gigawatt-hour as a measure of the economic efficiency of a project and a surrogate parameter for the levelized cost of energy.

The important part of this analysis is not the accuracy of the data and figures presented but the comparison of the projects that this technique provides, enabling us to identify which projects are more efficient without having to know the actual energy cost being negotiated in the power purchase agreement (which is not available for commercial reasons).

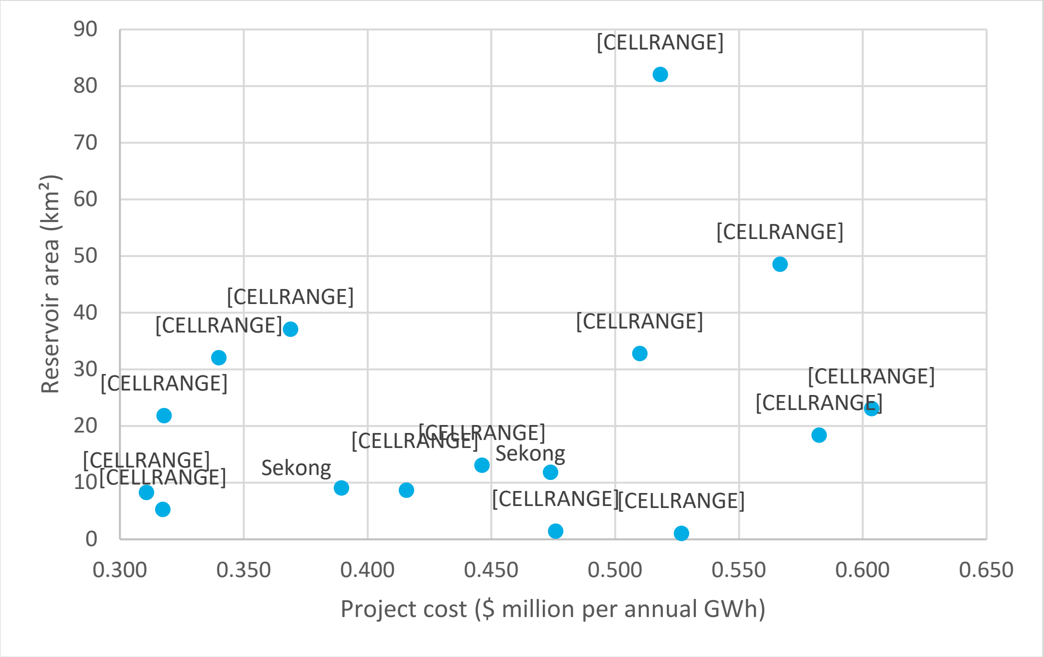
Project costs for some of the projects are uncertain because some cost estimates are from feasibility studies conducted up to 10 years ago. Projects with a high degree of uncertainty regarding cost include the Nam Kong projects and Sekong Downstream B.

Figure A.1: Resettled Persons per Gigawatt-Hour Versus Project Cost



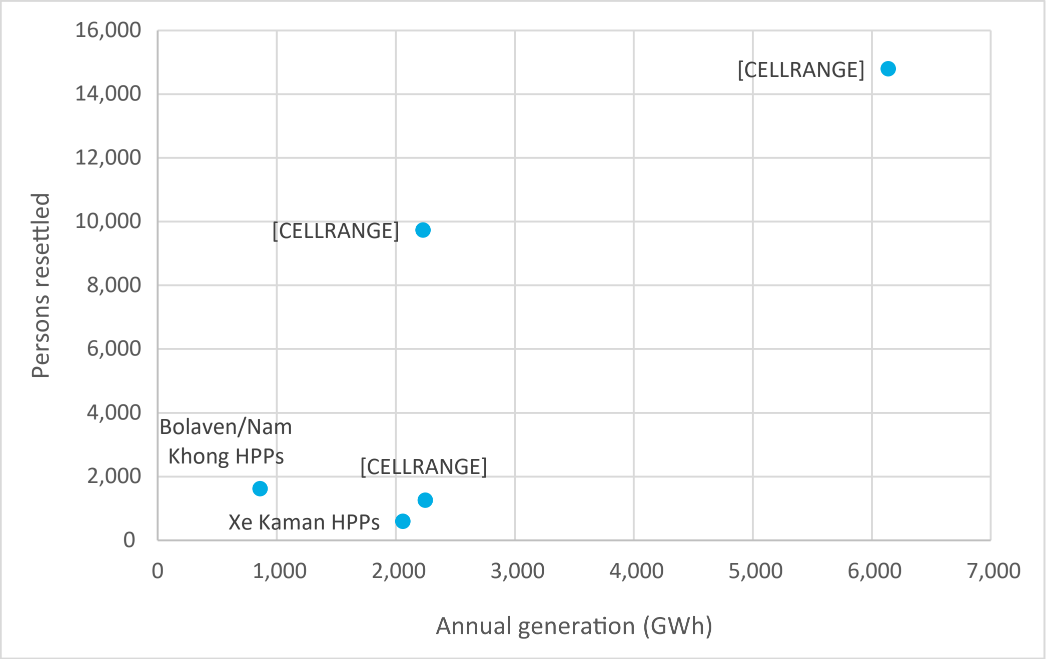
Note: GWh = gigawatt-hour.

Figure A.2: Reservoir Area Versus Project Cost



Note: km² = square kilometer; GWh = gigawatt-hour.

Figure A.3: Resettlement per Project Portfolio Versus Power Generation



Note: Completed 2020 is the project portfolio for present situation. GWh = gigawatt-hour.

The resettlement numbers are a combination of resettlement numbers in various environmental and social impact assessment reports and geographical information system analysis of affected villages and houses. Number of households recorded in resettlement reports were converted to persons by assuming an average of six persons per household. From the satellite imagery, individual houses were identified and the number of residents was estimated using average household size.

A.4 Clustering of Power Projects

The projects in the development pathways have been grouped into spatially defined clusters (Table A.5). The purposes of clustering power projects are to facilitate systematic, manageable analysis of the cumulative environmental and social effects of different power development pathways (see Chapter 5) for the Sekong Basin and to explore the benefits of joint operation of hydropower plants and management of water resources at the (sub)-basin level.

Existing and committed hydropower projects will easily meet Lao People's Democratic Republic's electricity demand until 2030, so new hydropower in the Sekong Basin will be for export to neighboring countries, particularly Thailand and Vietnam. Clusters were therefore selected to provide significant export capacity with minimal economic, environmental, and social costs and risks. A minimum size of 300 megawatts (MW) per cluster has been set as a reasonable limit.

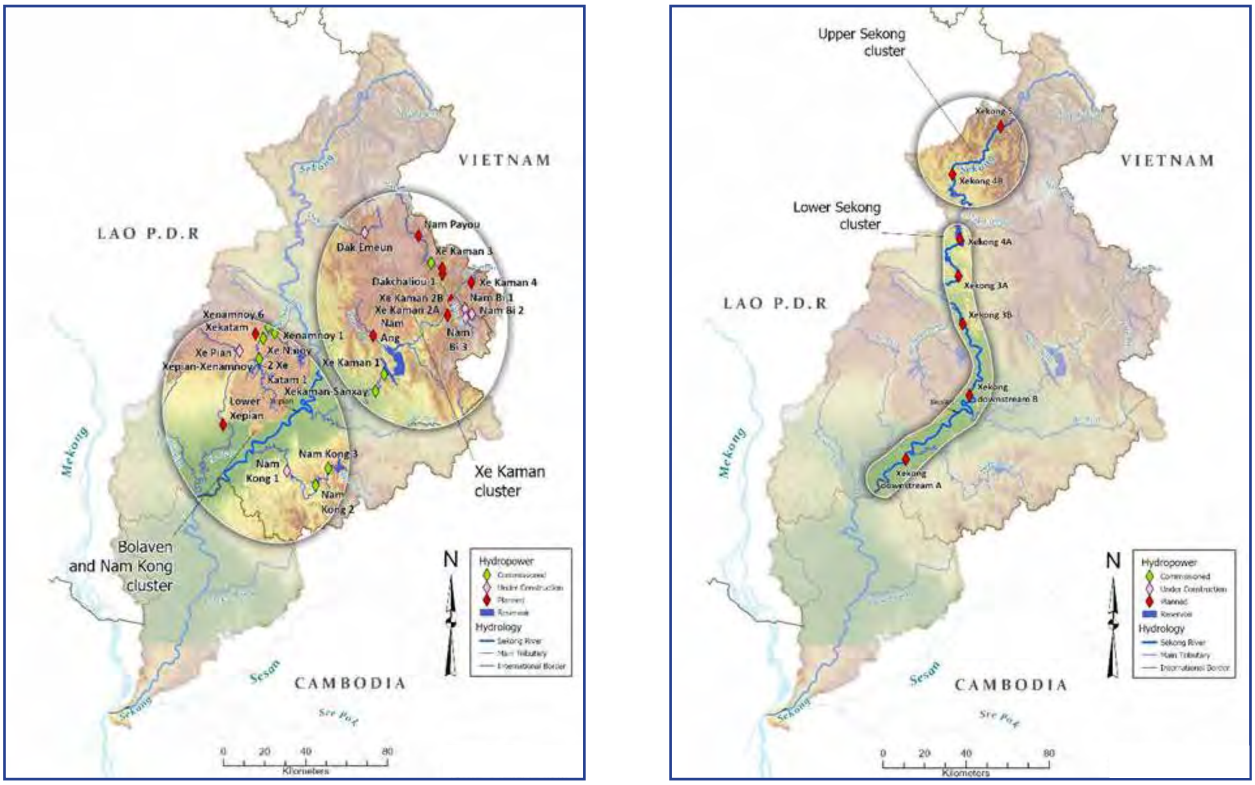
The hydropower project clusters are summarized in Table A.5, illustrated in Map A.1, and described in the subsequent sub-sections.

Table A.5: Project Clusters

Project name	Projects included	Installed capacity (MW)	Generation (% TWh per year)	Active reservoir volume (% m³)	Total reservoir area (km²)	Development pathway
Present situation	12 projects commissioned, as listed in Table A.1	**1,554**	6.16 (43)	3,928 (57)	224	
Upper Sekong cluster	Sekong 4B & 5	**505**	2.25 (16)	1,325 (19)	46	Full and intermediate
Lower Sekong cluster	Sekong 4A, 3A, 3B, Downstream A & B	**537**	2.20 (16)	571 (8)	76	Full
Xe Kaman cluster	Nam Emoun, Nam Bi 1,2,3, Nam Ang, Xe Kaman 2A, 2B, 4, Nam Pangou, Dachaliou 1,2	**605**	2.31 (16)	256 (4)	13	Full, conservative, and intermediate
Bolaven and Nam Kong cluster	Xe Katam, Xe Pian H Chot, Lower Xe Pian, Xe Namnoy 5, Nam Kong 1	**311**	1.21 (9)	800 (12)	23	Full, conservative, and intermediate
Totals	**35 projects**	**3,512**	**14.13**	**6,880**	**382**	

Note: MW = megawatt; TWh = terawatt-hour; m³ = cubic meter; km² = square kilometer.

Map A.1: Project Clusters



a. Tributary

b. Mainstream

A.4.1 Upper Sekong Cluster

This cluster comprises two large projects providing 505 MW, with a large seasonal reservoir (Sekong 5) located in the upper headwaters of the mainstream Sekong in a relatively remote part of the basin. Current access is by gravel road only, and the mountain region where these projects are located is sparsely populated. There are many mining concessions in the region, including coal mining that would be associated with a new coal-fired power plant near Kalum, also designed for power exports to Vietnam.

A.4.2 Lower Sekong Cluster

This cluster comprises a cascade of five large projects providing 537 MW, with several small reservoirs in cascade along the lower Sekong. These projects use lower heads, and the lowest projects in the cascade will have particularly low available heads in the flood season, when the river rises. The reservoirs will inundate some agricultural land along the banks of the mainstream Sekong and require resettlement of approximately 9,300 people.

A.4.3 Xe Kaman Cluster

This cluster comprises eight projects of varying size providing 605 MW, with only limited reservoir capacity for seasonal regulation, mainly at the Xe Kaman 2B site. All but one of these projects are located upstream of the large Xe Kaman 1 reservoir, which has already been impounded, and involve medium head use in tributary rivers near the border with Vietnam. Because of its proximity to Vietnam and the Xe Kaman sub-basin, the study includes in this cluster the Nam Emoun project on the Nam Emoun tributary, where construction recently started. Many of these projects can be accessed from the main highway linking Attapeu with Vietnam by short access roads. There is some need for resettlement, and there are some forest conservation areas in the catchment.

A.4.4 Bolaven and Nam Kong Cluster

This cluster comprises four projects providing 311 MW, with one seasonal reservoir at Nam Kong 1. It includes hydropower resources in the lower part of the Sekong Basin not yet committed or finalized. The cluster consists of projects with lower economic efficiency remaining in three tributary rivers—Nam Kong, Xe Pian, and Xe Namnoy—after the more profitable projects have been constructed. The economic return on these projects is likely to be low.

APPENDIX B
SEKONG BASIN HYDROLOGY AND FUTURE CLIMATE SCENARIOS

B.1 Approach and Methodology

B.1.1 Overall Approach

Data modeling undertaken for this study is summarized in Figure B.1 and described in Chapter 1, Section 1.2.5. Daily rainfall data over a 24-year period was fed into a U.S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS) hydrological model together with climate change data. The results of this model provide inputs to a Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) model, which is used to assess effects on ecological values, sediment, and floods.

B.1.2 Climate Change Modeling and Assessment

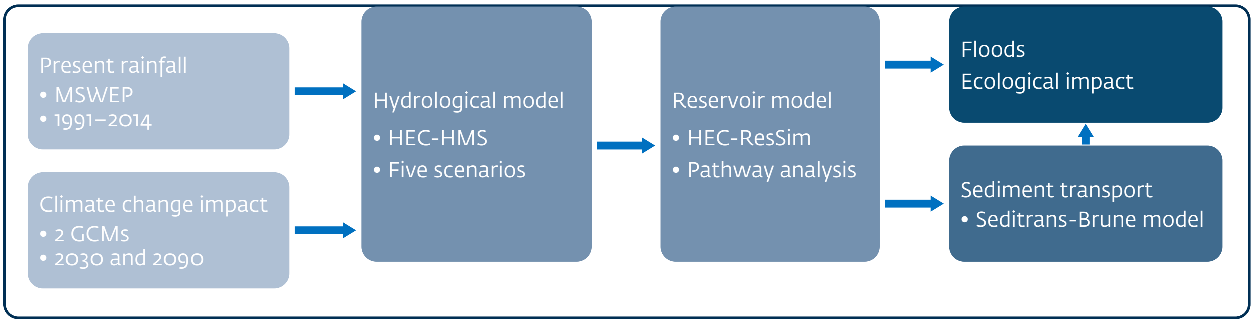
The climate change assessment started with an evaluation of information available from former projects and reports. In particular, several relevant Mekong River Commission (MRC) initiatives were identified.

- The MRC is working on the Mekong Adaptation Strategy and Action Plan, which includes a climate impact analysis and covers the entire Mekong Basin.
- The MRC is starting small local and regional adaptation initiatives that are in line with the Mekong Adaptation Strategy and Action Plan.
- Potential climate change effects on the basin, and more specifically the hydropower sector, are discussed in the MRC Basin Development Strategy 2016–2020 (MRC 2016b).

In support of the Mekong Adaptation Strategy and Action Plan, an extensive climate impact analysis based on general circulation model (GCM) simulations that contributed to the International Panel on Climate Change fifth assessment report (IPCC 2014) was conducted for the entire Mekong Basin. The future changes that the GCMs simulated are based on representative concentration pathways (RCPs) that belong to pre-defined emission scenarios (Van Vuuren et al. 2010). The MRC focused on RCP4p5 and RCP8p5:

- RCP4p5: representing moderate change with a global average temperature increase of 2°C by the end of this century; radiative forcing stabilizes before 2100 because of the introduction of technologies and strategies that reduce greenhouse gas emissions
- RCP8p5: representing extreme change with a global average temperature increase of 4°C by the end of this century; there is continuously increasing radiative forcing

Figure B.1: Modeling Chain for Impact Analysis



Note: MSWEP = multi-source weighted-ensemble precipitation; GCM = general circulation model; HEC-HMS = Hydrologic Engineering Center, Hydrologic Modeling System; Hec-ResSim = Hydrologic Engineering Center, Reservoir System Simulation.

From all available scenarios, three combinations of GCMs and RCPs were chosen, representing the following changes in conditions: wetter throughout the year, less rain in the dry season, and drier throughout the year. These scenarios were run through a basin-wide soil and water assessment tool hydrological model.[1] The results showed large variations in projected flows, on the order of –20 percent to +20 percent in annual average discharge, and thus there was a large variation in the effect on the hydropower sector as well. Adverse effects were shown to be greatest in the Sekong, Sesan, and Srepok river basins because of decreases in food security and decreasing water availability as the region depends greatly on crops and fishing.

For the Sekong cumulative impact assessment, the study followed an approach for the climate impact assessment similar to that of the MRC. The study used the datasets from the GCM simulations that support the International Panel on Climate Change fifth assessment report as inputs to a HEC-HMS model set up for the Sekong Basin because this enabled a more precise assessment of the effect of climate change on the flow characteristics of the Sekong River.

Data were obtained from the Inter-Sectoral Impact Model Intercomparison Project, which developed future climate change projections by bias-correcting the output of GCM simulations. The Inter-Sectoral Impact Model Intercomparison Project data portal[2] contains open data for four GCMs—Geophysical Fluid Dynamics Laboratory (GFDL)-ESM2M, Institut Pierre Simon Laplace (IPSL)-CM5A, Met Office Unified Model HadGEM2-es, and the Norwegian Climate Center Earth System Model-m—for 2006 to 2100.

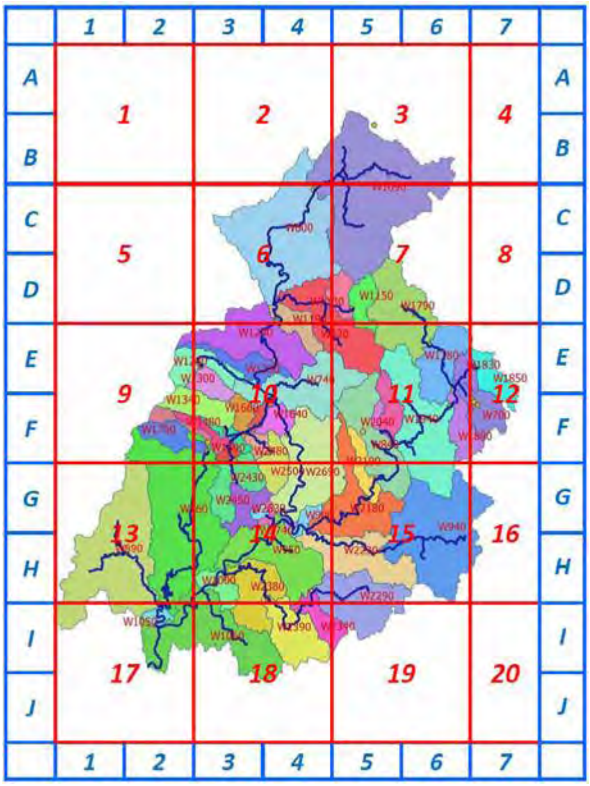
Future precipitation time-series data were obtained for these GCMs, and simulations for each GCM resulted in different projections for the Sekong River Basin. It was decided to base our scenario analysis on two GCMs that performed well according to the MRC analysis and provided a reasonable spread of potential changes (Table B.1). Two scenarios were selected because of the high computational demand of running multiple scenarios, especially because all simulations need to be run for all pathway and climate scenario combinations.

Table B.1: General Circulation Models Selected

General circulation model	Representative concentration pathway	Precipitation changes
Institute Pierre Simon Laplace Model CM5A-MR	8p5	Slight decrease in wet season, decrease in dry season
Geophysical Fluid Dynamics Laboratory ESM2M	8p5	Decrease in dry season, increase in wet season by 2085

Once the two scenarios were chosen, data were retrieved from the portal of the Inter-Sectoral Impact Model Intercomparison Project" for all mentions. The grid cells of the bias-corrected GCM data have a resolution of 0.5 degrees. The grid covering the Sekong Basin is shown in Figure B.2. Our analysis focused on the future time horizons 2030 and 2090, so there are four climate change scenarios: IPSL 2030, IPSL 2090, GFDL 2030, and GFDL 2090.

Figure B.2: Grid for Application of Conversion Factors for Climate Change Scenarios



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[1] SWAT (Soil and Water Assessment Tool), database, https://swat.tamu.edu/.

[2] https://esg.pik-potsdam.de/search/isimip/

For each grid cell, four values were obtained, corresponding to the two climate change scenarios for 2030 and 2090, which resulted in 80 conversion factors being used to convert the present-day rainfall series to the climate change–affected series.

B.1.3 Description of Hydrological Modeling Approach

The first step was to assess the hydrology of the Sekong River and its tributaries, with the main purpose being generation of inflow series for the present and future (climate-change affected) situations. These series formed the basis for reservoir modeling, which in turn formed the basis for hydropower modeling and subsequent assessment of ecological effects.

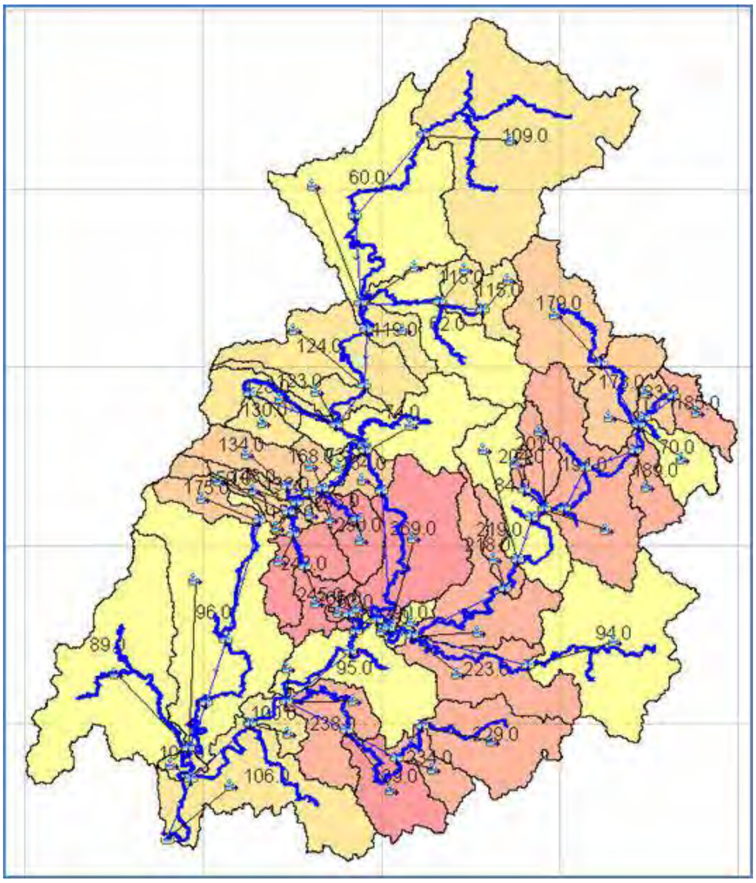
There are several hydrological models for the Sekong Basin. There is a soil and water assessment tool hydrological model coupled with the HEC-ResSIM model, but it focuses more on the sediment balance of the basin. There is also a distributed hydrological model, but it was set up with a main focus on the Sesan River (see Rasanen and Kummu 2013).

For the present study, it was decided to align modeling efforts with the Energy-Water Nexus (EWN) study (World Bank 2018), which a consortium led by CNR Engineering was simultaneously conducting. The core objective of the EWN study was to increase the understanding of the Ministry of Energy and Mines about the principles and processes for integrating water resources management into hydropower planning and management. The EWN study covers the Sekong Basin and uses two hydrological models that the Ministry of Energy and Mines previously developed using open-source software packages:

- HEC-HMS (hydrological and rainfall-runoff model with soil moisture accounting method)
- HEC-ResSIM (reservoir simulation model)

The schematization of the HEC-HMS model of the Sekong Basin is shown in Map B.1.

Map B.1: **U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System Model of the Sekong Basin**



The EWN study developed and updated these models with relevant features of the two basins, particularly the many existing and planned reservoirs. For the EWN study, the accuracy of the model was less important than its use for capacity-building. As a consequence, the HEC-HMS model that EWN updated was based on just five years of gauged rainfall data. This series was considered to be too short for the analysis required for the Sekong CIA, so a longer data series was sought.

In addition to the five years of rainfall data in the EWN HEC-HMS model, the study obtained daily rainfall series (Table B.2) and daily discharge series (Table B.3) from the MRC.

Although some daily rainfall series cover a long period, many values, sometimes many years, are missing. Nevertheless, there are three series with data (up to August 8, 2018) that are useful for comparison with the (fully continuous) daily global rainfall series used as input for the HEC-HMS model in this study.

Daily discharge series were also received from the MRC for several stations (Table B.3).

These discharge data series are of limited utility, being in some cases very short and in some cases not aligned with the 24-year period of global rainfall data the study selected. The daily discharge data also have many gaps (missing records). Of these stations, only the one at Attapeu is considered reliable (Meynell 2014) and so has been used for comparison with the modeling results.

Table B.2: **Daily Rainfall**

Station		Coordinates (Indian 1960 geodetic datum)		Country	Length of series
Code	Name	Latitude	Longitude		
140603	Siempang	14,115	106,388	Cambodia	01/01/1925–08/31/2018
150602	Saravan	15,717	106,433	Lao PDR	01/01/1929–12/31/2000
140705	Attapeu	14,467	106,833	Lao PDR	01/01/1988–12/31/2008
140704	Kontum	14,347	108,034	Vietnam	01/01/1923–08/31/2018
150607	Nikhom 34	15,183	106,433	Lao PDR	01/01/1998–12/31/2005
150605	Nonghine	14,750	106,217	Lao PDR	01/01/1979–12/31/2000
140715	Dak To	14,650	107,830	Vietnam	01/01/2001–08/31/2018
140505	Pathoumphone	14,767	105,967	Lao PDR	01/01/1979–12/31/2005
150609	Sekong	15,083	106,850	Lao PDR	01/01/1992–12/31/2008

Table B.3: **Daily Discharge**

Station		River	Coordinates (Indian 1960 geodetic datum)		Country	Length of series
Code	Name		Latitude	Longitude		
390103	Saravanne	Sedone	15,710	106,450	Lao PDR	01/01/1986–12/31/2000
430102	Siempang	Sekong	14,115	106,388	Cambodia	01/01/1965–01/01/1968
430105	M. May (Attopeu)	Sekong	14,807	106,843	Lao PDR	01/01/1989–12/31/2000
440201	Kontum	Dak Bla	14,347	108,034	Vietnam	01/01/1967–12/31/2000

The 24 years of global rainfall data—multi-source weighted-ensemble precipitation (MSWEP)—represent the historical situation (1991–2014). To simulate the effect of climate change on the hydrology, climate change scenarios have been prepared, and the present (daily) rainfall values have been multiplied by a factor representing the climate change scenario for a certain future time horizon.

B.2 Results of Hydrology and Climate Change Assessment

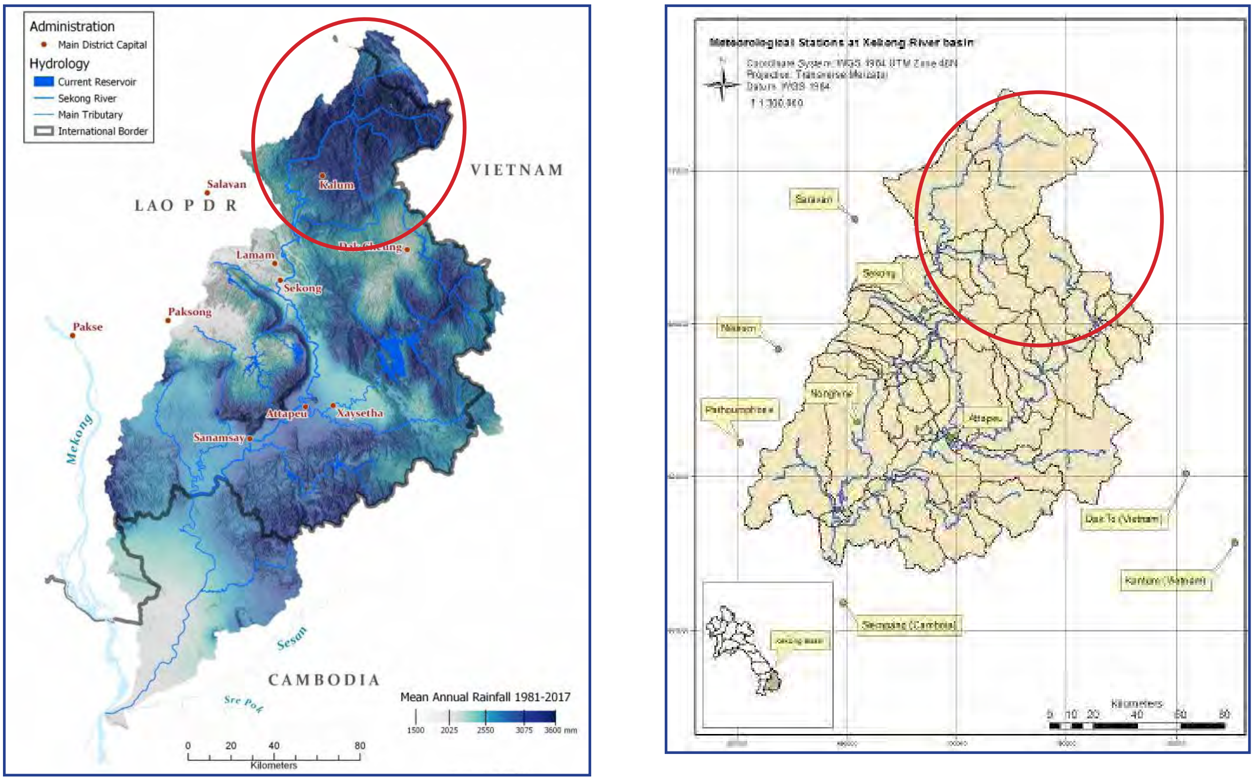
B.2.1 Present Situation

In the present study, the main drawback of the existing hydrological modeling with the HEC-HMS, the short series of just five years (2001–05), has been adjusted by changing to a different data source, as mentioned. In the following paragraphs, the steps that were followed are described in detail.

The original series of precipitation used for the rainfall-runoff modeling with the HEC-HMS model was short for the purpose of the study, with only five years of rainfall data (2001–05). Analysis of the measured data series showed that these series contain frequent gaps and are unequally distributed over the basin, with no stations in the upper northeast corner of the basin, where the highest-intensity rainfall occurs (Map B.2), and that some stations used in the modeling are located far outside the Sekong Basin, so it was decided to use a different source of data. Global data are a good alternative, especially a combination of satellite data and ground measurements (gauge corrected). An important advantage of satellite data over the measured rainfall series is that they are continuous, which allow for long model runs with the HEC-HMS and HEC-ResSim model.[3]

For discharge data, there are no sources other than field measurements, so such data need to be based on data from the MRC.

Map B.2: Rainfall Distribution over the Sekong Basin and Location of Precipitation Stations Used in U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System Modeling


a. Tributary

b. Mainstream

Note: Red circle indicates region with high rainfall without precipitation stations.

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[3] HEC-ResSim modeling is described in Appendix D.

For rainfall, a dataset was used that is an optimized combination of satellite precipitation data and in-situ observed precipitation, the MSWEP dataset (Beck et al. 2017), which Deltares and partner hydro-meteorological institutes in the EU FP7 project eartH2Observe developed.[4] This product was judged to be the most reliable gauge-corrected dataset in a recent study of 26 precipitation datasets (Beck et al. 2019). Nevertheless, precipitation estimation is difficult in mountainous areas, where gauge density is low and resolution of satellite products cannot capture the complexity of the topography. In addition, cloud cover during the rainy season hampers satellite rainfall data retrieval, so combining different sources of rainfall observations can lead to better results. Although the MSWEP dataset is available from 1979, the research team decided to retrieve MSWEP data from 1991 to 2014 because a longer series would have led to problems with the size of the data series and calculation times of the two models (HEC-HMS and HEC-ResSim). The series were extracted for all grid cells of 0.25 degrees resolution (approximately 25 x 25 km) in the Sekong Basin (Figure B.3).

MSWEP rainfall data were applied to each of the 53 Sekong sub-basins by overlaying a grid (Figure B.4). Rainfall values from the corresponding 0.25-degree resolution MSWEP dataset were then applied to each of the Sekong sub-basins defined in the HEC-HMS model.

Figure B.3: **Application of Multisource Weighted-Ensemble Precipitation Data to the Sekong Sub-Basins in the HEC-HMS**

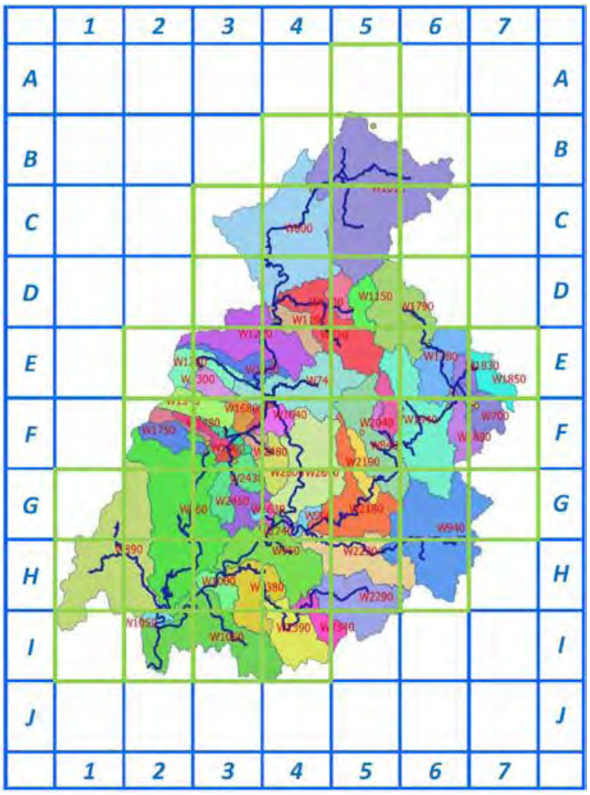
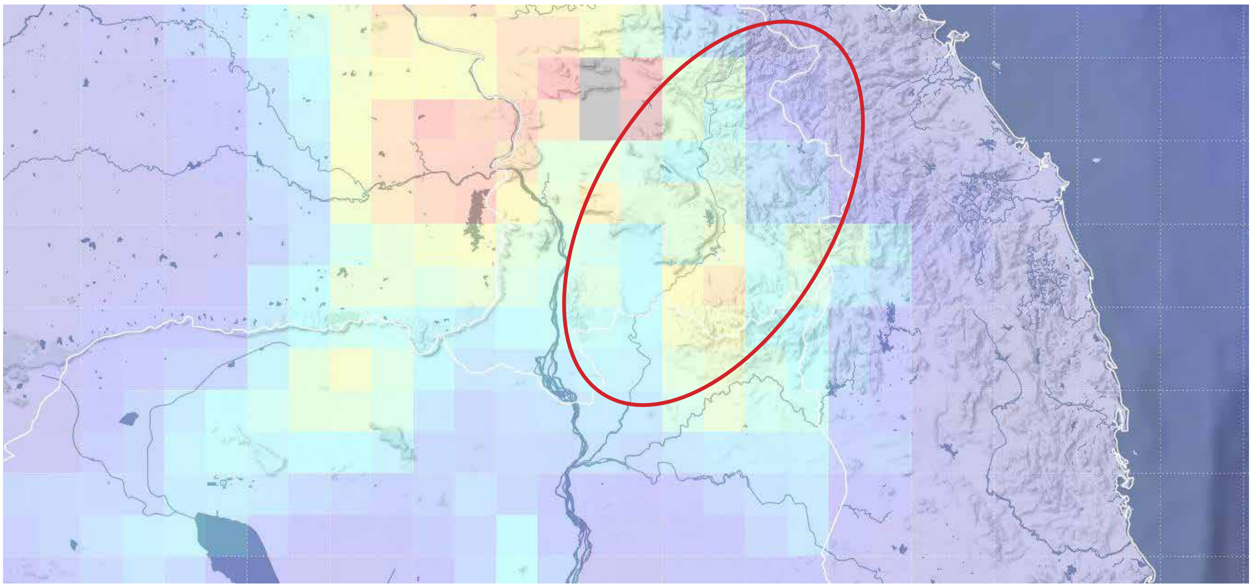


Figure B.4: **Modeling Chain for Impact Analysis**



Source: Beck et al. 2017.

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[4] MSWEP is a global, historic precipitation dataset (1979–2016) created by merging a wide range of data from physical monitoring sites (gauges) and satellite records of precipitation to provide reliable precipitation estimates over the entire globe. MSWEP has been validated at global scale using observations from about 70,000 gauges and hydrological modelling for about 9,000 catchments, with daily gauge corrections. More information can be found at the GLOHSO database website, http://www.gloh2o.org/.

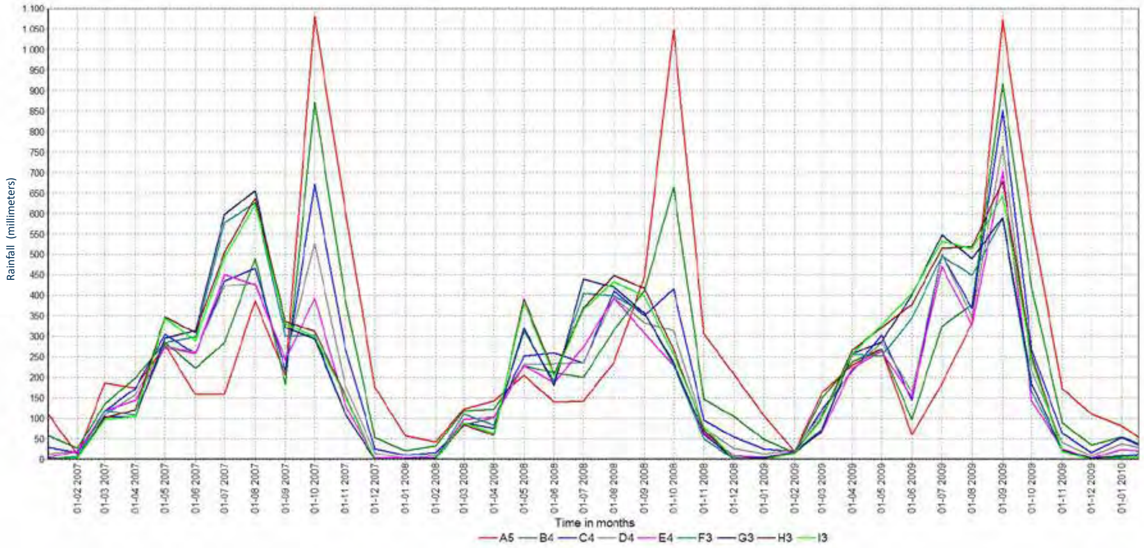
B.2.2 Assessment of MSWEP Dataset for the Sekong Basin

Once the MSWEP data from 1991 to 2014 had been retrieved from the server, they were compared with the series used in the existing HEC-HMS model and with the gauge data obtained from the MRC. Not only are those completely different types of data, but the MSWEP is also an average value over a cell, like the ones shown in Figure B.4, whereas the other data series are point measurements at gauges in the field.

First a comparison was made between the various MSWEP data series themselves for a number of cells (Figure B.5).

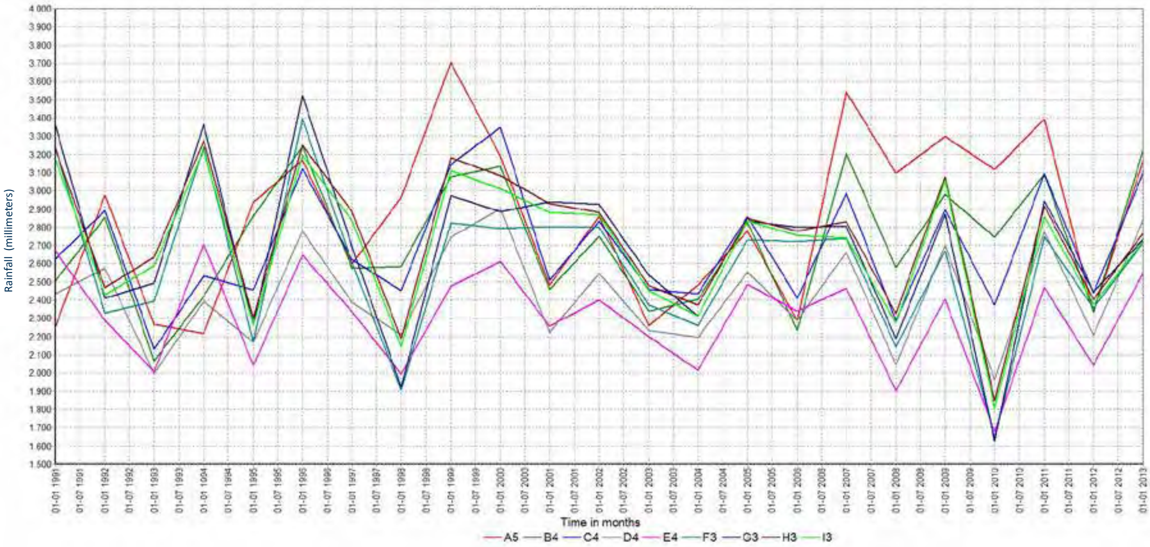
The north of the Sekong Basin has the highest rainfall (Figure B.4; cells A5, B4, C4 in descending order of rainfall depth), in correspondence with the map of annual rainfall over the basin (Map B.2), although this is not always the case, as is evident from a graph of average yearly rainfall for the same grid cells (Figure B.6).

Figure B.5: Comparison of Multisource Weighted-Ensemble Precipitation Monthly Values (North-South Transect of Grid Cells)



Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System, Mekong River Commission Database, and Multisource Weighted-Ensemble Precipitation.

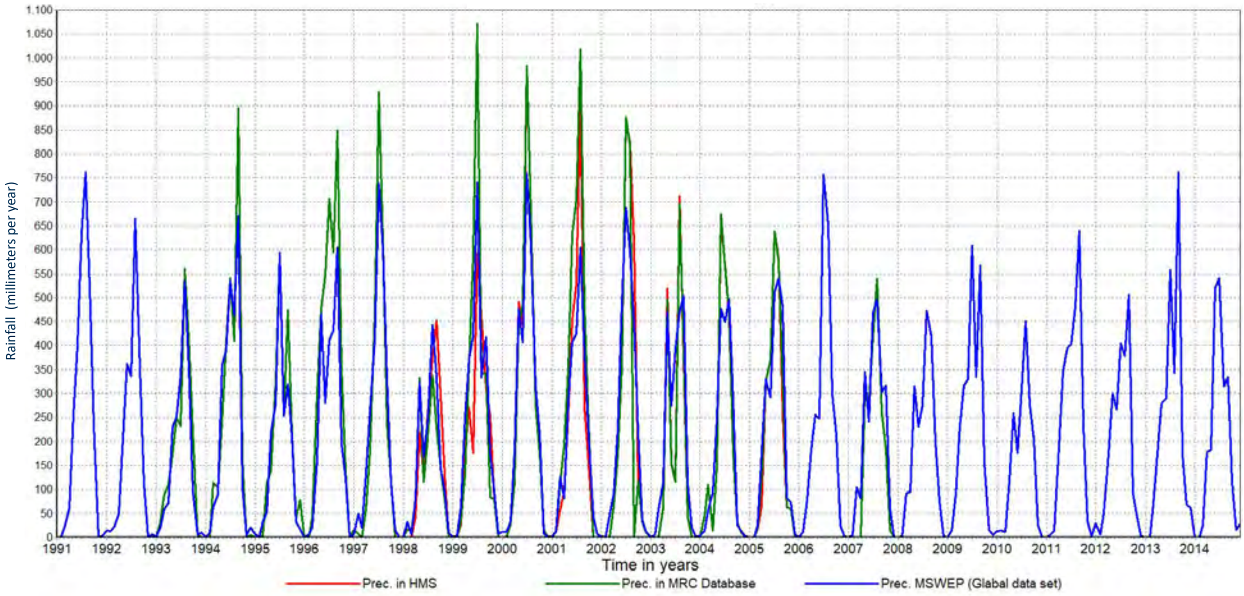
Figure B.6: Comparison of Multisource Weighted-Ensemble Precipitation Yearly Values (North-South Transect of Grid Cells)



Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System, Mekong River Commission Database, and Multisource Weighted-Ensemble Precipitation.

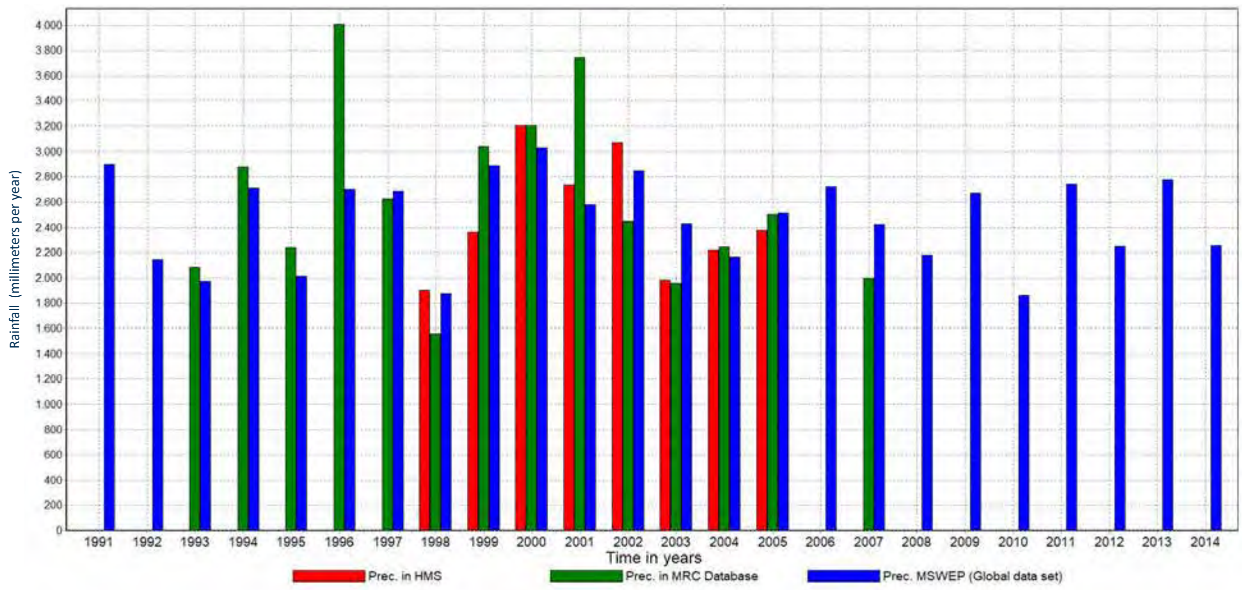
Monthly and yearly average values for the rainfall stations Pathoumphone (Figures B.7 and B.8), Dak To (Figures B.9 and B.10), and Saravan (Figures B.11 and B.12) were compared. For Attapeu, the only rainfall station located within the basin, a comparison is made which covers an overlapping period (original five-year modeling period; Figure B.13) and the new simulation period (Figure B.14).

Figure B.7: **Comparison of Monthly Rainfall at Pathoumphone**



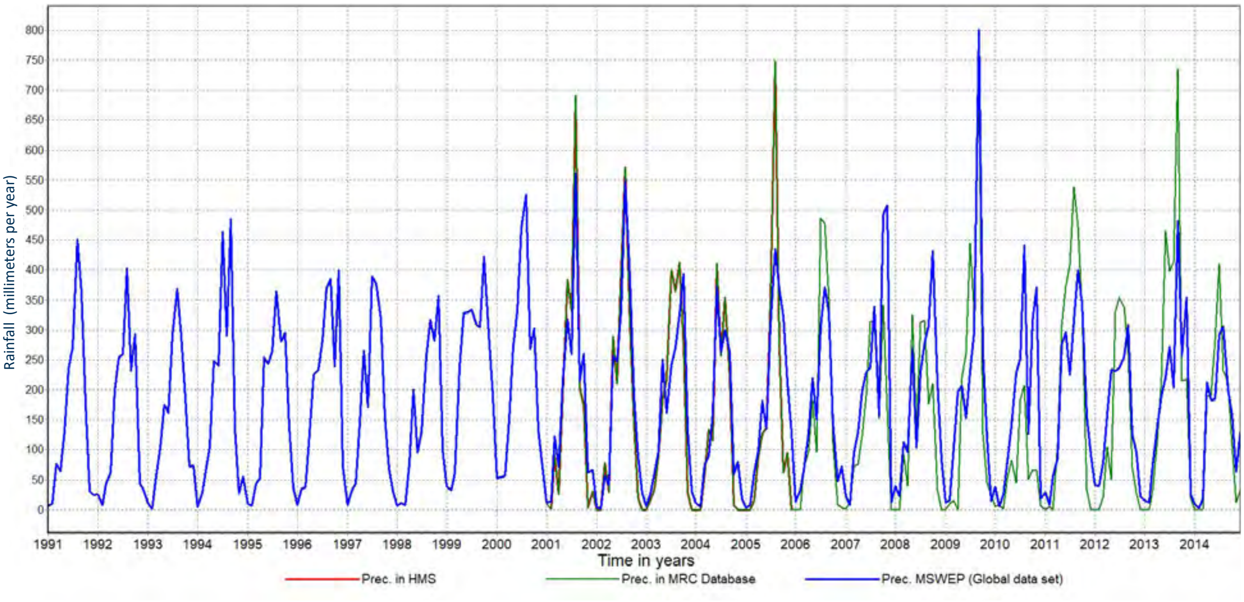
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.8: **Comparison of Yearly Rainfall at Pathoumphone**



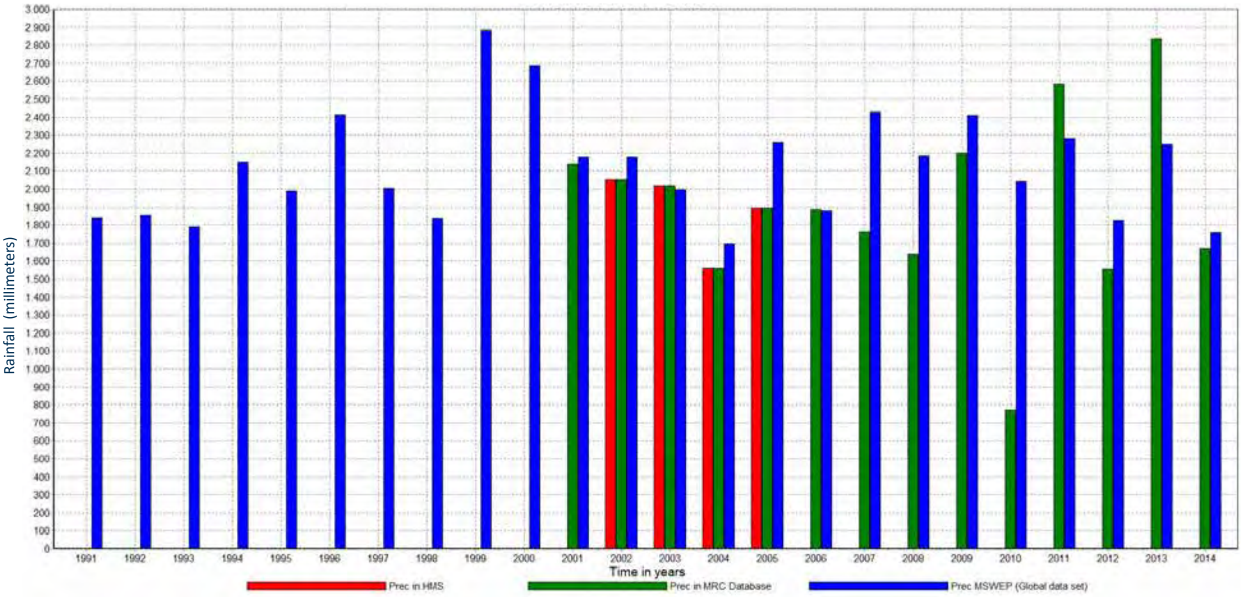
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.9: Comparison of Monthly Rainfall at Dak To



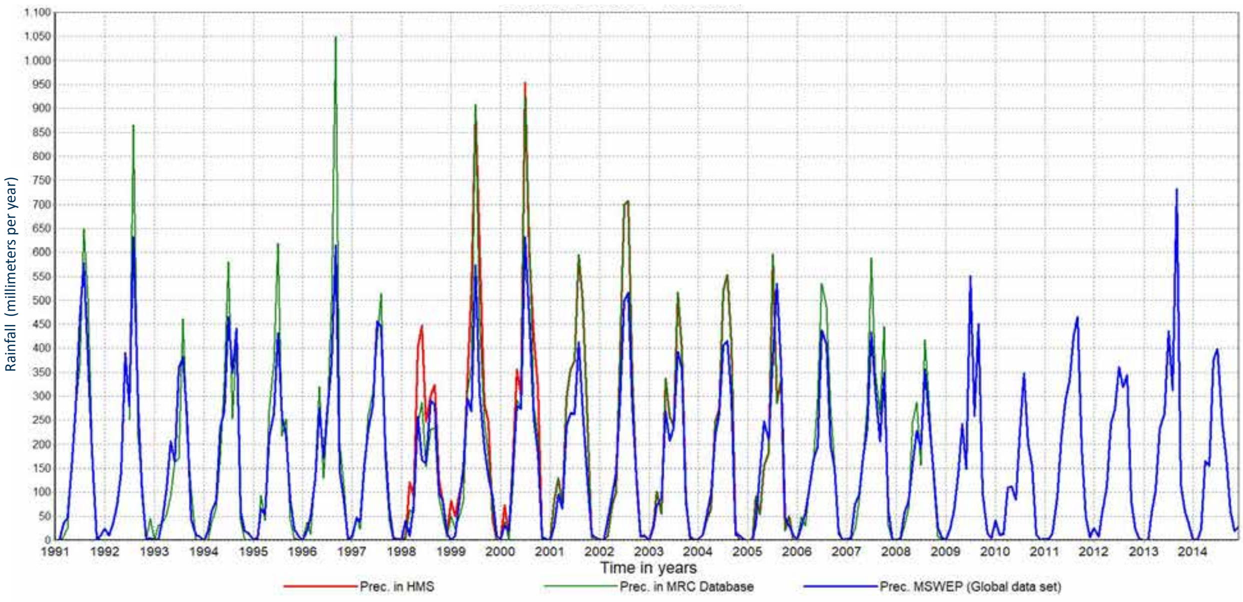
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.10: Comparison of Yearly Rainfall at Dak To



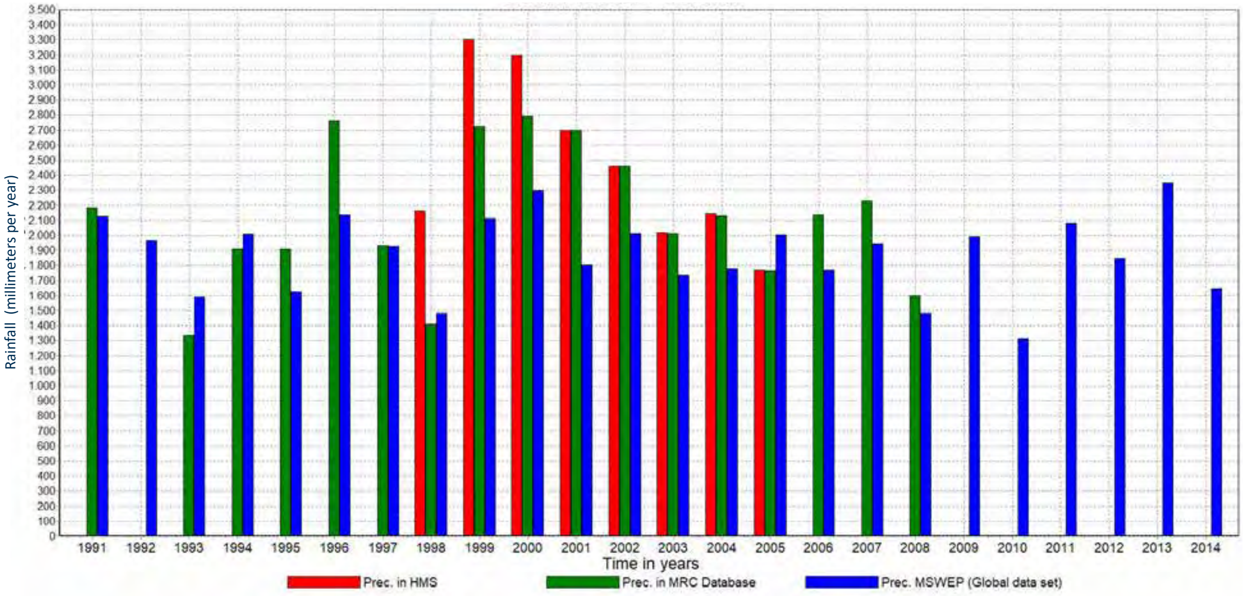
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.11: Comparison of Monthly Rainfall at Saravan



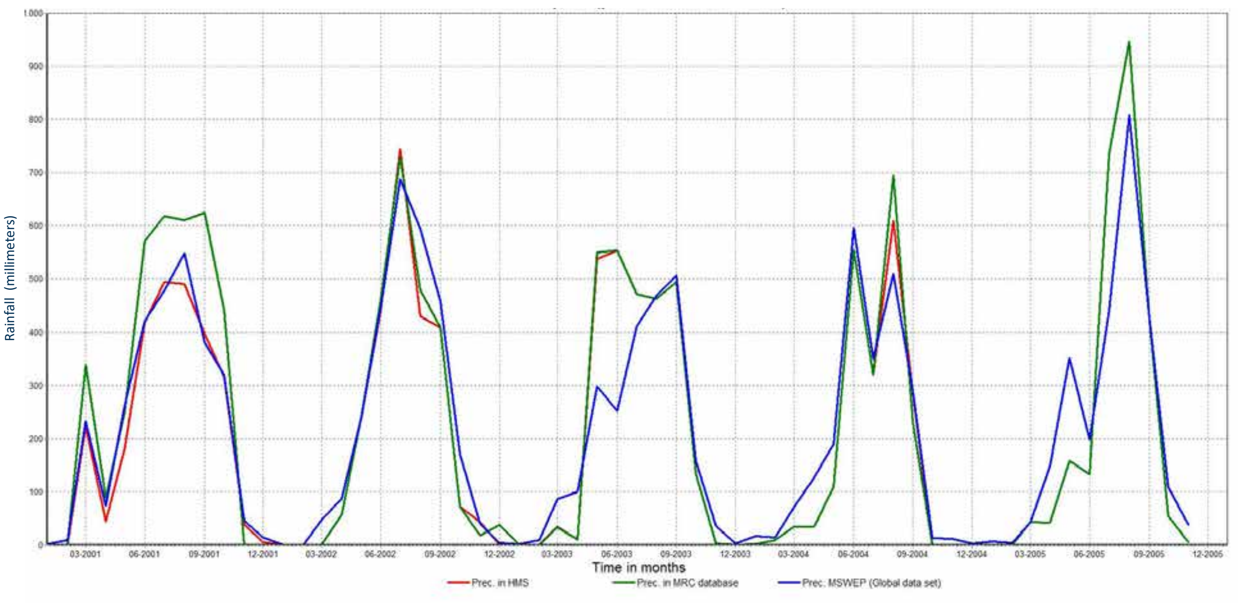
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.12: Comparison of Yearly Rainfall at Saravan



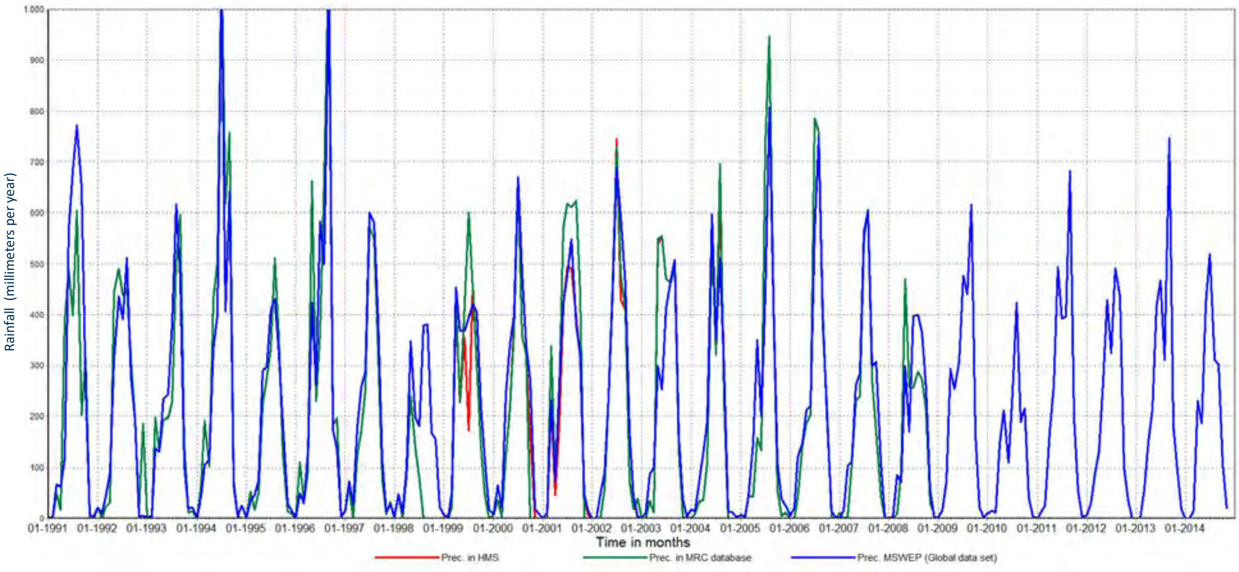
Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.13: **Comparison of Average Monthly Rainfall at Attapeu (2001–2005)**



Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

Figure B.14: **Comparison of Average Monthly Rainfall at Attapeu (1991–2014)**



Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (HMS), Mekong River Commission (MRC) Database, and Multisource Weighted-Ensemble Precipitation (MSWEP).

In each graph, rainfall values from three sources are plotted: those used in the HEC-HMS model, those obtained from the MRC database, and those extracted for that location from the MSWEP database server.

The most remarkable feature of the comparison of the three types of data is that there is often a substantial difference between the values used in the HEC-HMS model and those obtained directly from the MRC database, although for some stations, the data are identical (for example, for Dak To). It is less surprising that there are differences between the measured data (MRC database) and the global MSWEP dataset because the MSWEP data represent average rainfall over a larger area, although in general, average monthly values are similar enough to warrant application of the MSWEP data for simulation of discharges over a longer period (1991–2014) using the HEC-HMS model calibrated for the Sekong Basin.

B.2.3 Preparation of New Input Series for the HEC-HMS Model

To apply the new series of MSWEP daily rainfall values for 1991 to 2014, it was necessary to prepare a new set of daily rainfall values for each of the sub-basins in the HEC-HMS model based on a weighted average of the MSWEP values in the grid cells shown in Figure B.4. In the original HEC-HMS model of EWN with five-year rainfall data, a simple approach was followed: the rainfall station closest to each sub-basin represented the rainfall in that sub-basin, without any weighting. With the MSWEP dataset, which covers the entire Sekong Basin, it was possible to make weighted averages for each sub-basin, depending on which grid cells covered that particular sub-basin. This was achieved by setting up a spreadsheet with all the MSWEP daily rainfall series and assigning one or more of those series with their corresponding weights to each Sekong sub-basin. For most sub-basins, various grid cells cover the sub-basin, although for some of the smaller sub-basins, just one grid cell covered the entire surface (and thus the weighting factor could be set at 1.0) (Figure B.4). Once a matrix was prepared for all the sub-basins and their corresponding MSWEP grid cells with weighting factors, those weighting factors were used to prepare daily rainfall series per sub-basin for the entire period (1991–2014). These series were entered as time series in the HEC-HMS. Once this was prepared, the model could be run again for the present situation, but for 1991 to 2014.

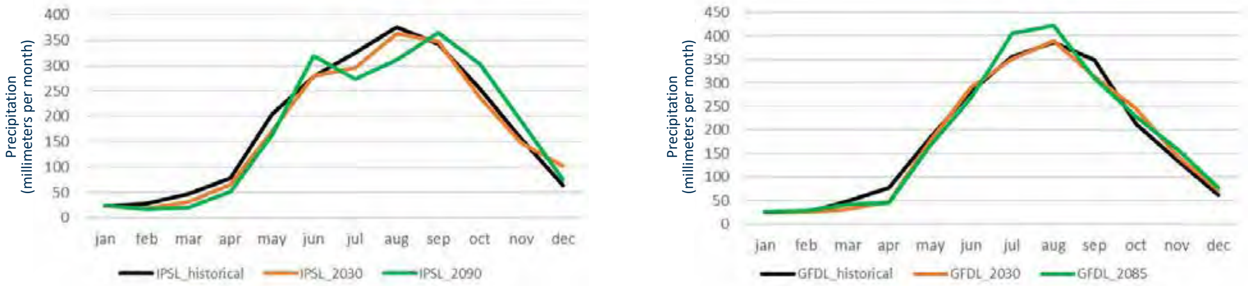
B.2.4 Climate Change Assessment

Figure B.15 displays monthly mean basin precipitation for the historical period (2000), near future (2030), and far future (2090), averaged over a surrounding 20-year period and over the same grid used in the hydrological modeling (Figure B.19, red grid cells). The daily generation circulation model (GCM) precipitation values for each grid, covering the historical period (1991–2010), the near future (2021–40), and the far future (2081–00), were averaged over the basin. Subsequently, the long-term monthly mean values were calculated.

Both selected scenarios indicate a slower onset of rainfall in February, March, and April, which could lead to a longer dry season. According to the Institut Pierre Simon Laplace (IPSL) GCM, by 2090, monthly rainfall would be lower for much of the wet season but higher in June and September, resulting in approximately the same total wet season precipitation. According to the Geophysical Fluid Dynamics Laboratory (GFDL) GCM, by 2090, there would be substantially more rainfall in the wet season, particularly in July and August.

The climate change modeling shows some geographical variation within the Sekong Basin. The monthly precipitation cycle and projected changes are displayed in Figures B.16 and B.17.

Figure B.15: Long-Term Monthly Mean Precipitation over the Sekong Basin Derived from IPSL and GFDL General Circulation Models for Representative Concentration Pathway 8p5 for Near Future (2030) and Far Future (2090)

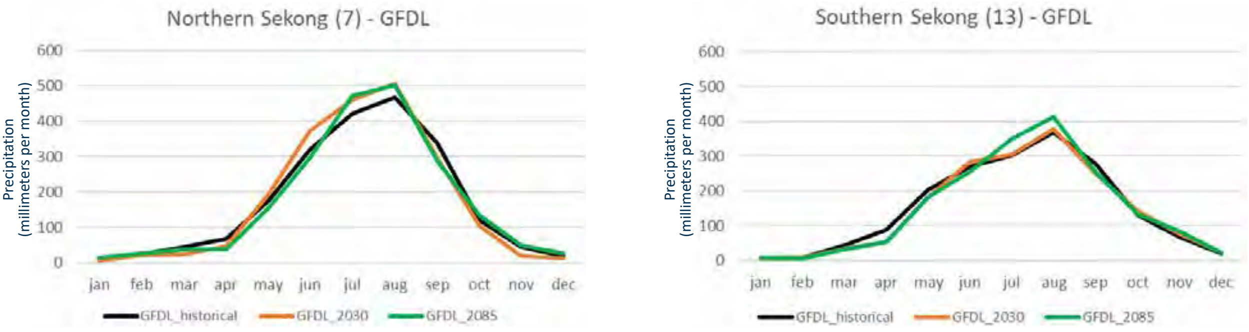


a. Sekong Basin average IPSL

b. Sekong Basin average GFDL

Note: IPSL= Institut Pierre Simon Laplace Model; GFDL = Geophysical Fluid Dynamics Laboratory.

Figure B.16: **Long-Term Monthly Mean Precipitation Derived from GFDL General Circulation Model for Representative Concentration Pathway 8p5 for Near Future (2030) and Far Future (2090) for North and South**


a. Northern Sekong

b. Southern Sekong

Note: GFDL = Geophysical Fluid Dynamics Laboratory.

The plots with GFDL precipitation (Figure B.16) show that there is more precipitation in the north than in the south. In the north, increased wet season precipitation is projected to be evident by 2030 and be sustained through to 2090, whereas in the south, increased wet season precipitation is projected to occur later. Reduced precipitation during the dry season is projected by 2030 in the north and the south of the basin.

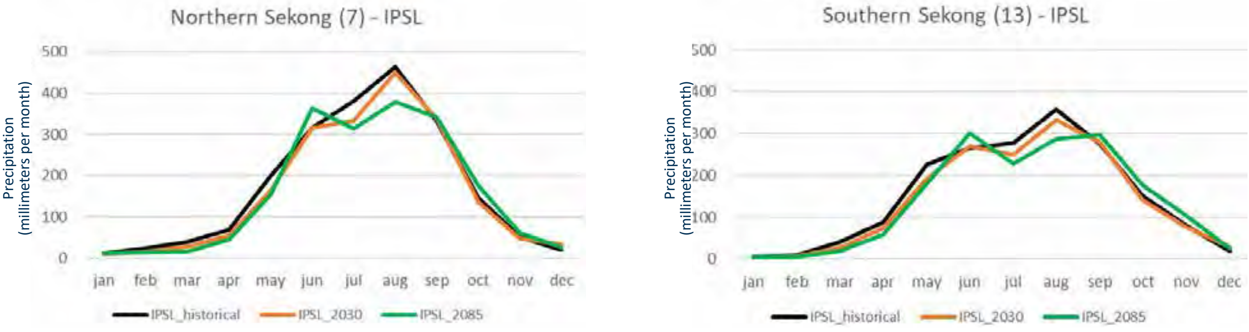
The results for IPSL GCM (Figure B.17) project similar changes in precipitation for the north and south, although absolute amounts are higher in the north.

The effect of climate change on precipitation varies throughout the basin—not only between the north and south, as discussed.

Figure B.18 displays projected monthly changes for 2030 derived for the 20 grid cells. The variation between grid cells is especially large for the dry season. For example, decreases of up to 60 percent are projected for March, but absolute rainfall amounts are only 30 mm, so the absolute decrease is small, which could result in a slightly longer dry season.

The variation is less for the wet season. Because the effect of climate change on precipitation varies in different parts of the Sekong Basin, change factors were derived for all 20 grid cells and applied those to historical precipitation levels instead of using an average conversion factor over the entire basin.

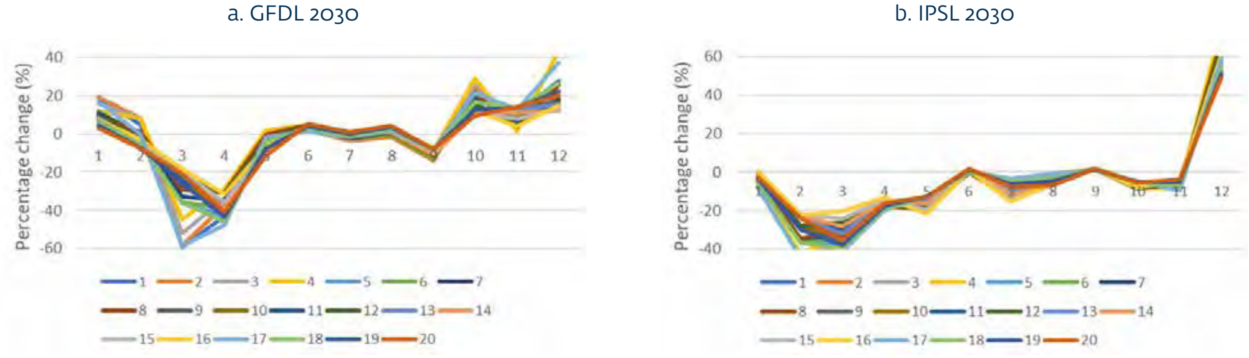
Figure B.17: **Long-Term Monthly Mean Precipitation Derived from IPSL General Circulation Model for Representative Concentration Pathway 8p5 for Near Future (2030) and Far Future (2090) for North and South**


a. Northern Sekong

b. Southern Sekong

Note: IPSL = Institut Pierre Simon Laplace Model.

Figure B.18: **Projected Monthly Precipitation Changes (%) for 20 Individual Grid Cells for GFDL and IPSL General Circulation Models for Near Future as Example of Geographic Variation**

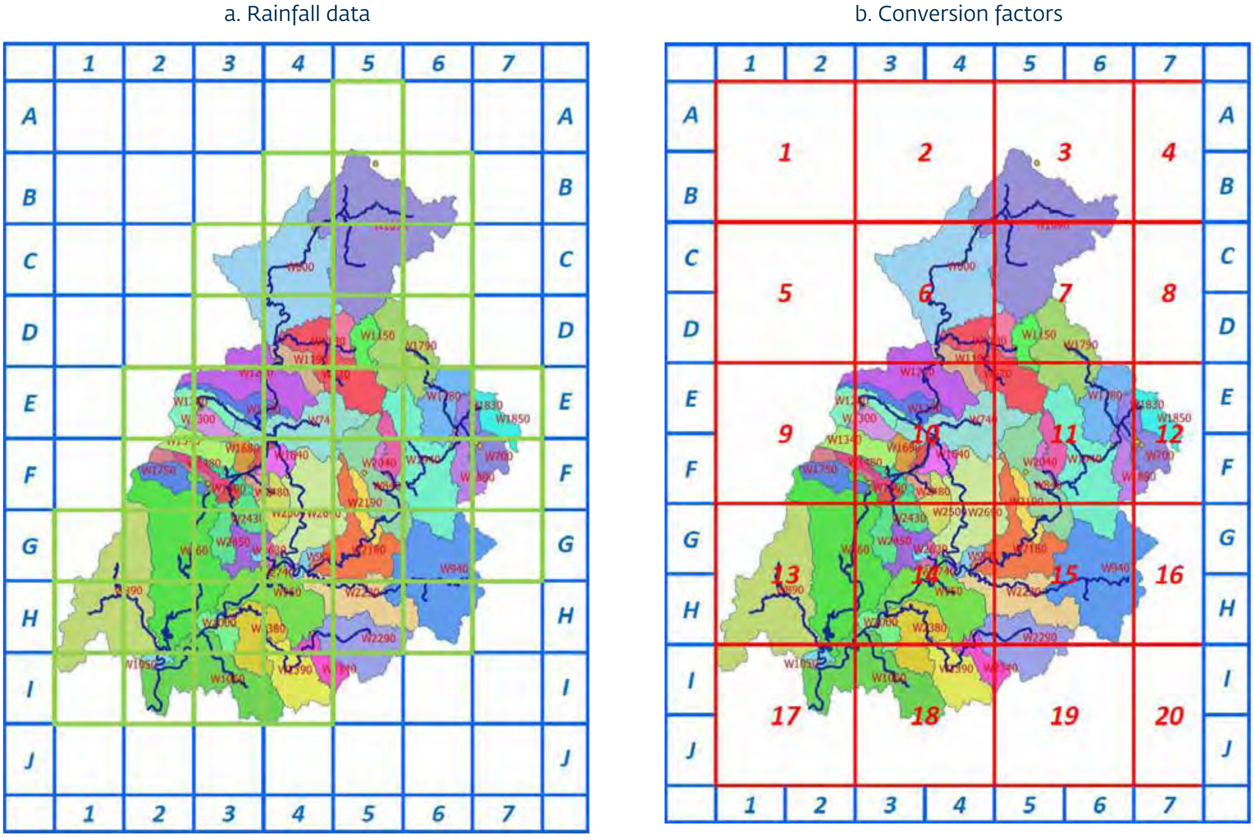

a. GFDL 2030

b. IPSL 2030

Note: Each colored line represents one grid cell. IPSL = Institut Pierre Simon Laplace Model; GFDL = Geophysical Fluid Dynamics Laboratory.

Using the results of the assessment of the effect of climate change on precipitation, these results can be used to convert the rainfall series for the present situation into new series representing the effect of climate change. For this conversion, factors were derived based on the resolution of the bias-corrected GCM grid, similar to that of the MSWEP daily rainfall series but less detailed (Figure B.19a for MSWEP rainfall series, Figure B.19b for climate change conversion factors).

Figure B.19: **Grids Used for MSWEP Rainfall Data Extraction and Application of Conversion Factors for Climate Change Scenarios**


a. Rainfall data

b. Conversion factors

The bias-corrected GCM data have a resolution of 0.5 degrees, whereas the MSWEP data have a resolution of 0.25 degrees. By projecting the GCM changes onto the historical MSWEP data, the HEC-HMS model can be forced with the highest-resolution precipitation data (0.25 degrees) for the future as well. There are four MSWEP grid cells in one climate change grid cell. As an example, for conversion of MSWEP rainfall in grid cell A5, a multiplication factor needs to be applied from climate change grid cell 3.

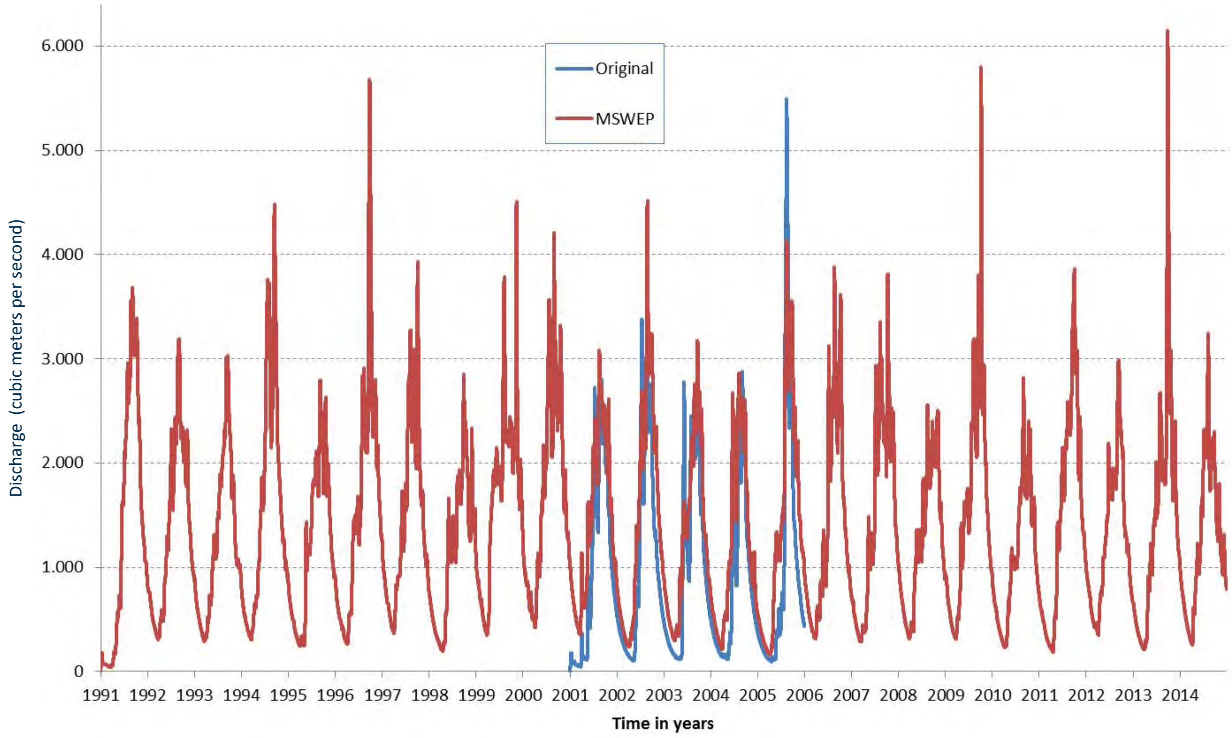
With the results of that assessment, the MSWEP daily rainfall series for the present situation are converted into four series for climate change scenarios: IPSL 2030, IPSL 2090, GFDL 2030, and GFDL 2090. These series have been entered into the HEC-HMS as alternative (climate change) meteorological scenarios.

B.2.5 Recalibration of HEC-HMS Model

The research team used the HEC-HMS model prepared for the EWN study (derived from gauge data) to calibrate the new HEC-HMS model (derived from MSWEP satellite data). Overlaying the two models (Figures B.20 and B.21) shows a good match, although base flow in the MSWEP model is significantly higher, which means a higher volume of total annual flow.

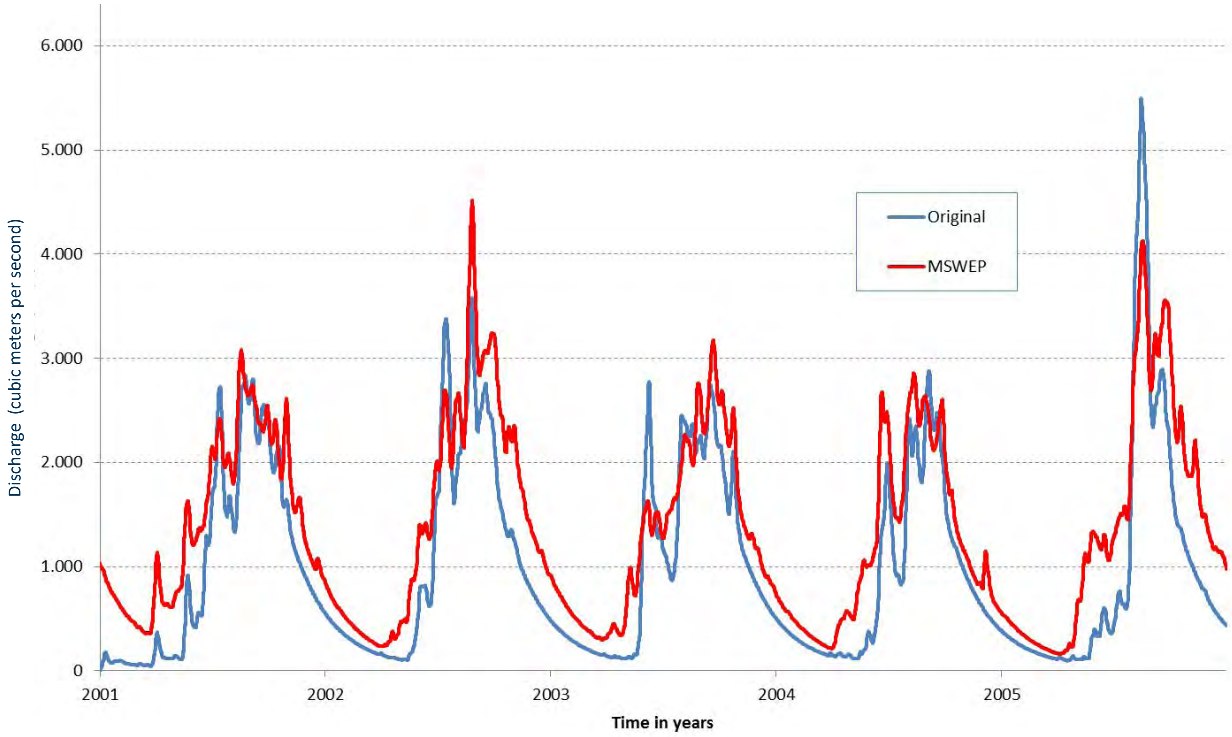
The large difference in the baseflow, which has a major effect on hydropower generation, was a reason to try to recalibrate the HEC-HMS model to have at least the low and medium flows sufficiently similar to measured (gauged) data. The model was recalibrated by adjusting the loss parameters of the soil-moisture accounting module in the HEC-HMS, using the Attapeu gauging station as a reference. This resulted in a much closer match between the simulated and measured hydrographs for the lower and medium flows, but the peak flows continue to be underestimated, probably because the global precipitation data (MSWEP) give an area-averaged value for each grid cell, and therefore flood peaks are difficult to simulate. Although this means that the overall average discharge for the simulated series per simulation period is lower than the measured value, this is probably not a major disadvantage because the high flow peaks will largely cause the storage reservoirs to flow over the spillway and will contribute little to hydropower generation.

Figure B.20: Modeling Results for Present Situation: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (Original EWN and Multisource Weighted-Ensemble Precipitation Input), 1991–2014



Note: MSWEP = multi-source weighted-ensemble precipitation.

Figure B.21: **Modeling Results for Present Situation: U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System (Original EWN and Multisource Weighted-Ensemble Precipitation Input), 2001–05**



Note: MSWEP = multi-source weighted-ensemble precipitation.

B.2.6 Results of New Simulations with HEC-HMS Model—Present Situation

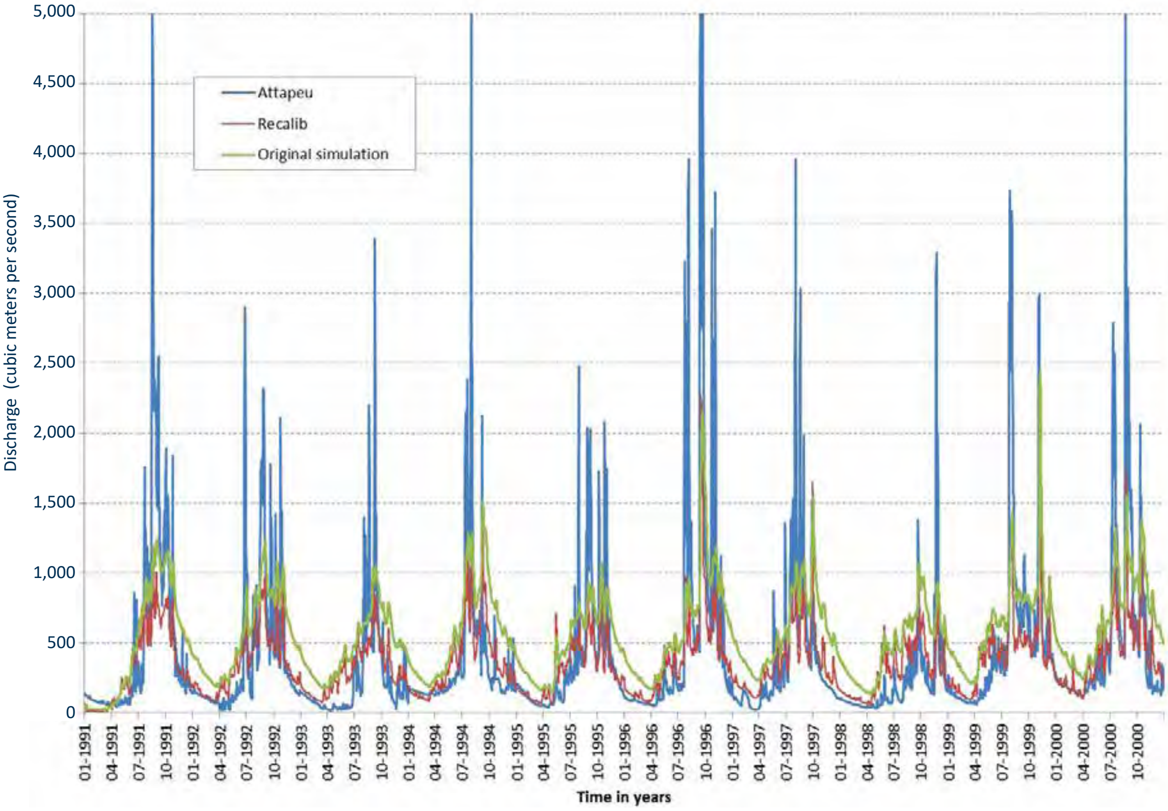
The recalibrated HEC-HMS model was used to simulate flows at the Attapeu gauging station, and the results were compared with measured data collected at the Attapeu gauging station for 1991 to 2000. (Measured data were unavailable beyond 2000.) The full period is shown in Figure B.22 with the maximum discharge cut-off at 5,000 cubic meters per second to show more clearly the differences in low and medium flows between the three hydrographs. The recalibrated model gives more accurate results for lower flow values (closer to measured values at the Attapeu gauging station). Figures B.23 (1994–95) and B.24 (1998–99) show more clearly the improvement in model calibration but also demonstrate that the model only occasionally simulates the higher (flood) values properly.

A closer match between the HEC-HMS model and measured data was obtained for the outlet of the basin. Measurements are available from the Veunkhane gauging station for 2001 to 2005, which allows the original (EWN) simulation results, the new (recalibrated) model, and the Veunkhane gauging station to be compared (Figure B.25).

The results of the two simulations (EWN) and recalibrated model with MSWEP global rainfall data are very similar, and both correspond reasonably well with the measured data at Veunkhane.

The full series of daily flow values for the 53 sub-basins in the HEC-HMS model are stored in the HEC Data Storage System database and were used for subsequent modeling of hydropower generation in the HEC-ResSim model (Appendix D).

Figure B.22: Results of U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System Simulations (1991–2000) for Original and Recalibrated Models and in Attapeu Gauging Station (Cut-Off at 5,000 m³/s)



Note: m³/s = cubic meters per second.

Figure B.23: Detail of Simulation with U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System, 1994–95

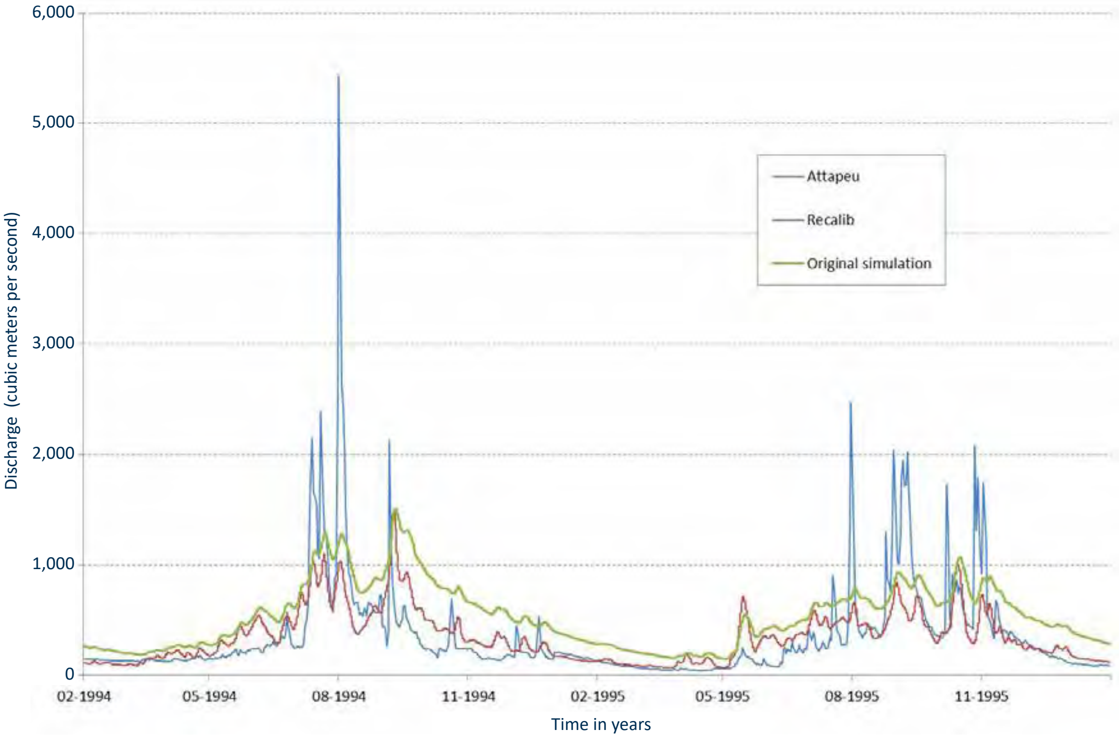


Figure B.24: Detail of Simulation with U.S. Army Corps of Engineers, Hydrologic Engineering Center Hydrologic Modeling System, 1998–99

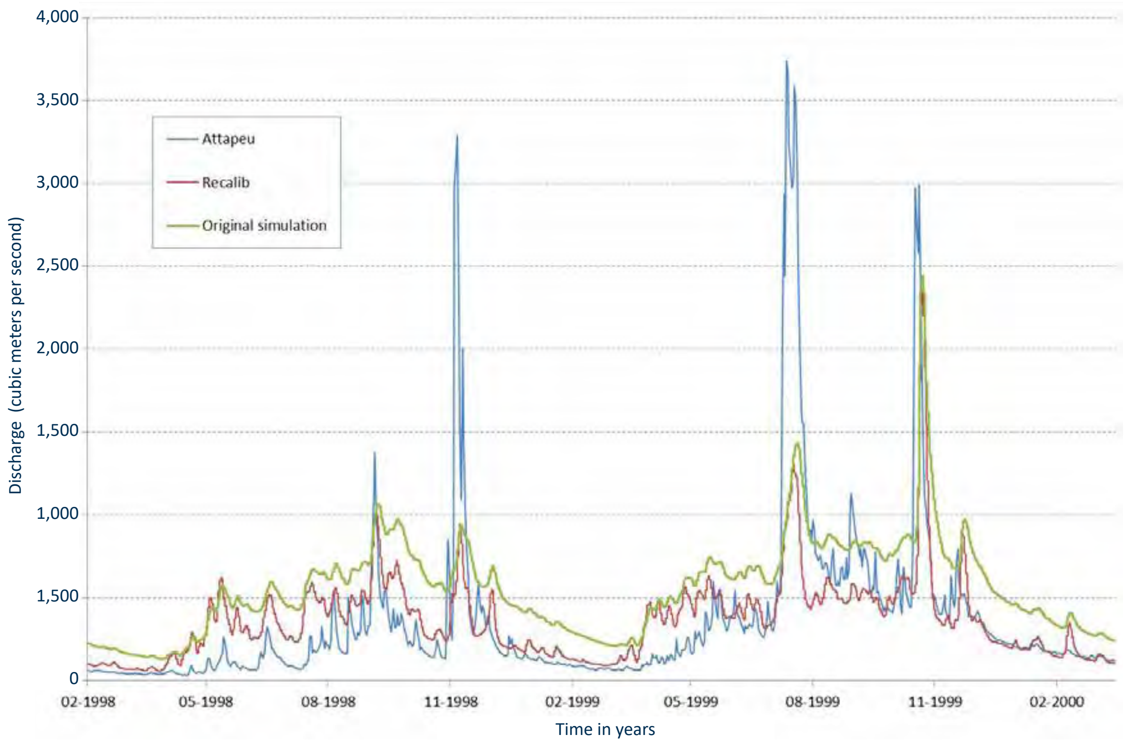
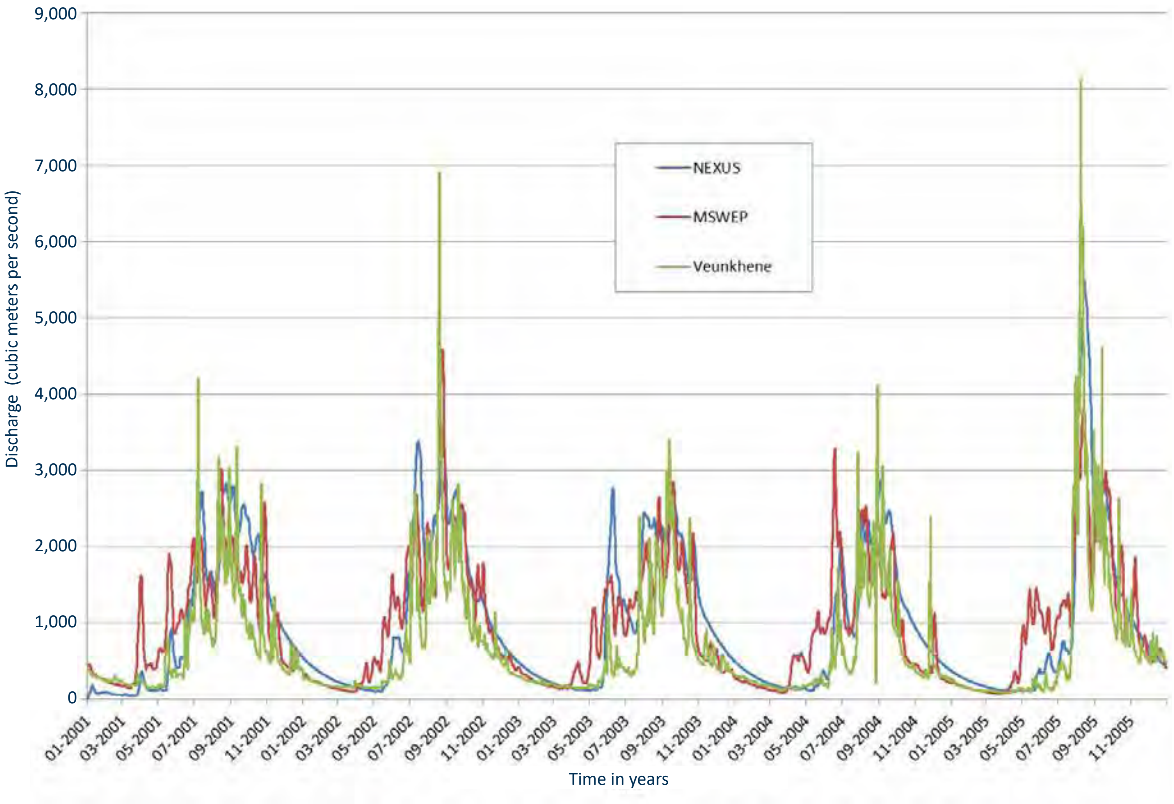


Figure B.25: Results at Sekong Basin Outlet from Energy-Water Nexus Project, Recalibrated Model, and Veunkhane Gauging Station (2001–2005)



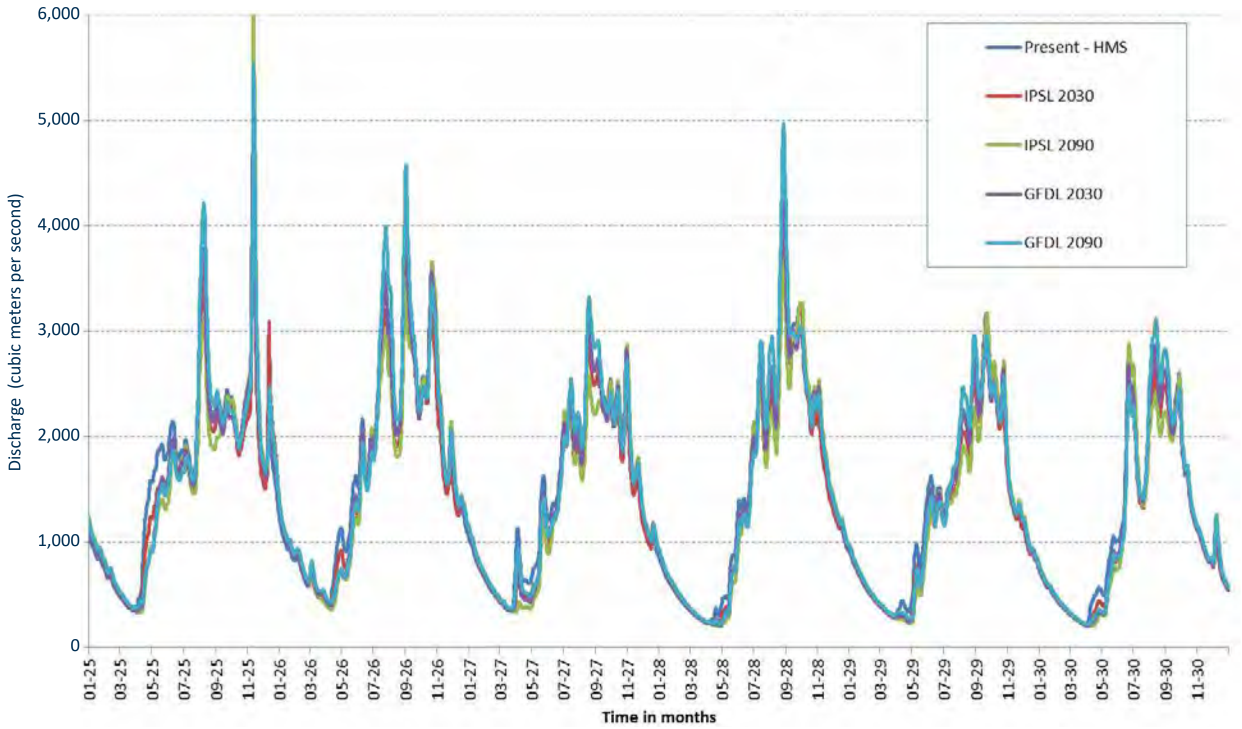
Note: MSWEP = multi-source weighted-ensemble precipitation.

B.2.7 Results of New Simulations Using HEC-HMS Model—Climate Change

Hydrological flows were simulated over a 24-year period for the four climate change scenarios, again with the first four years as a “warm-up” period to exclude the effect of the choice of initial conditions. There was only a very small effect of climate change on the final results. As an example, Figure B.26 illustrates the discharges at the outlet of the Sekong Basin for a five-year period (2025–30). These hydrographs show little variation in flow between the HEC-HMS model (which does not factor in climate change) and adjusted model, taking into account the four climate change models.

The climate change analysis conducted as part of this study was not aimed at studying flood hydrology specifically and therefore gives no indication whether future return intervals for extreme floods are expected to decrease. The current dam safety review should address this question.

Figure B.26: Effect of Climate Change Scenarios on Discharge at the End of the Sekong Basin



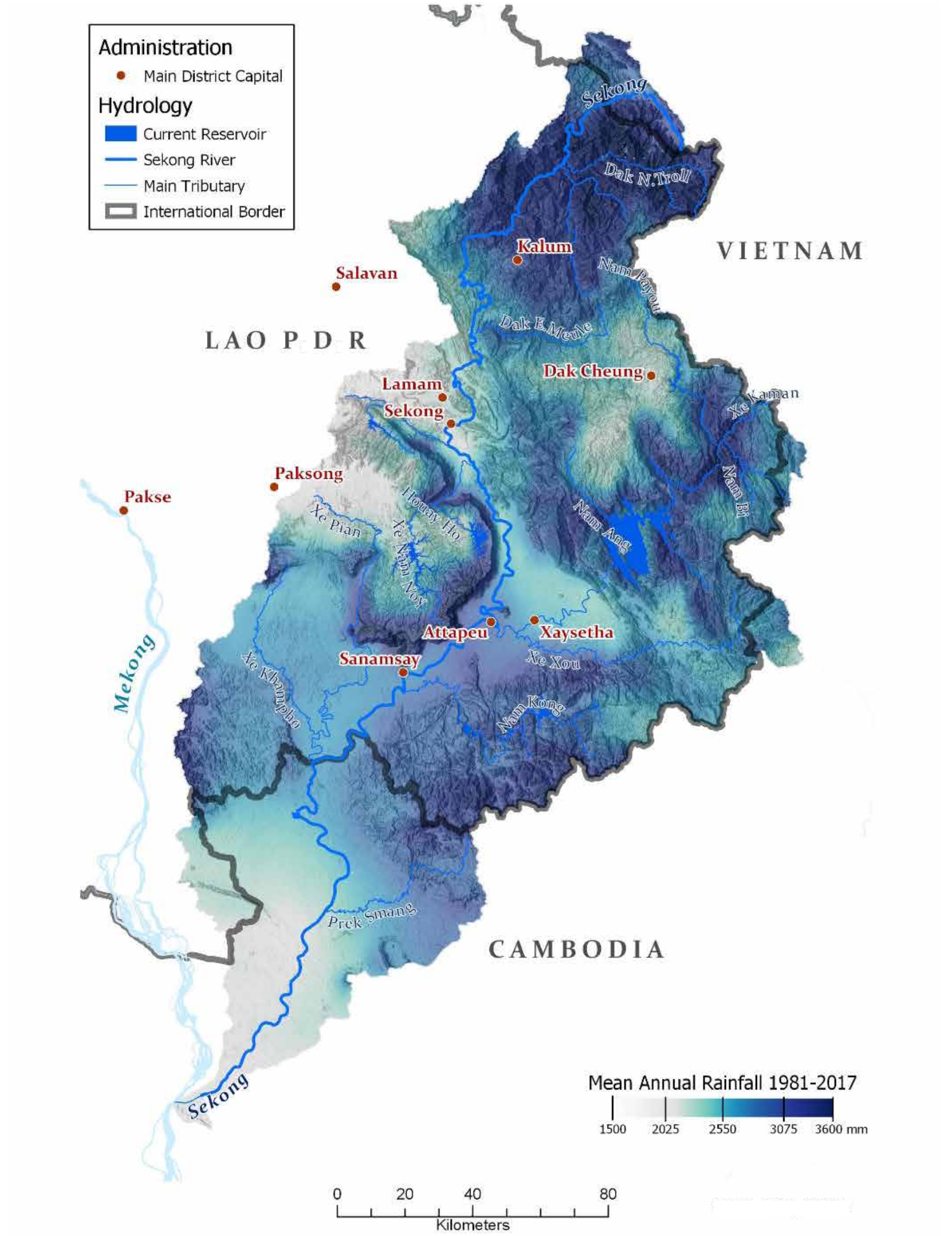
Note: HMS = Hydrologic Modeling System; IPSL = Institut Pierre Simon Laplace Model; GFDL = Geophysical Fluid Dynamics Laboratory.

APPENDIX C
SUPPORTING BASELINE AND SITUATIONAL ANALYSIS

C.1 Hydrology and Water Resources

There are a number of gauging stations in the Sekong Basin, most of them in the lower parts, for example, at Attapeu, and the quality of the data is not known. Some stations measure only gauge height and thus do not provide data relevant to the present study. Meynell (2014) states that the records from Attapeu are the most comprehensive dataset of flows in the Sekong. There are also a number of meteorological stations, but most of the series are intermittent, with many missing values.

Map C.1: Mean Annual Precipitation



Mean annual rainfall of the Sekong Basin ranges from 1,400 mm to 2,900 mm (Meynell 2014). Nearly 60 percent of the basin receives 1,700 mm to 1,900 mm per year, and 23 percent receives 2,300 mm to 2,700 mm. Mean annual temperature of the Sekong Basin is 21°C to 28°C. Temperatures in 56 percent of the basin are 21°C to 22°C, but approximately 33 percent of the area experiences much higher temperatures. Distribution of mean annual rainfall over the basin is shown in Map C.1 and temperature in Map C.2.

Map C.2: Mean Annual Temperature

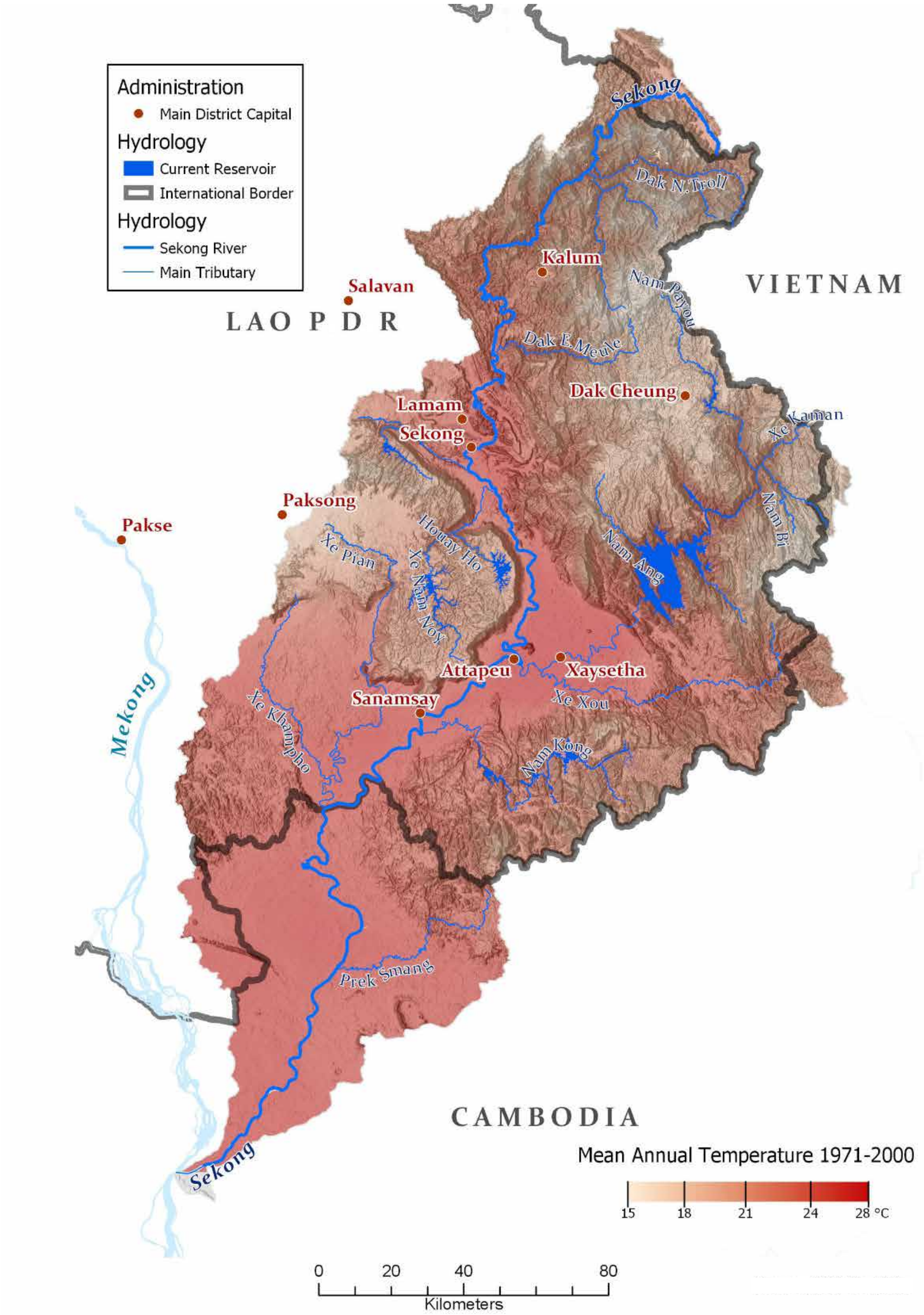
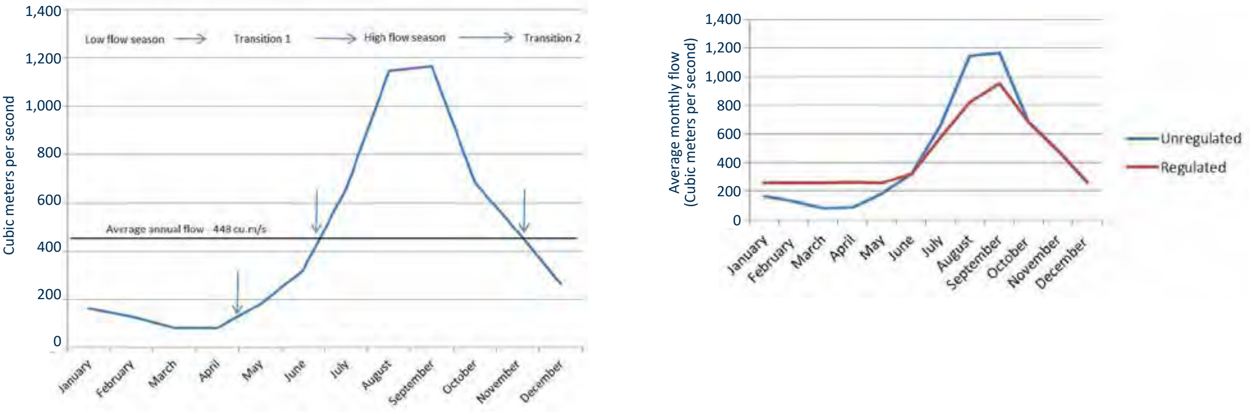


Figure C.1: Mean Monthly Flow Distribution for the Sekong River at Attapeu—Transitions from Low- to High-Flow Phases and Effect of Regulation due to Hydropower Reservoirs in Basin



a. Average monthly flows in Sekong at Attapeu (1989–2005)

b. Comparison of average monthly flows in a fully regulated Sekong

Source: Meynell 2014.

Figure C.1 shows how the Sekong River flow changes during the year in response to monsoonal rainfall patterns. Transitions from low- to high-flow phases are indicated in panel a. The effect of regulation due to hydropower reservoirs in the basin is illustrated in panel b.

C.2 Fish Diversity

Fish and other aquatic resources from the Sekong River are important for the population's livelihood, second only to agriculture as a source of income (IUCN, n.d.). Fisheries contribute 35 percent to 40 percent of annual household income through trade or sale and provide 80 percent of the protein consumed in the basin. In the Lao PDR part of the basin, mean annual consumption of fish has been estimated at nearly 50 kg per person.

As the last major free-flowing tributary to the Mekong River, the Sekong River provides unobstructed passage for migratory fish between the headwaters and the South China Sea, via the Mekong mainstream, the Tonle Sap Great Lake, and the Vietnam Delta. As such, the Sekong River contains a high level of fish diversity and endemism, with many species spawning only in its unique habitats. Estimates of numbers of fish species in the Sekong River vary from 175 to 265, with approximately two-thirds of these being migratory.[1] Geographic data from the International Union for Conservation of Nature (IUCN) between 2007 and 2013 suggest that 21 endangered and critically endangered fish species are present in the basin (Table C.1) (IUCN 2017). Some of the IUCN distribution data are old, however, and several species have a very small overlap with the Sekong Basin, which could indicate that there are actually fewer endangered fish species in the Sekong Basin.

Thirty-one of 62 fish conservation zones[2] in Lao PDR are within the Sekong Basin (Map 3.2)—half the national total. There are four national protected areas (NPAs) and one Ramsar site in the Sekong Basin (Map 3.3). The Ramsar site is the Beung Kiat Ngong Wetland, which is 2,360 hectares of swamps, lakes, and marshes that are important for spawning fish, turtles, and birds. It contains more than 350 species of medicinal plants and is the only place in Lao PDR where peatland is found.[3]

During provincial and village consultations, it was reported that fish diversity and abundance have declined drastically in the last 15 years in Champasak, Sekong, and Attapeu provinces. This was attributed to the combined pressures of overfishing, industry, mining, agriculture, and hydropower development on the tributaries. Extremely high rates of decline in total fish abundance were noted, including important food fish species such as *Poropuntius*, *Schistura*, and *Sewillia*.

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[1] Meynell (2014) reports 213 species on the Sekong, of which 64 are identified as migratory.

[2] Fish conservation zones are legally defined protected areas where fishing is prohibited to help restore fish stock. This is a community co-management framework in which locals actively help enforce the regulations. http://www.wwf.org.la/projects/comfish/

[3] https://rsis.ramsar.org/ris/1941

Table C.1: Endangered and Critically Endangered Fish Species Where Geographic Ranges Overlap the Sekong Basin

Scientific name	English name	International Union for Conservation of Nature Red List status	Status consultations
Aaptosyax grypus	Mekong giant salmon carp	Critically endangered	Very rare
Catlocarpio siamensis	Giant carp	Critically endangered	Reported in the Sekong River and main tributaries
Datnioides pulcher	Siamese tiger perch	Critically endangered	Reported in Pak Kayong area
Hemitrygon laosensis	Mekong freshwater stingray	Critically endangered	Reported in the Sekong River and main tributaries
Laubuca caeruleostigmata	Flying minnow	Critically endangered	Reported in Pak Kayong area
Pangasianodon gigas	Mekong giant catfish	Endangered	Potentially gone
Pangasianodon hypophthalmus	Striped catfish	Endangered	Reported in Pak Kayong area
Pangasius sanitwongsei	Giant pangasius	Endangered	Reported in the Sekong River
Poropuntius bolovenensis	n.a.	Endangered	Reported in Pak Kayong and Nong Kheuang Yai areas
Poropuntius consternans	n.a.	Endangered	Reported in Pak Kayong, Nong Kheuang Yai, and Phaosamphan areas
Poropuntius deauratus	n.a.	Endangered	Reported in Nong and Kheuang Yai areas
Poropuntius lobocheiloides	n.a.	Endangered	Reported in Pak Kayong area
Poropuntius solitus	n.a.	Endangered	Reported in Pak Kayong area
Pristis pristis	Large-tooth sawfish	Endangered	Very rare
Probarbus jullieni	Julien's golden carp	Endangered	Reported in the Sekong River and main tributaries
Probarbus labeamajor	Thick-lipped barb	Endangered	Reported in Nang Yong and Nong Kheuang Yai areas
Schistura bairdi	n.a.	Endangered	No information
Schistura bolavenensis	n.a.	Endangered	Reported in small upstream streams
Schistura spilotera	n.a.	Endangered	Reported in Nang Yong area
Sewillia breviventralis	Butterfly loach	Critically endangered	Reported in Nong Kheuang Yai area
Urogymnus polylepis		Endangered	No recent sightings

Note: n.a. = not applicable.

C.3 Ecosystems and Natural Resources

The IUCN (2017) Red List indicates that there are many flora and fauna species in the Sekong Basin, and some are threatened (Table C.2). According to the Integrated Biodiversity Assessment Tool, there are approximately 89 globally threatened vertebrate species, of which 21 are critically endangered, 32 endangered, and 36 vulnerable. The species list contains 18 birds, 28 mammals, eight reptiles, 31 fishes, and two amphibians.

Many of the reported globally threatened species have small population numbers and are threatened across the Sekong Basin because of overfishing, hunting, habitat loss, land use change, and deforestation, but there are areas across the basin that function as refuge areas for threatened species, such as the Xe Pian NPA. The basin's wildlife zones are as follows:

- *Montane forest in upper Sekong (Kaleum)*. Forest condition remains good in the Xe Sap NPA at the Sekong headwaters and along the Lao–Vietnamese border, which is designated as a biodiversity corridor area. The lower area of the upper Sekong is more degraded and has been transformed into secondary forest and fallow and hill rice agricultural land.
- *Pine forest (Dak Cheung)*. Pine forest condition remains good in the northeast of Dak Cheung of Sekong Province along the Lao PDR–Vietnamese border as part of the biodiversity conservation corridor and to the south along the Phou Kathong National Protection Forest and biodiversity conservation corridor. Few endangered species reside here, but there are some gibbon and douc langur. Along the road from the Sekong provincial capital to Dak Cheung, the pine forest is highly degraded.
- *Mixed evergreen forests*. Forest condition remains good in the Dong Ampham NPA and along the Lao PDR–Vietnamese border, which is designated as a biodiversity corridor area. Various large mammals are reported in this sub-ecosystem zone, such as Asian elephants, banteng, gaur, gibbons, and douc langur.
- *Mixed deciduous forest (Nam Kong)*. Forest condition remains good in the upper hills, on the border with Cambodia from Ban Phou Nyang on the east of Phouvong District and to the western part of Phouvong District. The number of large mammals here is similar to that of the Dong Ampham NPA. The forest in the lower foothills and along the access road to Nam Kong 1, 2, and 3 hydropower plants (HPPs) is degraded, and secondary forest and hill rice cultivation prevail. Large rubber tree plantations are situated along the road from Phouvong District to Nam Kong 1 HPP.
- *Bolaven upper evergreen forest (Paksong)*. Forest condition is fairly good in Xe Khampho area, Houy Ho watershed, upper Xe Pian–Xe Namnoy, and upper Xe Katam. Various large mammals such as Asian elephants, tiger, gaur, and gibbons have been reported in this area. Parts of this subzone, especially along the roads, have been converted into cash crop plantations, especially coffee plantations.
- *Floodplain*. Wetland and riparian ecosystems with dry dipterocarp forest (the Xe Pian NPA) prevail here, and forest condition remains good. Various large mammals are reported here, such as tiger, banteng, gaur, gibbon, and douc langur. This area contains wetland and seasonal wetland complexes with dry dipterocarp forest landscapes. Some of the wetland areas have been exploited and are thus degraded.

Table C.2: Globally Threatened Fauna (Vertebrate) Species in the Sekong Basin

Taxon	Critically endangered	Endangered	Vulnerable	Total
Birds	7	5	6	18
Mammals	5	10	13	28
Reptiles	2	2	4	8
Amphibians	0	2	0	2
Fish	7	13	13	31
Total	**21**	**32**	**36**	**89**

Source: IUCN 2017. https://www.iucnredlist.org/.

C.4 Supporting Analysis on Terrestrial Ecology

C.4.1 Selection of Indicator Species

A list of terrestrial species in the Sekong Basin that were critically endangered and endangered was derived from the IUCN Red List with the Sekong Basin boundaries and from the Integrated Biodiversity Assessment Tool (IBAT) database (IUCN 2017 and IUCN n.d.). See Table C.3.

Table C.3: **Globally Threatened Fauna Species According to IBAT and Zone**

Scientific name	Common name	Conservation status	Upper Sekong		Dak Cheung		Dong Ampham		Nam Kong		Pak Song		Lower Sekong	
			IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present
Amphibian														
Leptobrachium xanthops	Giant frog	Endangered	X		X		X		X					
Leptolalax melicus	Musical leaf-litter toad	Endangered			X		X		X					
Bird														
Asarcornis scutulata	White-winged duck	Endangered					X		X				X	X
Ciconia episcopus	Woolly-neck stork	Vulnerable	X		X		X	X	X				X	X
Clanga	Greater spotted eagle	Vulnerable	X		X		X	X	X		X		X	
Emberiza aureola	Yellow-breasted bunting	Critically endangered									X		X	
Garrulax konkakinhensis	Chestnut-eared laughing thrush	Vulnerable	X		X		X		X					
Gracula robusta	Nias hill myna	Critically endangered	X		X		X		X		X		X	
Gracula venerata	Tenggara hill myna	Endangered	X		X		X		X		X		X	
Gyps bengalensis	White-rumped vulture	Critically endangered	X		X		X	X	X	X	X		X	X

Scientific name	Common name	Conservation status	Upper Sekong		Dak Cheung		Dong Ampham		Nam Kong		Pak Song		Lower Sekong	
			IBAT data	**Present**	**IBAT data**	**Present**	**IBAT data**	**Present**	**IBAT data**	**Present**	**IBAT data**	**Present**	**IBAT data**	**Present**
Gyps tenuirostris	Slender-billed vulture	Critically endangered	X		X		X		X		X		X	
Mulleripicus pulverulentus	Great slaty woodpecker	Vulnerable	X	X	X		X	X	X		X		X	X
Pavo muticus	Green peafowl	Endangered	X		X		X	X	X	X	X		X	X
Sarcogyps calvus	Red-headed vulture	Critically endangered	X		X		X		X		X		X	X
Leptoptilos javanicus	Lesser adjutant	Vulnerable					X	X			X		X	X
Heliopais personatus	Masked finfoot	Endangered			X		x						X	
Sterna acuticauda	Black-bellied tern	Endangered			X		X		X		X		X	
Pseudibis davisoni	White-shouldered ibis	Critically endangered											X	X
Pseudibis gigantean	Giant ibis	Critically endangered											X	X
Grus antigone	Sarus crane	Vulnerable											X	X
Fish														
Bangana behri		Vulnerable	X		X		X		X				X	
Hypsibarbus lagleri		Vulnerable											x	
Labeo pierrei		Vulnerable	X		X									
Pangasius sanitwongsei	Giant pangasius	Critically endangered	X				X		X				X	X
Aaptosyax grypus	Mekong giant salmon carp	Critically endangered							X				X	X
Catlocarpio siamensis	Giant carp	Critically endangered											X	X
Cirrhinus microlepis	Small-scaled mud carp	Vulnerable											X	
Epalzeorhynchos munense	Red fin shark	Vulnerable							X				X	
Datnioides pulcher	Siamese tiger perch	Critically endangered									X		X	X
Datnioides undecimradiatus		Vulnerable											X	

Scientific name	Common name	Conservation status	Upper Sekong		Dak Cheung		Dong Ampham		Nam Kong		Pak Song		Lower Sekong	
			IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present
Laubuca caeruleostigmata	Flying minnow	Endangered											X	X
Osphronemus exodon	Elephant ear gourami	Vulnerable							X				X	
Hemitrygon laosensis	Mekong freshwater stingray	Endangered											X	X
Pangasianodon hypophthalmus	Striped catfish	Endangered											X	
Pangasius krempfi		Vulnerable											X	
Poropuntius bolovenensis		Endangered	X		X									
Poropuntius consternans		Endangered	X		X									
Poropuntius deauratus	Yellow tail brook barb	Endangered	X		X									
Poropuntius lobocheiloides		Endangered	X		X									
Poropuntius solitus		Endangered	X		X									
Pristis	Large tooth sawfish	Critically endangered	X											
Probarbus jullieni	Jullien's golden carp	Endangered											X	X
Schistura spiloptera													X	
Pangasianodon gigas	Mekong giant catfish	Critically endangered											X	
Probarbus labeamajor	Thick-lipped barb	Endangered											X	
Tenualosa thibaudeaui	Mekong herring	Vulnerable											X	
Urogymnus polylepis		Endangered											X	
Scaphognathops bandanensis		Vulnerable											X	
Pseudohemiculter dispar		Vulnerable	X		X		X		X					
Schistura bolavenensis		Endangered	X		X									
Yasuhikotakia nigrolineata	Black-lined loach	Vulnerable	X		X								X	

Scientific name	Common name	Conservation status	Upper Sekong		Dak Cheung		Dong Ampham		Nam Kong		Pak Song		Lower Sekong	
			IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present
Schistura kontumensis		Vulnerable					X		X					
Sewellia breviventralis	Butterfly loach	Critically endangered					X		X					
Mammal														
Orcaella brevirostris	Irrawaddy dolphin	Vulnerable							X				X	
Rucervus eldii	Eld's deer	Endangered											X	
Aonyx cinereus	Asian small-clawed otter	Endangered											X	
Arctictis binturong	Binturong	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Arctonyx collaris	Greater hog badger	Vulnerable	X	X	X		X	X	X	X	X	X	X	X
Bos gaurus	Gaur	Vulnerable	X	X	X		X	X	X	X	X	X	X	X
Bos javanicus	Banteng	Endangered					X	X					X	X
Bos sauveli	Kouprey	Critically endangered					X		X		X		X	
Cuon alpinus	Dhole	Endangered		X		X	X	X	X	X	X	X	X	X
Chrotogale owstoni	Owston's civet	Endangered	X	X	X		X	X	X					
Elephas maximus	Asian elephant	Endangered	X		X		X	X	X	X	X		X	
Lutrogale perspicillata	Smooth-coated otter	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Macaca arctoides	Stump-tailed macaque	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Macaca leonina	Northern pig-tailed macaque	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Manis javanica	Sunda pangolin	Critically endangered	X	X	X	X	X	X	X	X	X	X	X	X
Manis pentadactyla	Chinese pangolin	Critically endangered	X	x	X		X		X		X			
Muntiacus vuquangensis	Large-antlered muntjac	Critically endangered	X	X	X		X		X					
Neofelis nebulosa	Clouded leopard	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X

Scientific name	Common name	Conservation status	Upper Sekong		Dak Cheung		Dong Ampham		Nam Kong		Pak Song		Lower Sekong	
			IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present	IBAT data	Present
Nomascus gabriellae	Buff-cheeked gibbon	Endangered	X	X	X	X	X	X	X	X		X	X	X
Nycticebus bengalensis	Bengal slow loris	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Nycticebus pygmaeus	Pygmy slow loris	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Panthera tigris	Tiger	Endangered	X	X	X		X	X	X	X	X	X	X	X
Pseudoryx nghetinhensis	Saola	Critically endangered	X	X										
Pygathrix nemaeus	Red-shanked douc langur	Endangered	X	X	X		X	X	X	X	X	X		
Rusa unicolor	Sambar	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X
Trachypithecus germaini	Indochinese lutung	Endangered	X	X	X	X	X	X	X	X	X	X	X	X
Ursus thibetanus	Asiatic black bear	Vulnerable	X	X	X	X	X		X	X	X	X	X	X
Viverra megaspila	Large-spotted civet	Endangered	X	X	X		X		X		X		X	
Reptile														
Bungarus slowinskii	Red river krait	Vulnerable	X		X		X		X					
Crocodylus siamensis	Siamese crocodile	Critically endangered	X		X		X		X				X	X
Cuora bourreti	Bourret's box turtle	Critically endangered	X		X		X	X	X					
Cuora mouhotii	Keeled box turtle	Endangered	X		X		X		X					
Naja siamensis	Black and white spitting cobra	Vulnerable	X		X		X		X		X		X	
Ophiophagus hannah	King cobra	Vulnerable	X	X	X	X	X	X	X	X	X		X	X
Protobothrops sieversorum	Three-horned scaled pit viper	Endangered	X		X		X		X					
Python bivittatus	Burmese python	Vulnerable	X	X	X	X	X	X	X	X	X	X	X	X

Note: Some super-endemic fish species that are not globally threatened were excluded. IBAT = Integrated Biodiversity Assessment Tool.

The species from the list were discussed with regard to their presence and estimated population size during the stakeholder consultations in the field with local communities and at the district level with relevant officers in September 2018. Then the criteria for short-list selection of species was applied. The selection criteria considered not only conservation status of globally threatened species but also species' uniqueness, sensitivity, connectivity, and importance for food, beliefs, economic value, and the like. A score from 0 to 3 was given for each criterion. See Table C.4.

Terrestrial species with a total score of 6 points or higher were selected for the short list (Table C.5).

Table C.4: Criteria for Selection of Short List for Terrestrial Species

Characteristic	Points
Unique, super-endemic species with limited distribution and requiring specific habitats	2
Species requiring large areas for ranging and sensitive to decreased habitat connectivity	3
Species particularly sensitive to habitat disturbance	2
Identified by species stakeholders as important for food and livelihoods	1
Species assessed as important for conservation by environmental specialists	3
Species with importance for cultural values and belief systems	2
Critically endangered species	2
Endangered species	1
Vulnerable species	0.5

Table C.5: Short List of Selected Terrestrial Species for Detailed Valued Environmental Component Analysis

Scientific name	English name	Conservation status
Nomascus anamensis	Buff-cheeked gibbon	Endangered
Pygathrix nemaeus	Red-shanked douc langur	Endangered
Elephas maximus	Asian elephant	Endangered
Crocodylus siamensis	Siamese crocodile	Critically endangered
Pavo muticus	Green peafowl	Endangered
Bos javanicus	Banteng	Endangered
Pseudibis davisoni	White-shouldered ibis	Critically endangered
Sterna acuticauda	Black-bellied tern	Endangered

Source: IUCN 2017.

C.4.2 Assessing Effects on Terrestrial Fauna and Valued Sekong Basin Habitats

Habitat loss or inundation from hydropower reservoirs is a direct effect, but habitat fragmentation can also create indirect habitat pressure by blocking movement of various terrestrial species. Associated access roads may also increase chances for hunting and harvesting of forest resources.

Effects on terrestrial biodiversity have been estimated based on area of habitat loss of protected areas and calculated as follows for the different pathways:

Habitat loss = Total reservoir area / Total protected area affected

Degree of habitat loss, calculated in percentage of total protected area, can be categorized or ranked (Table C.6).

Table C.6: Habitat Loss

Habitat loss (percentage take of protected area)	Score	Degree of habitat loss (modification)
≥ 20	4	Severe
15–20	3	High
5–10	2	Moderate
> 5	1	Slight

Transmission lines. The zone of influence of a transmission line is wider than the strip of land that the transmission line takes, covering the indirect effects on biodiversity in the conservation area (for example, from greater poacher access for hunting, wildlife trade, collection of forest products, and simple disturbance by people using the transmission line corridor and its access roads). It is calculated by taking a one-kilometer zone of influence on each side of the transmission line as it traverses the conservation area. The calculation of zone of influence is as follows:

$$\text{ZoI} = \sum[\text{width} + 2(1\text{km}) \times \text{length}]$$

A *degree of fragmentation* refers to the effects of separating wildlife populations from each other within a conservation area. Many species cannot or do not (because they are frightened) cross open spaces such as those that transmission lines create because they require unbroken, undisturbed habitat. As a result, the areas of continuous habitat become smaller and have smaller carrying capacities for the species than the original, undisturbed area. This may result in the decline or local extinction of some species; existing transmission lines and roads may already have fragmented some conservation areas under the present situation (2020). New reservoirs, transmission lines, and access roads will increase fragmentation for the different pathways by 2030. Degree of fragmentation was ranked (Table C.7).

Table C.7: Fragmentation

Degree of fragmentation	Number of fragments	Size of largest fragment as percentage of original protected area
Total	6	25–49
Partial	4	50–79
Minimal	2	80–99
None	0	100

The degree of fragmentation indicator was used to estimate the number of conservation areas that transmission lines, reservoirs, and access roads would fragment under each pathway.

Project location and threatened species.
The location of each project, especially reservoirs and transmission lines, will affect the degree of threat to biodiversity. If renewable energy projects, dams, or reservoirs are located entirely or mainly inside a protected area, the threat is considered severe (Table C.8).

Table C.8: Threat to Biodiversity

Location	Score	Threat to biodiversity
Wholly or mainly inside protected area	4	Severe
1 kilometer from protected area	3	High
5 kilometers from protected area	2	Moderate
> 5 kilometers from protected area	1	Slight

The protected areas also have differences in importance based on the number of globally threatened (critically endangered, endangered, and vulnerable) species in them. With more globally threatened species, risks to biodiversity are assumed to be higher. The number of globally threatened species in each protected area was based on the Integrated Biodiversity Assessment Tool website.

Globally threatened terrestrial species were categorized as shown in Table C.9.

Table C.9: Globally Threatened Species in Protected Areas

Number of globally threatened species present in protected areas	Score	Importance of protected areas for biodiversity
≥ 30	4	Very high
20–29	3	High
10–19	2	Medium
< 10	1	Low

A final composite assessment (scored from 0 to 4, in line with the general valued environmental component assessment) of protected areas affected by renewable energy projects and their transmission lines was calculated. The composite scoring considered level of habitat loss, location of energy projects with regard to protected areas, level of fragmentation, and number of globally threatened species within a protected area affected by an energy project.

C.4.3 Cumulative Impact Assessment Analysis and Results

Impacts on selected indicator species (Table C.5) were assessed with regard to changes in forest habitat and key conservation areas for the present situation and the three future pathways. Several of the other valued environmental components depend on forest habitat for sustainable use or conservation, including hardwood timber, non-timber forest products (assessed under Chapter 3 in Main Report), valued terrestrial fauna, and protected areas and key biodiversity areas. Forest loss, including of conservation forest, is discussed in Chapter 3.

Forest areas are under pressure in the Sekong Basin, and the resource base has declined in recent decades. Hydropower development is likely to contribute to this continued decline because it will inundate additional forested areas. The estimated loss of forest types under the different pathways is presented in Table C.10.

Hydropower development is only one cause of forest loss in the Sekong River Basin, with logging and conversion of forest to mining and plantation land also playing significant roles. Mining has placed as much or more pressure on forest land than hydropower, and if new concessions in the basin are granted, this pressure is likely to increase.

Table C.10: Summary of Inundated Forest Areas Under Each Pathway

Development pathway	Production forest (hectares)	Conservation forest and/or national protected areas (hectares)	Protection forest (hectares)	Regeneration forest (hectares)	Total forest loss (hectares)
Present situation	422	3,408	12,924	118	16,872
Full	5,843	2,324	860	1,743	11,196
Intermediate	651	2,192	500	1,928	5,271
Conservative	651	625	86	1,928	3,290

C.4.4 Key Conservation Areas

The status of conservation areas important for terrestrial fauna under the present situation was compared with that under the full development pathway (Table C.11). Several of the selected indicator species are found in these key conservation areas. In the present situation, the Dong Ampham National Protected Area (NPA) has lost 1.86 percent (3,641 hectares), and the Nam Kong National Protected Forest (NPF) has lost 0.46 percent (937 hectares). Specifically, the Xe Khaman 1 and Nam Kong 3 projects have caused habitat fragmentation of these conservation areas. Transmission lines from the Nam Kong 2 and 3 dams to the main grid have also fragmented these conservation areas.

Under present conditions, the cumulative effect on the Dong Ampham NPA is of high concern (with an average cumulative impact score of 3.00, large); that of the Nam Kong and Bolaven Upstream NPFs is slightly less but still moderate to large (score of 2.25 for both). The effect on the Dong Ampham NPA is slightly higher for the full development pathway (score 3.25, large). For the Nam Kong and Bolaven Upstream NPFs, there will be minor differences, whereas the effect on the Xe Pian and Xe Sap NPAs is greater (Table C.11).

Two thousand hectares less will be affected in key conservation areas under the conservative development pathway (with no Sekong mainstream dams) than under the full development pathway. This is specifically related to no development of Sekong 5 in the Xe Sap NPA and Sekong Downstream A in the Nam Kong NPF. The conservation value of the Xe Sap NPA will be maintained because no area will be taken, and there will be no fragmentation related to hydropower plant development.
For the intermediate pathway, Sekong 5 will affect the Xe Sap NPA. Sekong 4B is not associated with any important conservation areas.

Table C.11: Estimated Cumulative Impacts of Key Conservation Areas

Key conservation area	Number of projects	Project footprint (hectares)	Impact score according to category				Cumulative impact score
			Level of habitat loss	Number of projects interacting	Degree of fragmentation	Globally threatened species	
Present situation							
Dong Ampham NPA	2	3,641	2	4	2	4	3.00
Nam Kong NPF	3	937	1	4	2	4	2.75
Xe Pian NPA	1	10	1	2	0	4	1.75
Xe Sap NPA	0	0	0	0	0	4	1.0
Boloven NPF	9	12,706	3	3	2	3	2.75
Full development pathway							
Dong Ampham NPA	8	4,266	3	4	2	4	3.25
Nam Kong NPF	5	1,048	1	4	2	4	2.75
Xe Pian NPA	1	10	1	4	0	4	2.25
Xe Sap NPA	1	1,567	1	4	1	4	2.50
Boloven NPF	13	13,204	3	3	2	3	2.75

Note: NPA = National Protcted Area; NPF = National Protected Forest.

C.4.5 Indicator Species

Development of renewable energy projects in the Sekong Basin will threaten Asian elephants most under the present situation and gibbons as well under the full development pathway. This is not only because of development of renewable energy projects but also because of additional stressors and drivers such as mining, road development, plantations, hunting, and population increase in general. Human conflict with Asian elephants in the Sekong Basin has been reported at Ban Houy in Xanxay District due to the construction of the Xe Khaman 1. Also, greater road access as part of the renewable energy development projects may lead to more hunting and habitat disturbance, which could also threaten gibbons, banteng, red-shanked douc langurs, white-shouldered ibis, green peafowl, and Siamese crocodiles. The development pathways are not the greatest pressure on wildlife species, and there will be marginal differences between them.

The full development pathway will affect forest habitats, key conservation areas, and terrestrial fauna moderately, and the conservative and intermediate pathways will affect them slightly to moderately. Other factors such as mining, plantations, transmission line and road development, hunting, and forest resource extraction will cumulatively exacerbate the effect of all pathways.

C.5 Renewables

Other than hydropower, there are currently no renewable energy projects in the Sekong Basin, although investors are exploring a number of possible solar and wind projects. These plans are outlined below.

C.5.1 Solar Photovoltaic Energy

Solar photovoltaic investments are expanding rapidly throughout the world because of falling costs of panels and large-scale project development. Recent tenders indicate that solar will soon become economical without subsidies wherever sunlight is plentiful and land is inexpensive (near the tropics and in non-forested areas not used for agriculture or other purposes). The potential for solar is high in Lao PDR but not necessarily in remote regions and forested areas.

Solar power and hydropower can be integrated in pump storage design whereby solar energy is used to pump water into hydropower reservoirs during the day when the sun is shining and used for hydropower generation at night.

In the Sekong Basin, nine proposals for large-scale, ground-mounted solar photovoltaic plants with the potential to provide up to 5 terawatt-hours (TWh) of energy per year have been identified. The aggregate land take of these projects will be more than six square kilometers, mostly in Attapeu Province, although only three projects have memoranda of understanding, and there will be challenges with integrating such large projects into the existing weak transmission grid and balancing rapid fluctuations in solar output.

Large-scale solar projects in the Sekong Basin will presumably be designed for export because existing hydropower already satisfies energy demand from Lao consumers on the southern grid. Access to long-distance transmission lines will be required, but even large-scale solar projects may not be able to finance dedicated transmission lines because they generally have a low plant utilization factor (15–20 percent). Solar projects will therefore be more feasible where transmission capacity already exists, for example, where hydropower projects are exporting to Vietnam and Thailand.

C.5.2 Floating Solar Photovoltaic

The owner of Xe Kaman 1 reservoir, the Viet-Lao Joint Stock Company, in partnership with Convalt Energy has proposed floating solar power as an addition to the HPP at Xe Kaman 1 reservoir. A press release from June 2018 indicates that 250 megawatts (MW) of ground-mounted solar and 280 MW of floating solar will be developed. This presumably can be exported to Vietnam through existing transmission lines.

By 2017, the largest floating solar plant in the world[4] had reached 40 MW, and larger ones are being planned, so it is conceivable that a 280-MW plant could be realized within the planning horizon of 2030 at an energy price of $0.07 to $0.1 per kilowatt-hour (levelized cost of energy). Annual energy production is expected to be approximately 400 gigawatt-hours (GWh) from a 280-MW plant, mainly outside the monsoon season, which supplements maximum hydropower production in the wet season.

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[4] The largest plant is in Huainan, in China's eastern Anhui Province. See WEC (2017).

Nevertheless, it is unlikely that maximum output in megawatts from the Xe Kaman 1 HPP will change from the current capacity of the grid connection to Vietnam until the first phase of solar photovoltaic projects has been tested and proven successful and economical. Some additional investments may be needed in reactive compensation to maintain voltage stability. The Vietnam power system uses hydropower for daily peaking operations, and as such, the floating solar project cannot provide additional peaking power capacity to Vietnam and will not increase export capacity of guaranteed power.

Because of variable weather conditions, delivery of solar power at the time of peak demand cannot be guaranteed. Solar energy is, therefore, usually regarded as a supplement to firm power and so is likely to attract a lower price than hydropower, which delivers reliable power during peak demand.

In principle, similar floating solar plants could be introduced on other larger hydropower reservoirs in the Sekong Basin, and the technology is rapidly being introduced on an increasingly larger scale around Asia (including China and the Greater Mekong subregion).[5] The main advantage over ground- and roof-mounted arrangements is that floating plants avoid loss of land.

There is little published research on the environmental effect of floating solar because the technology is new. On nutrient-rich water it can be expected that the reduction in light caused by the surface floats would reduce local primary production of phytoplankton and so reduce risk of eutrophication. The shade could also provide refuge for fish normally subject to predation from surface or airborne predators. Conversely, a reduction in phytoplankton could cause a reduction in zooplankton and thus a decline in fishery productivity. There are likely to be some positive and some negative environmental effects, but in cases in which floating solar alleviates the need for new dam developments and regulation of river systems, the overall effect is likely to be positive.

Solar photovoltaic on a hydropower reservoir surface can provide renewable energy that involves minimal environmental and social conflict provided other reservoir users (for example, boatmen and fishermen) are involved in siting decisions. If the technology takes off by 2030, it should be viewed as a provider of additional renewable energy, not of reliable peak power. No other floating solar investments have, therefore, been incorporated into the base-case scenario, although they might be studied in the other pathways.

An assumption of 1,000 GWh of additional energy from 600 MW of ground-mounted and floating solar photovoltaic seems reasonable for future developments, but one can assume no peak power transfer in addition to what the hydropower projects can provide to fulfill export agreements.

C.5.3 Wind Power

A Thai investor group has proposed the first wind power project in Lao PDR. The 600-MW Monsoon Wind Power project will occupy 68,000 hectares in Sekong and Attapeu Provinces roughly where indicated in Map C.3. This location was chosen not only because of its promising sources of wind energy but also because of limited conflicting land use. The new transmission line for the project requires less than 40 kilometers to connect to the 220-kilovolt (kV) Électricité du Vietnam (EVN) grid in Vietnam, and export of power to Vietnam seems likely, although the Thai project sponsors are exploring options for exporting to Thailand. The investors have conducted public consultations with nearby villages; no resettlement of local communities is envisaged.

In this part of Lao PDR, average monthly wind speed is highest from October to January, when hydropower output from run-of-river plants is receding. The wind energy would therefore supplement hydropower, and it is quite likely that the project can be financed and commissioned by 2030, especially if the planned 220-kV transmission connector to Vietnam is also constructed. It is not known how much energy the plant could provide, but a reasonable estimate would be 1.5 TWh to 2.0 TWh annually. This exceeds domestic demand forecasts, and therefore it is assumed that it will become part of the planned export quota for Thailand or Vietnam, although as with floating solar photovoltaic, the output is unreliable and not suited to peak power exports.

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[5] The Greater Mekong Subregion is a natural economic area bound together by the Mekong River and covering 2.6 million square kilometers with a combined population of approximately 326 million. It includes Cambodia, the People's Republic of China (specifically, Yunnan Province and Guangxi Zhuang Autonomous Region), Lao PDR, Myanmar, Thailand, and Vietnam. See Asian Development Bank, "Greater Mekong Subregion," https://www.adb.org/countries/gms/main.

Map C.3: Location of Proposed Monsoon Wind Park and Various Solar Farms

In the Sekong Basin, the largest environmental and social effects of large wind farms are likely to be from land take, new access roads and transmission lines, and the possible effect on local bird life. Installation of modern land-based wind power requires long, straight access roads to transport the more than 60-meter-long blades from the nearest port. Although the International Energy Agency has quoted a need for a land area of 60 square kilometers, only a small percentage of this land will be directly affected for access roads, foundations, and crane stand areas. The area is unlikely to include primary forest with high tree canopy because such a site would be unsuitable for wind power. It is not known how visible the turbines would be from any nearby sites of tourist interest.

C.6 Grid Expansion and Other Infrastructure

C.6.1 Transmission Lines in the Sekong Basin

The Electricité du Laos (EDL) transmission system in the Sekong Basin currently operates at 115 kV, with the main supply from the Xeset HPPs to the north of the basin and Houay Lamphan in the west on the Bolevan Plateau.

There are 230-kV transmission lines for export from Xe Kaman Sanxay going east into Vietnam and collecting power from other projects in the Xe Kaman tributary basin. Similarly, there is an export line from the Houay Ho project to Thailand and a separate export line from the Xe Pian–Xe Namnoy project to be commissioned in 2020.

C.6.2 International Grid Integration Plans

The Lao PDR Ministry of Energy and Mines, with support from international development partners, is exploring the possibility of connecting the separate power grids in Vietnam and Lao PDR. This will enable a considerable increase in ability to extract power from the Sekong region. The location and layout of the cross-border interconnection will determine the pace and pattern of development of many of the hydropower projects planned in the Sekong Basin.

The Lao PDR–Vietnam Power Interconnection Project includes extension of the 230-kV network already connected to Vietnam and run synchronously with the Vietnamese system. Three hundred and twenty-two MW from the Xe Kaman 1 and Xe Kaman Sanxay projects are already connected to Pleiku in Vietnam. The Nam Kong cascade of three power plants will add a further 270 MW when operational. There are also possibilities to connect the Sekong 3A and 3B projects and some small and medium HPPs to the same 230-kV system through 115-kV extensions from the Xe Kaman 1 substation. The design of this interconnector is expected to enable a maximum export load of 942 MW to Pleiku.

The Xe Kaman 3 project (250 MW) is connected to the EVN system at a substation at Thanhmy, north of Pleiku. The Nam Emoun project and Xe Kaman 4 would add a further 199 MW when they were completed in 2020. Up to five small hydropower projects with a total capacity of approximately 100 MW could also be connected, giving a maximum export capacity of 548 MW through this interconnector.

Both cross-border 230-kV connections will facilitate at least 1,500 MW of export to Vietnam. Alternative routes and configurations are being analyzed, with a major new switching station being planned at Hatxan near Sekong. The Lao PDR–Vietnam Power Interconnection project will fulfill the ambitions of both countries to increase power trade to 3,000 MW by 2025 and 5,000 MW by 2030. On this basis, it is likely that all of the hydro capacity proposed for the Sekong Basin can be exported to Vietnam or locally to the Lao PDR distribution system.

A long-term plan includes raising the transmission voltage to 500 kV, enabling large capacities to be exported while the grid systems of Lao PDR and Vietnam continue to operate as separate synchronous systems. Most of the Sekong mainstream projects (except Sekong 3A and 3B) must find alternative connection lines for export, including Sekong Downstream A and B, Sekong 4A and 4B, and Sekong 5.[6] The full development pathway would require export capacity for all these projects, but no information is available on how these projects will connect to Thailand or Vietnam.

C.7 Power Demand and Hydropower Operation and Dispatch

C.7.1 Institutional Set-Up

The power sector in Lao PDR is organized under the Ministry of Energy and Mines and the government-owned utility EDL. Pertinent features of the Lao PDR power system are summarized below:

- State-owned transmission and distribution network managed by a central electricity authority (EDL)
- Total electrical energy consumption in 2017 of 5,000 GWh
- Ninety-five percent electrification ratio but low per capita consumption of 600 kilowatt-hours per year
- High transmission and distribution losses
- Network connections with Thailand, China, and Vietnam
- Independent power producers owning most generation capacity
- Most independent power producer generation (>4,000 MW) exported to Thailand and Vietnam
- EDL transmission grid comprising three weakly connected power systems

For the Sekong cumulative impact assessment study, it is relevant to focus on the southern power grid and the transmission interconnections with Thailand and Vietnam. Although it is likely that the separate EDL power grids will be strengthened and operating under a single EDL dispatch center

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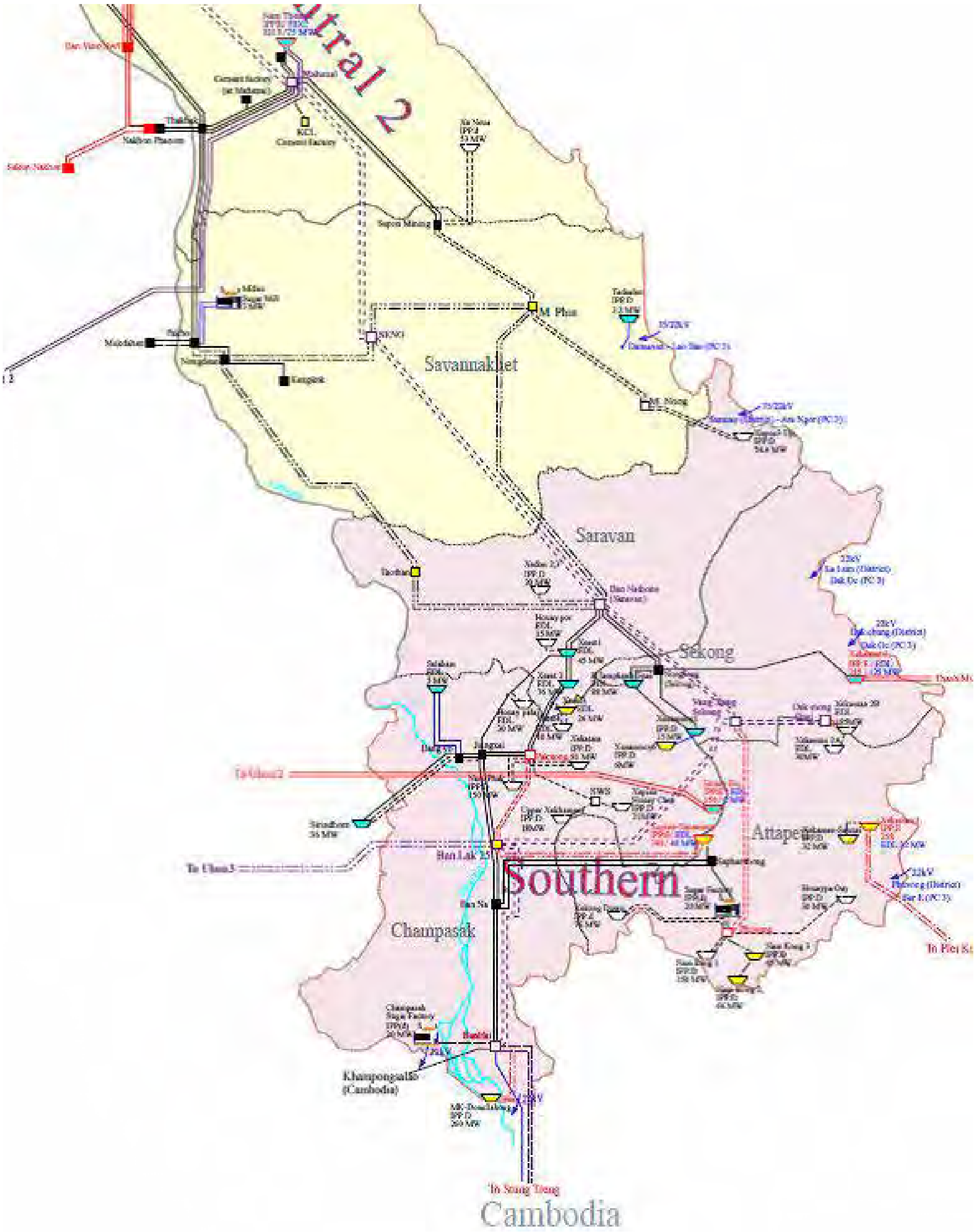
[6] The power destination is Lao PDR for Sekong Downstream A and B and Thailand for Sekong 4A, 4B, and 5.

by 2030, the EDL grid development has little relevance for the power sector base-case pathway definition. Because additional domestic electricity demand in Lao PDR is minimal, projects exporting peak power to Thailand and Vietnam will dominate hydropower development in the Sekong River Basin. This report therefore describes the expected power sector scenario for the basin in terms of each of the three countries: Lao PDR, Thailand, and Vietnam. Cambodia is expected to continue using domestic power resources rather than depend heavily on import from Lao PDR and is therefore not discussed here.

The southern EDL grid is at 115 kV and supplies only to the western part of the Sekong Basin (Map C.4). The eastern part is supplied from Vietnam and is therefore controlled from the Vietnamese dispatch center.

Map C.4: Power System (115 kV) of the Lao People's Democratic Republic, 2017



Note: Red lines are 230-kV lines for export.

C.7.2 Power Supply and Demand in Lao PDR

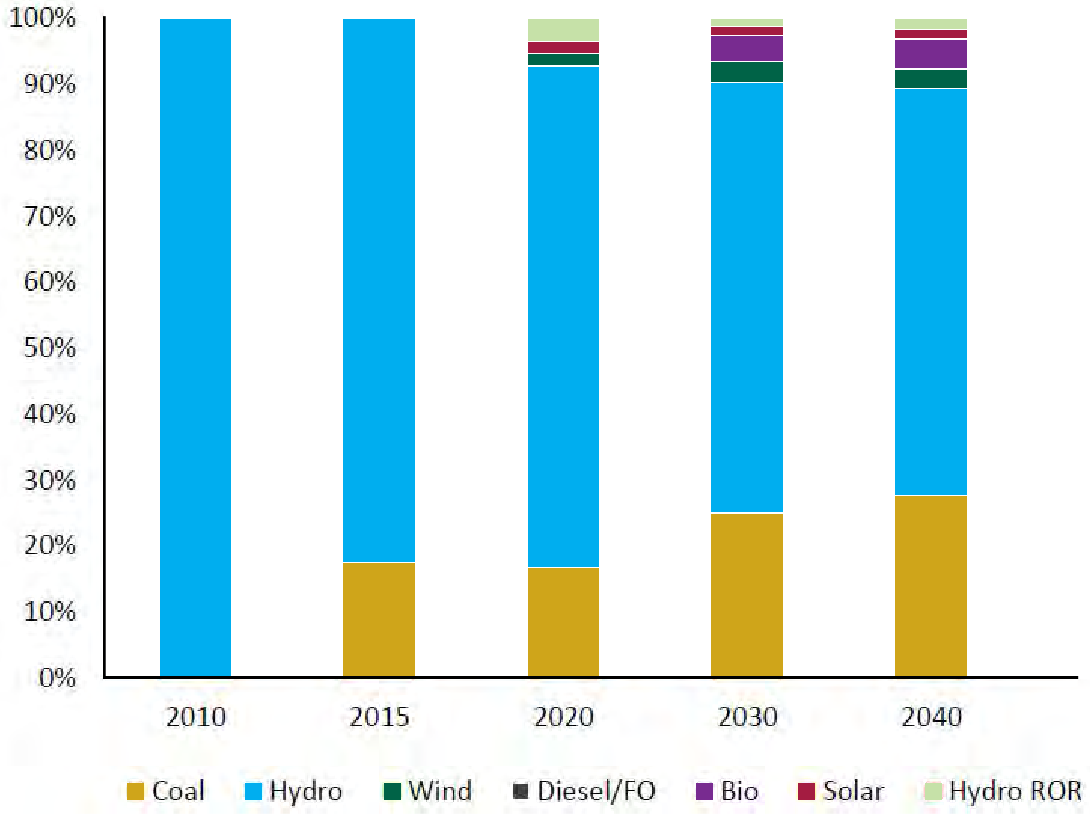
Until 2015, hydropower, predominantly from the Nam Ngum plant, which has a large reservoir and can therefore provide a reliable year-round supply, entirely supplied the Lao PDR power system. There will be a gradual reduction in dependence on hydropower to 65 percent by 2030, with the remainder being met from coal-fired thermal plants and some solar photovoltaic and wind farms. The 1,878-MW Hong Sa coal-fired plant in northwestern Lao PDR already provides some power to EDL and exports the remainder to Thailand. Figure C.2 presents Lao PDR's anticipated power generation mix.

Annual growth in energy demand has been in double digits since 2012 but from a low base. Growth in energy demand slowed to 6.5 percent from 2016 to 2017, and because electrification of rural areas nationwide is nearly complete, annual rate of growth to 2030 is not expected to exceed that. Demand from the southern regions of Lao PDR is expected to grow in the coming years but not as fast as from the central region, where demand will increase from Vientiane, Luang Prabang, and tourist centers in the north. How fast demand in the south grows will depend largely on the pace of investment in the numerous mining concessions awarded. Assuming 6 percent annual growth on average, national demand will be approximately 10 TWh in 2030 but still with only a minor portion in the south. All proposed larger hydropower projects in the Sekong Basin are expected to seek export power purchase agreements with the Electricity Generating Authority of Thailand or EVN.

The 115-kV EDL system extends south to Stung Treng in Cambodia near the confluence of the Sekong and Sesan rivers. This provides for some export potential to Cambodia, but that may not continue once the lower Sesan hydropower project in Cambodia is commissioned.

The potential for large-scale export from Lao PDR to Cambodia is not likely to be significant until the 500-kV regional interconnector system is in place after 2030.

Figure C.2: Anticipated Power Generation Mix for Lao PDR (Until 2040)



Source: IES and MKE 2016.

Note: FO = fuel oil; ROR = run-of-river.

C.7.3 Power System in Thailand

The latest available data on the Thai power system are from 2017, when peak demand was close to 28,578 MW. The power forecast released in 2015 indicated that this would rise to more than 44,400 MW by 2030, but this might need to be revised downward because gross domestic product has slowed, and power demand stagnated from 2016 to 2017.

Nonetheless, based on the latest official power forecast, there are many plans for adding capacity to the Thai power system. To offset retirement of older plants, more than 57,400 MW of new capacity is needed by 2036, of which some 23,700 MW is expected to come from renewables, including hydropower, meaning that the need for new thermal capacity is therefore nearly 34,000 MW.

Thailand has only 2,952 MW of hydropower capacity, and its remaining unexploited hydropower resources are limited. Therefore, imports from HPPs in neighboring countries are required, particularly to provide a fast response to variations in peak demand. In 2017, nearly 20 independent power producer HPPs (>15 MW) were operating in Lao PDR, supplying approximately 3,500 MW of power to Thailand during peak demand periods. Of these, only the Houay Ho project (152 MW) lies in the Sekong Basin; the others are in central Lao PDR. The 1,285-MW Xayaburi project north of Vientiane will come online soon, and 1,225 MW is to be exported from it to Thailand. The 410-MW Xe Pian–Xe Namnoy project will also come online soon. There are 1,800 MW of export capability from the Hongsa coal-fired plant in the north. Thailand has agreed to import 9,000 MW from Lao PDR by 2030, but only 2,000 MW of the agreed-upon 9,000 MW is not yet allocated to specific projects, so the new Sekong projects (after Xe Pian–Xe Namnoy) are hoping to fill this 2,000 MW. The receiving power utilities in neighboring countries will decide how much power they need, and when they need it, as is the case for many of the existing hydropower projects in Lao PDR.

C.7.4 Power System in Vietnam

The latest available data on the EVN power system are from 2017, when annual energy demand was approximately 186 TWh. Peak power demand was close to 20,000 MW in 2013 and was probably approaching 30,000 MW in 2017. Energy demand seems to be growing steadily at 10 to 15 percent annually based on annual gross domestic product growth of approximately 7 percent.

Total hydropower and pumped storage capacity was approximately 16,000 MW in 2017 in more than 30 different large hydropower projects. Despite plans to introduce an additional 5,000 MW of new hydropower by 2030, the share of hydropower and pumped storage will fall from 30 percent to near 15 percent by 2030 because of ambitious plans for 6,000 MW of new wind power and 12,000 MW of solar power.

There are many undeveloped hydropower sites in Vietnam, but there is a trend to develop multi-purpose reservoirs where flood control as well as hydropower is an important benefit. The latest power development plan indicates a need for close to 500 TWh of annual energy and 127,000 MW of capacity by 2030, almost triple current capacity. The main supply of Vietnamese power is from coal- and gas-fired thermal plants, accounting for 63 percent of energy supplied at present, increasing to 70 percent by 2030. Normally, renewables provide less energy than thermal power plants, having plant utilization factors of 15 to 40 percent. Thermal energy will remain the backbone of Vietnam's power system and the provider of base load power.

Available reports do not indicate how much of the new hydropower capacity is expected to come from imports from Lao PDR, but hydropower projects will retain their role as suppliers of reliable peak power to the Vietnamese power system while thermal plants provide the base load.

Much of this imported power (around 900 MW) is expected to come from the Xe Kaman tributary to the Sekong River, where 570 MW is being supplied from three already operating power plants. There are plans for a further 200 MW in three new HPPs on the Xe Kaman and a new cascade on the Nam Bi tributary, including 130 MW in three separate power stations.

All of these plants are expected to be synchronized with the south Vietnamese grid, and decisions about power generation (dispatch) is effectively made from Vietnam. This situation is expected to continue beyond 2030, meaning that there will be two separate power systems serving power plants and substations in the Sekong Basin: one run by EDL and one by EVN. It is expected that the EVN system will require short-term variability in output from its HPP generators, meaning that flows below EVN-connected hydropower stations will vary rapidly as the EVN dispatch center ramps the units up and down.

Table C.12: Power Demand in Lao People's Democratic Republic, Thailand, and Vietnam, 2017

Demand	Lao PDR	Thailand	Vietnam	Lao PDR % of total
Megawatt peak	928	28,578	(29,500)	1.5
Annual terawatt-hours	5	189	186	1.3
Megawatt hydropower installed	4,700	2,952	(16,000)	20.0
Hydro annual terawatt-hours	22	4	(60)	25.6

Note: Values extrapolated from older data.

Some import agreements already require a wheeling of power through Vietnam to supply towns and rural centers elsewhere in Lao PDR. This situation will prevail for a few years until construction of the Lao PDR–Vietnam transmission interconnector described.

C.7.5 Power Export to Vietnam and Thailand

Current power demand in all three countries is compared in Table C.12. Lao PDR accounts for less than 2 percent of aggregate demand from all three countries and 20 to 26 percent of hydropower capacity. Base load production is from coal- and gas-fired thermal power plants, with hydropower providing flexibility to cover peak demand during weekday and evening peak load periods. This in turn means that output from Lao PDR HPPs for export to Thailand and Vietnam varies greatly from hour to hour.

Export and import intentions from each country's power development plan are summarized in Table C.13. Lao PDR plans to export 11,700 MW of power to Thailand and 841 MW to Vietnam by 2040. In contrast, the power development plan for the Electricity Generating Authority of Thailand shows only a little more than 4,200 MW imported from Lao PDR—a mismatch of approximately 7,500 MW.

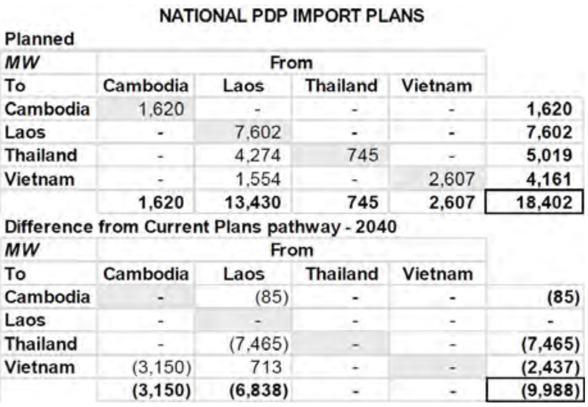
Vietnam plans to import more than 1,500 MW of power from Lao PDR by 2040, which could be met from hydropower projects in the Sekong Basin, including on the Xe Kaman and Nam Bi tributaries.

If the mismatch in Thailand is confirmed, there will be approximately 7,500 MW of hydropower projects not likely to reach a power purchase agreement to export to Thailand, and many of these may be in the Sekong River Basin.

C.7.6 Xe Kong Kalum Thermal Power Plant for Export to Vietnam and Associated Coal Mining

There are plans to develop a large-scale coal-fired power plant for export to Vietnam, based on anthracite found in the Sekong Basin. Concession agreements for mining coal have been granted and extend over large parts of Kalum District. If developed, there could be up to 1,800 MW installed, although there is doubt whether proven resources will be sufficient for more than 900 MW. The Kalum project is mainly for export to Vietnam through a dedicated interconnector or through the stage 2 network upgraded to 500 kV. Because the exact location and size of the power plant is unknown, this power plant is not included in the study.

Table C.13: National Power Development Import Plans in the Mekong Region



NATIONAL PDP IMPORT PLANS

Planned

MW	From				
To	Cambodia	Laos	Thailand	Vietnam	
Cambodia	1,620	-	-	-	**1,620**
Laos	-	7,602	-	-	**7,602**
Thailand	-	4,274	745	-	**5,019**
Vietnam	-	1,554	-	2,607	**4,161**
	1,620	**13,430**	**745**	**2,607**	**18,402**

Difference from Current Plans pathway - 2040

MW	From				
To	Cambodia	Laos	Thailand	Vietnam	
Cambodia	-	(85)	-	-	**(85)**
Laos	-	-	-	-	-
Thailand	-	(7,465)	-	-	**(7,465)**
Vietnam	(3,150)	713	-	-	**(2,437)**
	(3,150)	**(6,838)**	-	-	**(9,988)**

Source: MRC 2018.

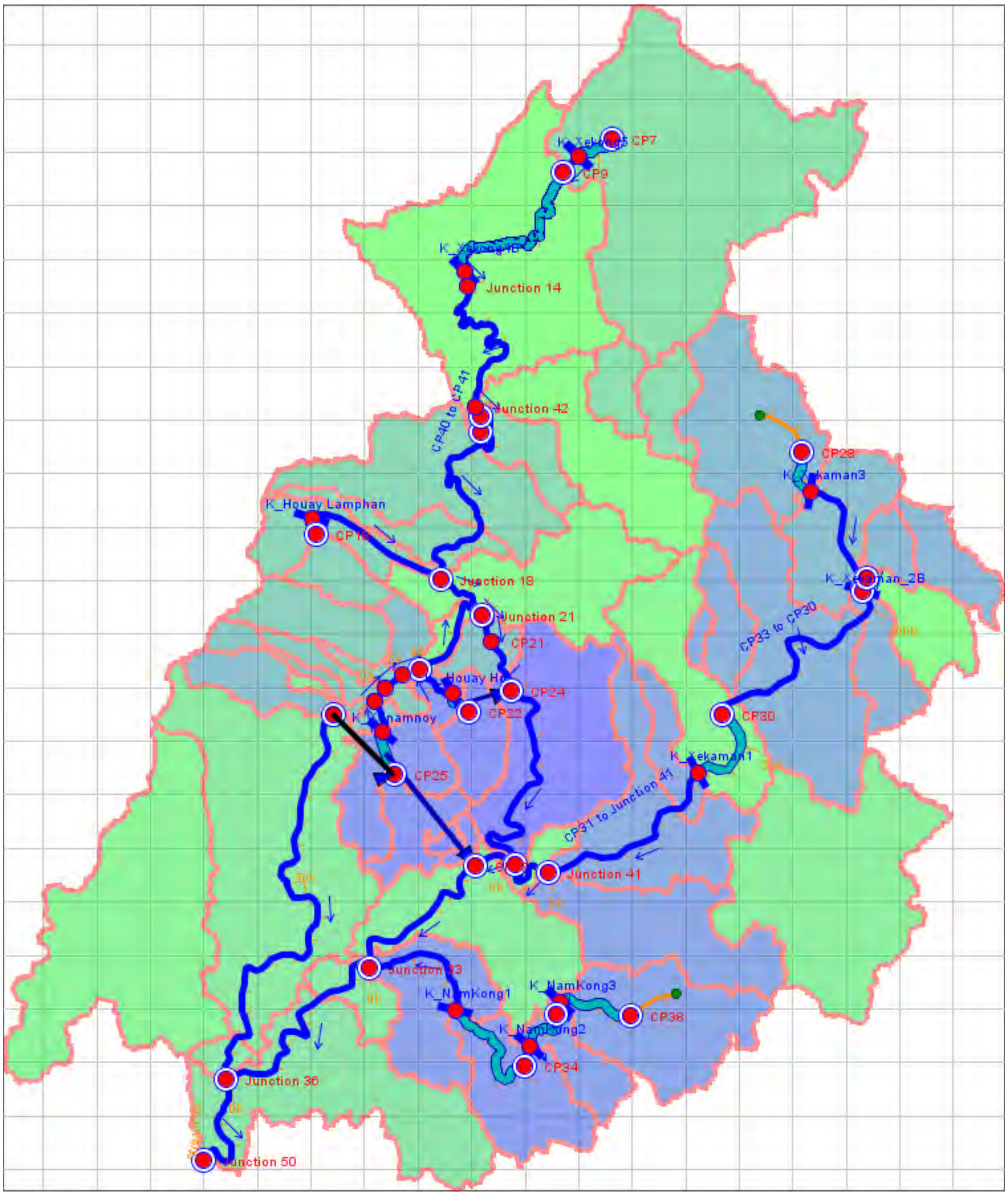
Note: PDP = Power Development Plan

APPENDIX D
WATER BALANCE MODELING

D.1 Model Set-Up

Reservoirs have been modeled using the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center Reservoir System Simulation (HEC-ResSim) water balance modeling software. A HEC-ResSim model was created using up-to-date information on existing and planned hydropower projects in the Sekong Basin (Appendix B). Map D.1 shows the new model configuration.

Map D.1: **Screenshot of Model in U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center Reservoir System Simulation**



The aim of the modeling is to ascertain seasonal flow variation caused by storage reservoirs. Only the 12 largest reservoirs are included in the model. Smaller reservoirs are expected to operate as run-of-river or daily peaking reservoirs and do not affect daily mean flows significantly. The 12 reservoirs included in the model are shown in Table D.1.

The model is run with hourly time steps, but output is exported as daily time steps. There is no river routing in the model, so the exact timing of some flood peaks may be a day or so earlier than in the field.

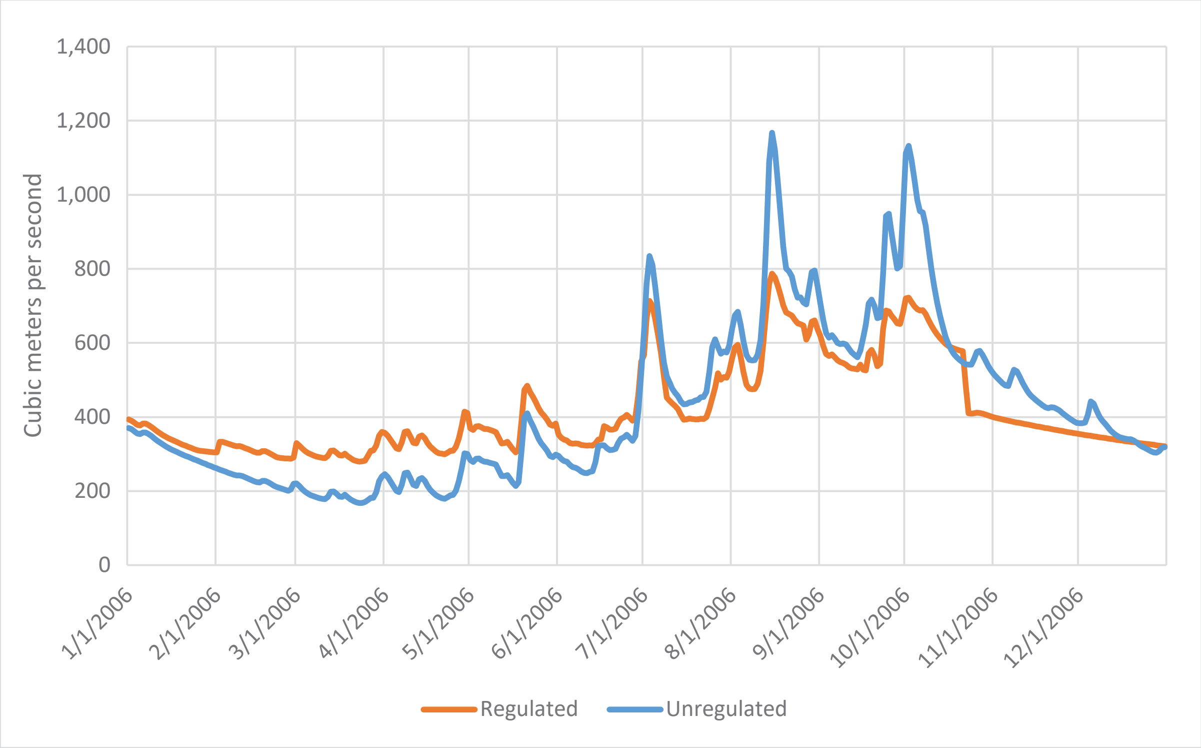
Real-life operation of hydropower plants and reservoirs depends on details of power purchase agreements, which are project specific. We decided to model reservoir operations to make the flow as even as possible because this is understood to be a standard requirement; see, for example, the publicly available Xe Pian–Xe Namnoy power purchase agreement. The power station release cannot exceed maximum station outflow and has been selected never to empty the reservoir completely. This is expected to give close to optimal firm energy production, which is the goal of developers exporting to Thailand and Vietnam. An example of this is shown in Figure D.2.

Table D.1: **Reservoirs Included in the HEC-ResSim Model**

Name	Full supply level (meters above sea level)	Minimum operating level (meters above sea level)	Active reservoir volume (m^3)	Active reservoir (% of annual inflow)
Houay Lamphan Gnai	820	795	141	34
Nam Kong 1	320	287	505	38
Nam Kong 2	427	420	29	3
Nam Kong 3	542	521	471	52
Xe Kaman 1	230	218	1,683	36
Xe Kaman 2B	370	340	217	10
Xe Kaman 3	960	925	109	12
Houay Ho	883	861	527	176
Xe Pian–Xe Namnoy	787	745	908	71
Sekong 4A	200	180	460	6
Sekong 4B	291	277	180	4
Sekong 5	485	440	1,145	29

Note: m^3 = cubic meters.

Figure D.2: **Flow into and out of Xe Kaman 1 Reservoir in Average Year**



D.2 Water Balance Assessment and Results

Four pathways have been modeled: present situation, full development pathway, intermediate development pathway, and conservative development pathway. In addition, HEC-ResSim models natural (unregulated) flow. We also modeled for climate change 2090 using two different climate models for the full development pathway. (See Map 5.1, Chapter 5, for a visual representation of the full development pathway.) These results are presented in terms of major tributary rivers and the Sekong mainstream at various points of interest.

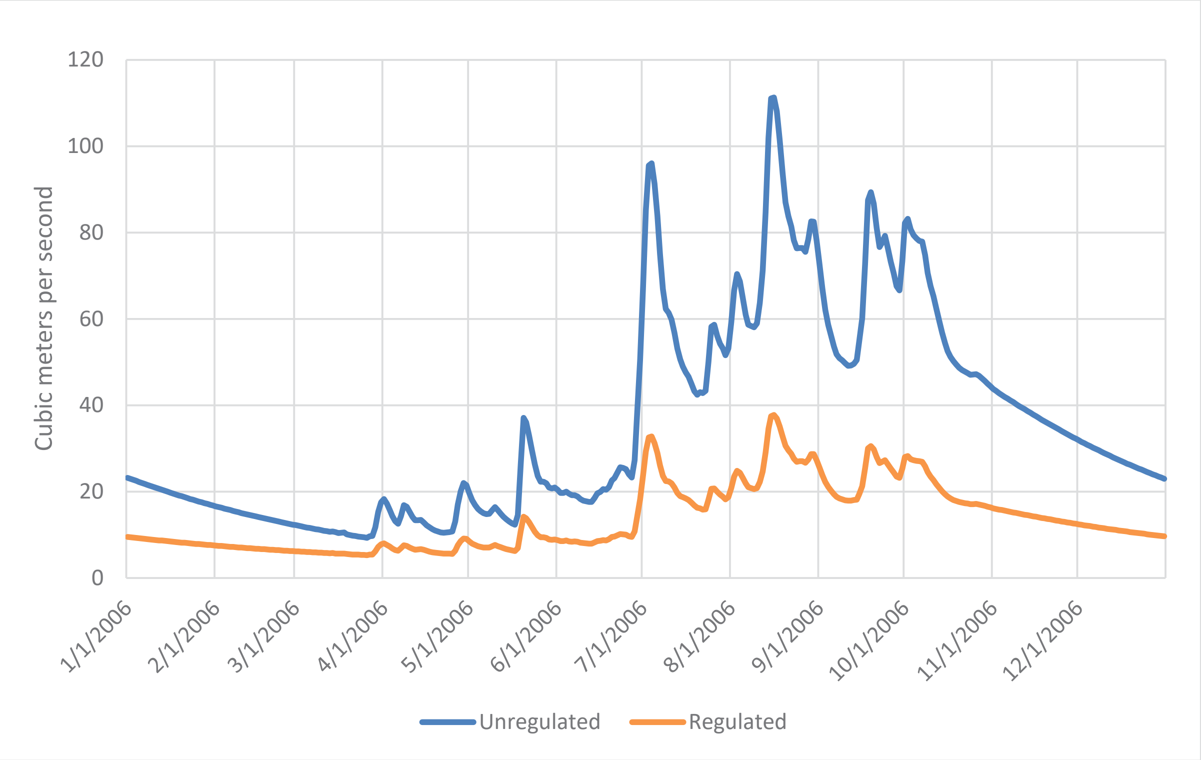
The assessment of cumulative effects is summarized in terms of degree of hydrological modifications caused by all reservoirs, river diversions, and hydropower plants included in each of the pathways. Degrees of modification have been assigned for each stretch of river or tributary based on alteration of flood regime and of low flows.

D.2.1 Xe Namnoy, Xe Pian, Xe Katam, and Houay Ho Tributary Rivers

These tributaries are the subject of extensive hydropower development, but the greatest single hydrological effect comes from the large seasonal Xe Pian–Xe Namnoy reservoir, which captures and diverts much of the flow in the headwaters (Figure D.3).

A significant reduction in flow will be observable in the Xe Pian River downstream of the dam. The residual Xe Namnoy flow at the confluence with the Xe Katam will be more than halved and flood peaks reduced to approximately 35 percent of their natural values. Despite inflows from the Xe Katam reservoir, there will be an overall reduction in flow in the Sekong River below the confluence with the Xe Namnoy. Further downstream, at the outlet from the Xe Pian–Xe Namnoy power plant, the flow in the Sekong River will again increase.

Figure D.3: Regulation of Flows in the Xe Namnoy River as a Result of the Xe Pian–Xe Namnoy Reservoir (from 2020 in All Pathways)



D.2.2 Xe Kaman, Nam Bi, and Nam Ang Tributary Rivers

The large Xe Kaman 1 reservoir has a substantial seasonal regulating effect on the Xe Kaman River below the Xe Kaman Sanxai power plant (Figure D.4). This reservoir dominates regulation of the river and is large enough to capture most of the monsoon floods except in very wet years. Depending on how the reservoir is being operated, there will be a two- to four-month delay in flood water moving downstream. Floods will be much smaller and later, even in wet years. In dry years, no flood rise may occur at all. Low-flow situations will be changed substantially, with minimum flows being as much as five times as great.

One new seasonal storage reservoir, the Xe Kaman 2B, upstream of the Xe Kaman 1 reservoir, will have a small additional effect that reinforces the changes described above, but the effect of the Xe Kaman 1 reservoir will overshadow that. There are six other projects planned upstream, but all will have minimal reservoir storage for hourly peaking operation. Because of the limited additional cumulative effect on flow regulation, the seven planned projects located upstream of the Xe Kaman 1 reservoir have been included in all development pathways.

The Xe Xou tributary enters the Xe Kaman just before its confluence with the Sekong mainstream. The Xe Xou has much of its catchment in the Dong Amphan National Protected Area and is assumed to be unregulated in all development pathways. It contributes significantly to volatility in the lower Xe Kaman during the wet season (June–October, Figure D.5). Although the regulating effect of dams in the Xe Kaman catchment suppresses flood peaks, the Xe Xou (if unregulated) will have an important role in providing flood pulses and sediment transport within the lower Sekong Basin.

Figure D.4: Flows Downstream of the Xe Kaman Sanxai Power Plant

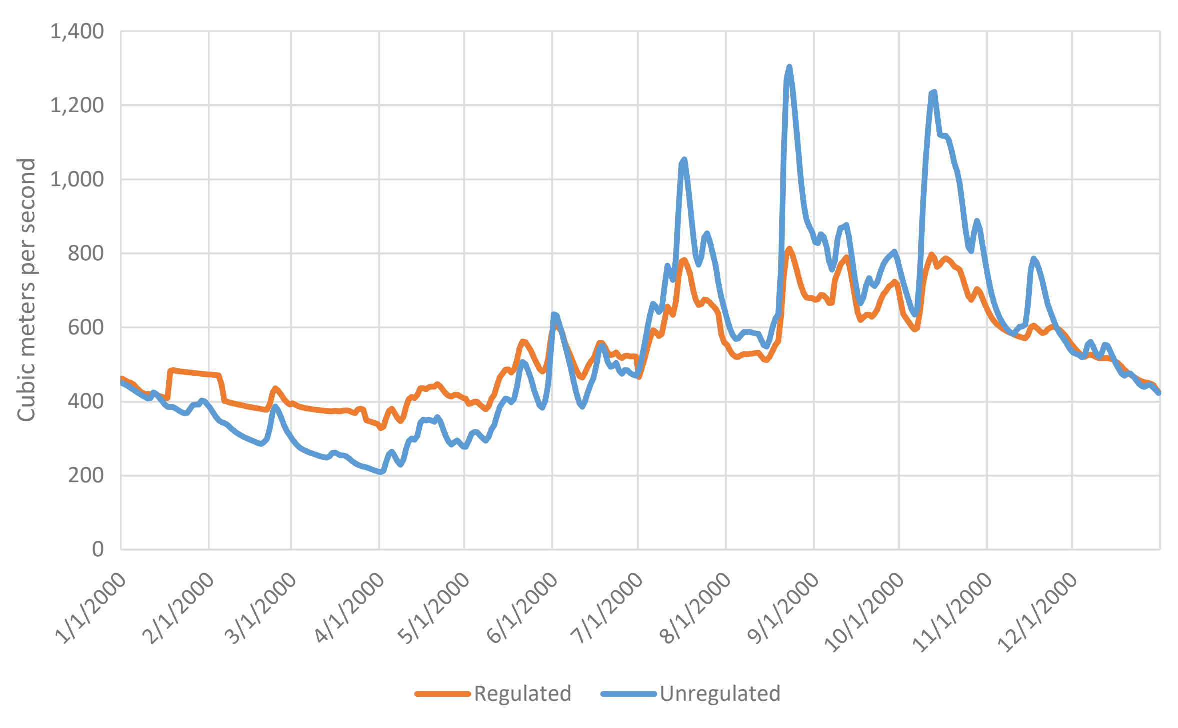
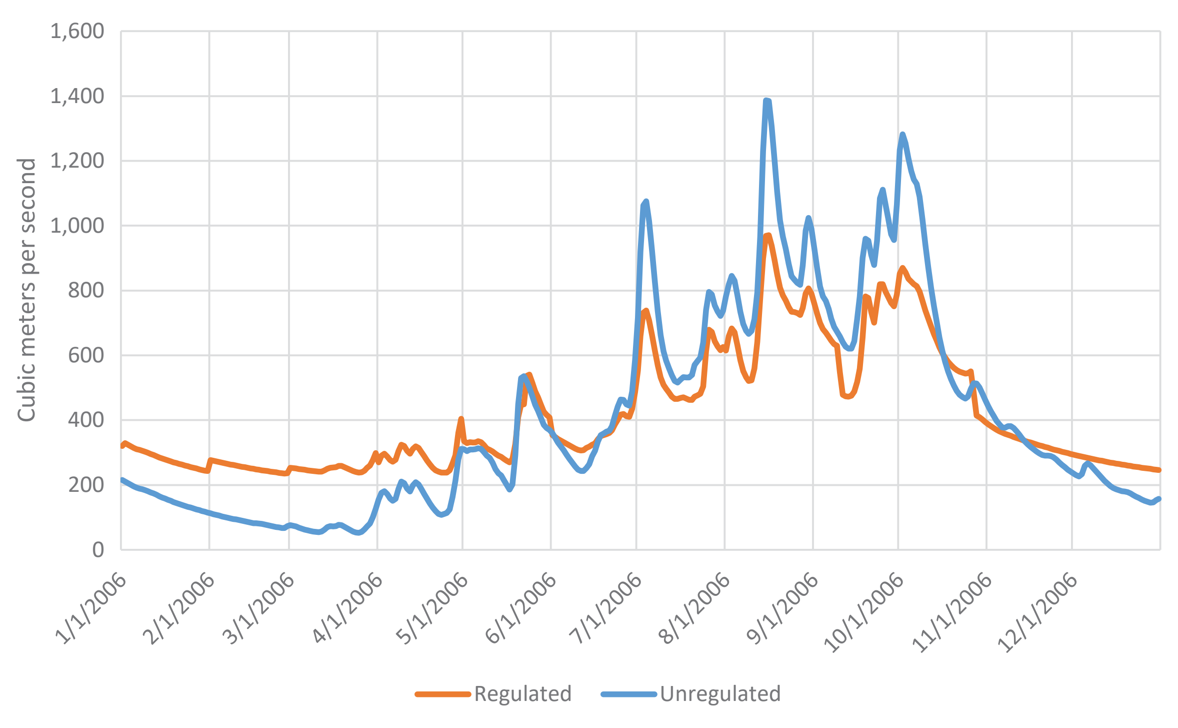


Figure D.5: Effect of Existing Reservoirs on Flows in the Xe Kaman Below Confluence with Xe Xou



D.2.3 Upper Sekong

The Upper Sekong has only one diversion reservoir on the Vietnamese side of the border. This A Luoi project regulates the upper reaches of the Sekong and transfers water to the Vietnamese rivers flowing eastward to the Vietnamese coast. It is not known what releases are being made to the Sekong River from the dam, but for illustration purposes, we assumed in the model that no flow is being released down the Sekong. The catchment for A Luoi is not included in the Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS) or HEC-ResSim models.

The present situation (2020) shows close to natural flow variability along the upstream Sekong. Major changes in flow regime occur if the Upper Sekong portfolio (Sekong 5 and 4B) is built as in the full development and intermediate pathways. These reservoirs are much larger than the inflow and will be able to almost completely regulate Upper Sekong flows, removing flood events in almost all years.

Even in wet years, arrival of the flood peak will be delayed until both reservoirs have been refilled, and some flood spill may occur as late as December in very wet years. The typical flow regulation in the full and intermediate development pathways is shown in Figure D.6.

D.2.4 Nam Emoun Tributary River

The Nam Emoun tributary drains a catchment area of 462 square kilometers at the confluence where the Nam Emoun project is under construction. There is no large seasonal reservoir planned on this tributary, so there will be no observable changes in the flow regime along the Nam Emoun except for the effect of peaking operation on hourly flow variations immediately below the new power plant.

The planned Sekong 4A project will collect and regulate runoff from the Upper Sekong and the Nam Emoun; the result below this dam is shown in Figure D.7.

If we consider the flow regime of the mainstream Sekong north of Attapeu above the confluence with the Xe Kaman, we observe contributions from unregulated tributaries, but several other factors influence the flow regime (Figure D.8). First, the power plant has diverted regulated inflow from the Xe Pian tributary that is delivered into the Sekong downstream of Attapeu and the confluence with Xe Kaman and Xe Xou. We assume this flow is relatively constant all year round. Second, the effect of regulating reservoirs in the full development pathway is still visible in delaying flood peaks by two months and reducing their magnitude.

Figure D.6: **Effect of Upper Sekong Portfolio on Flows Above Confluence with Nam Emoun**

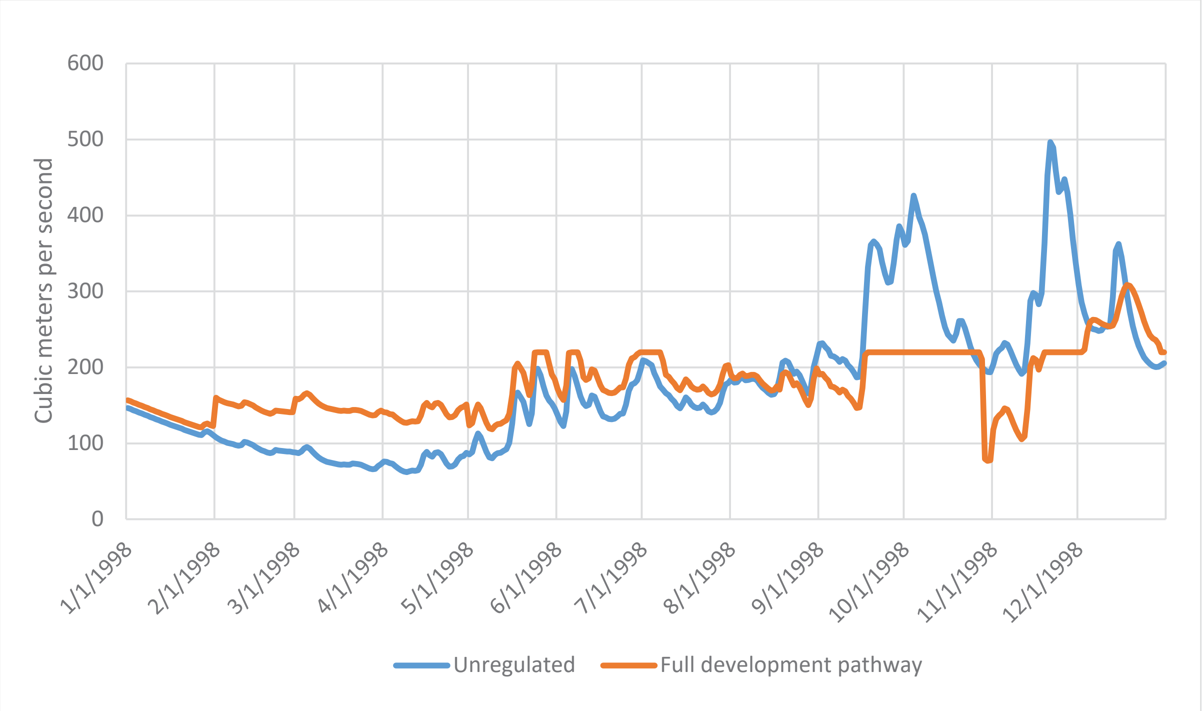


Figure D.7: **Flow Regulation Below Sekong 4A**

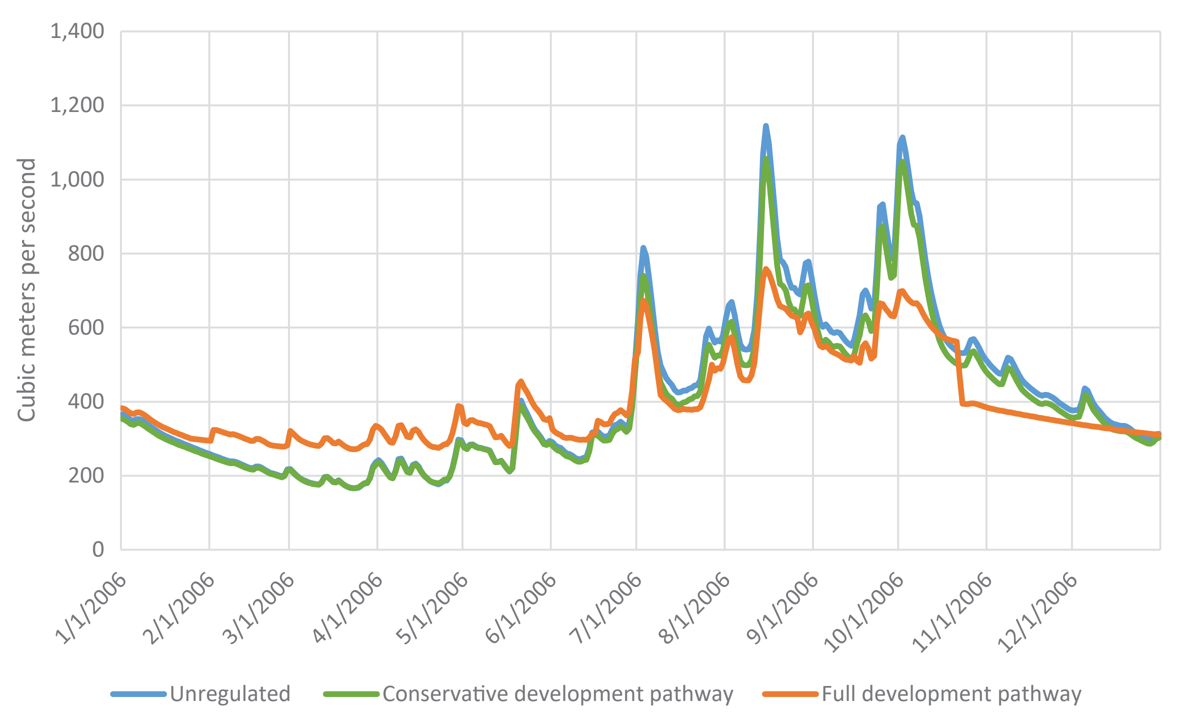
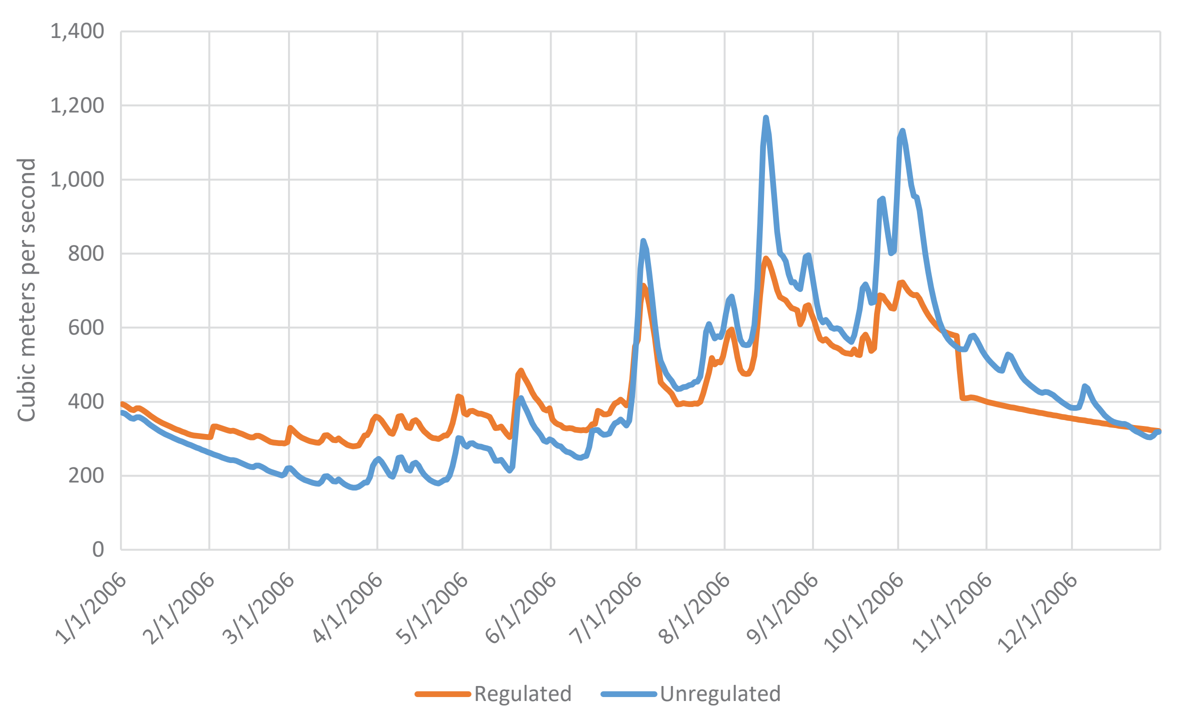


Figure D.8: **Flows in Sekong North of Attapeu Above Xe Kaman Confluence, Regulated and Unregulated**



D.2.5 Nam Kong Tributary

The large Nam Kong 3 reservoir already substantially regulates the Nam Kong tributary, which will be even more regulated after the impoundment of another large reservoir, Nam Kong 1, the furthest downstream of the cascade of three dams.

Figure D.9 shows the substantial effect these reservoirs have on the flow regime in the downstream Nam Kong. Assuming the reservoirs are operated as seasonal regulating reservoirs, they will capture flood runoff in all normal and dry years, with only occasional late spills of flood waters in October if the reservoirs have all been filled. The frequency and magnitude of flood peaks will be greatly reduced, as will sediment transport past the dams. The river geomorphology below these dams will experience some of the largest changes anywhere in the Sekong Basin, with steady flows all year round and rare flood peaks occurring three to four months later than before.

D.2.6 Lower Sekong

In the lower Sekong River below the confluence with the Nam Kong, the low-flow situation changes considerably as a result of flow regulation from the Xe Pian–Xe Namnoy power plant and from the heavily regulated tributaries of Xe Kaman and Nam Kong. Under the full development pathway, in which seasonal reservoirs regulate all upstream tributaries and the Sekong mainstream, the only tributary providing sediment and some flow variation is the Xe Xou.

To illustrate the effect of flow regulation that hydropower reservoirs provide, an average hydrological year has been simulated (Figure D.10) for three scenarios: unregulated, moderately regulated, and highly regulated flow. Moderately regulated takes into account the hydrological effect of three large tributary hydropower projects: Xe Kaman 1, Xe Pian-Namnoy, and Nam Kong 3. Highly regulated adds the proposed Sekong mainstream hydropower projects.

Figure D.9: Flows Below Nam Kong 1 Power Plant After Completion

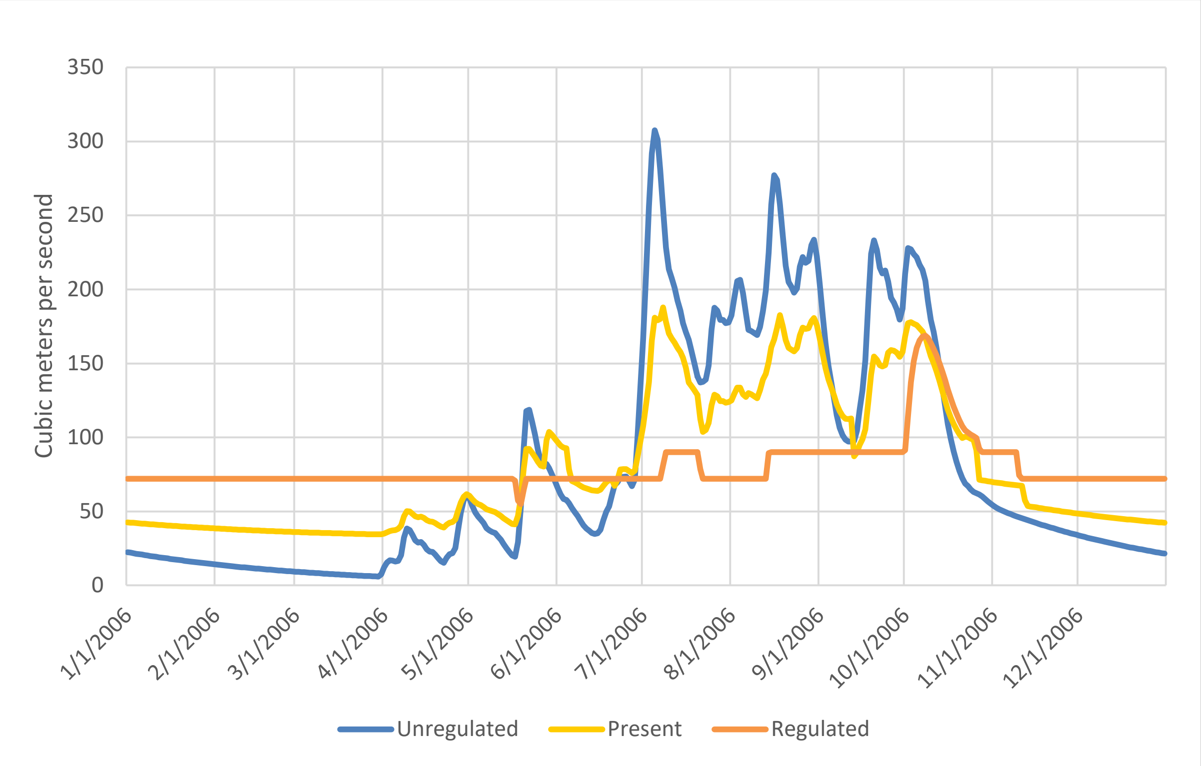
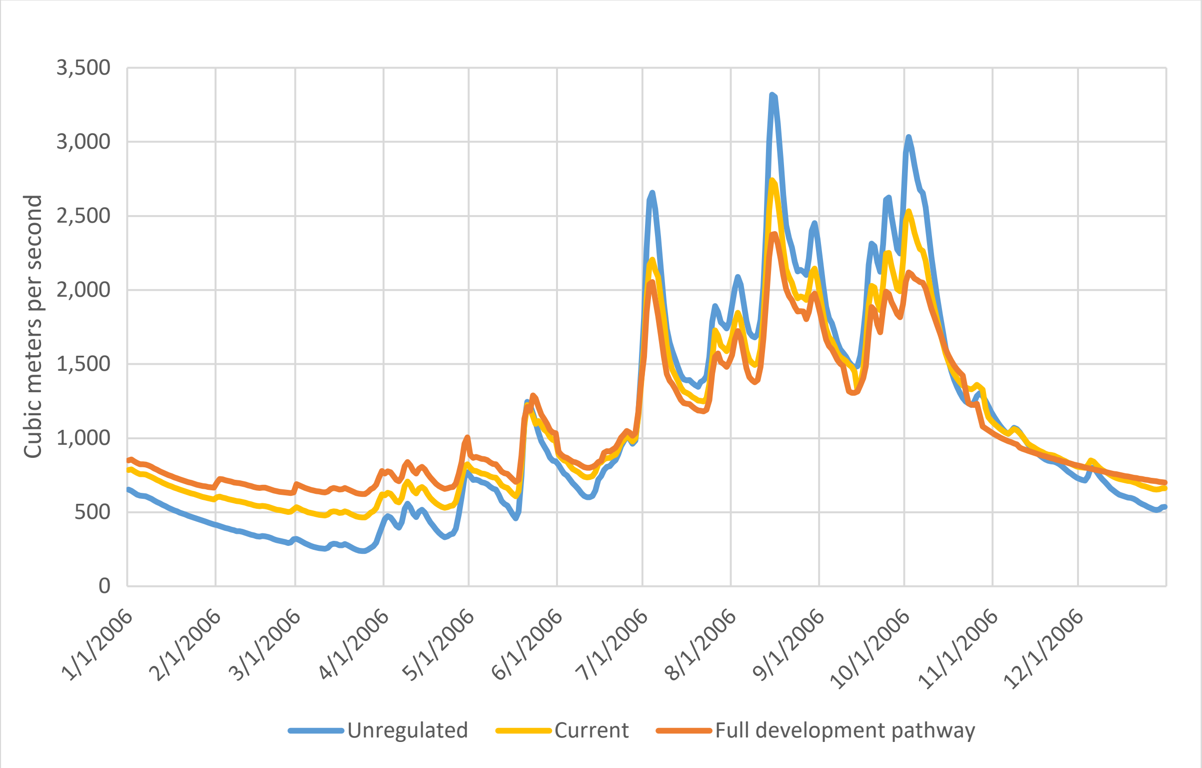


Figure D.10: **Flow Regimes Below Nam Kong Confluence in Average Year**

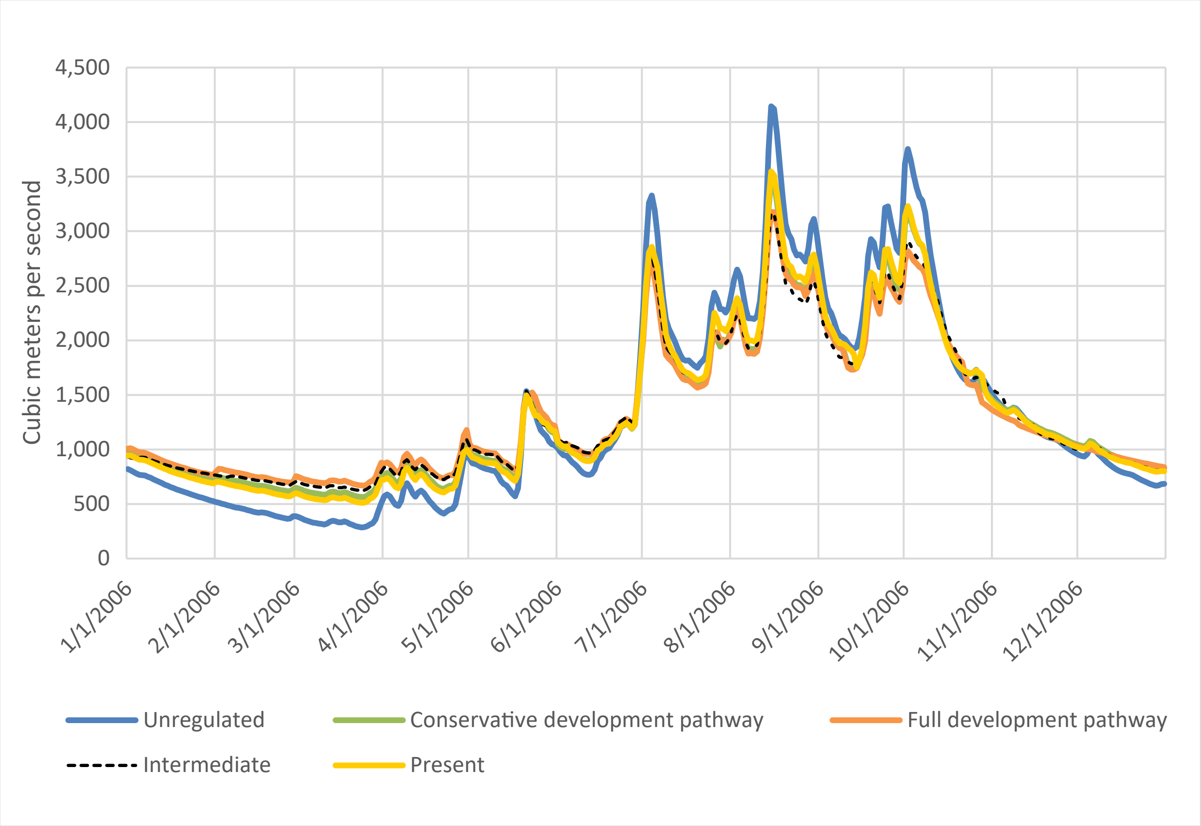


D.2.7 Lower Sekong After Entering Cambodia

After the confluence with the Xe Pian and Xe Khampho rivers, the Sekong leaves the Lao PDR and becomes a Cambodian river, where the aggregated effect of various development pathways can be seen (Figure D.11). The largest observable change is the low-flow month of March, when low-flow values nearly double. Peak flood levels are approximately 500 to 1,000 cubic meters per second lower, but this is less than 20 percent less than today’s flood peaks. There is little indication of significant delays in arrival of the rising flood or the flood peak because the large tributaries of the Nam Emoun, Xe Xou, Nam Kamphon, and the lower part of the Xe Pian River still contribute as free-flowing rivers.

A slight difference is observed in how the Sekong 5 and 4B reservoirs regulate flows under the full and intermediate but not the conservative development pathway. The flow volatility of the free-flowing tributaries mentioned above remains dominant over the seasonal regulating effect of these two upstream regulating reservoirs.

Figure D.11: **Flow Regimes Below Border with Cambodia Under Various Pathways, Showing Effect of Upper Sekong Regulating Reservoirs**



APPENDIX E
SEDIMENT MODELING AND ASSESSMENT

E.1 Model Set-Up

E.1.1 Brune's Curves

Multiconsult's Seditrans-Brune model is a nodal model for reservoir sedimentation based on Brune (1953) curves for sediment transport.

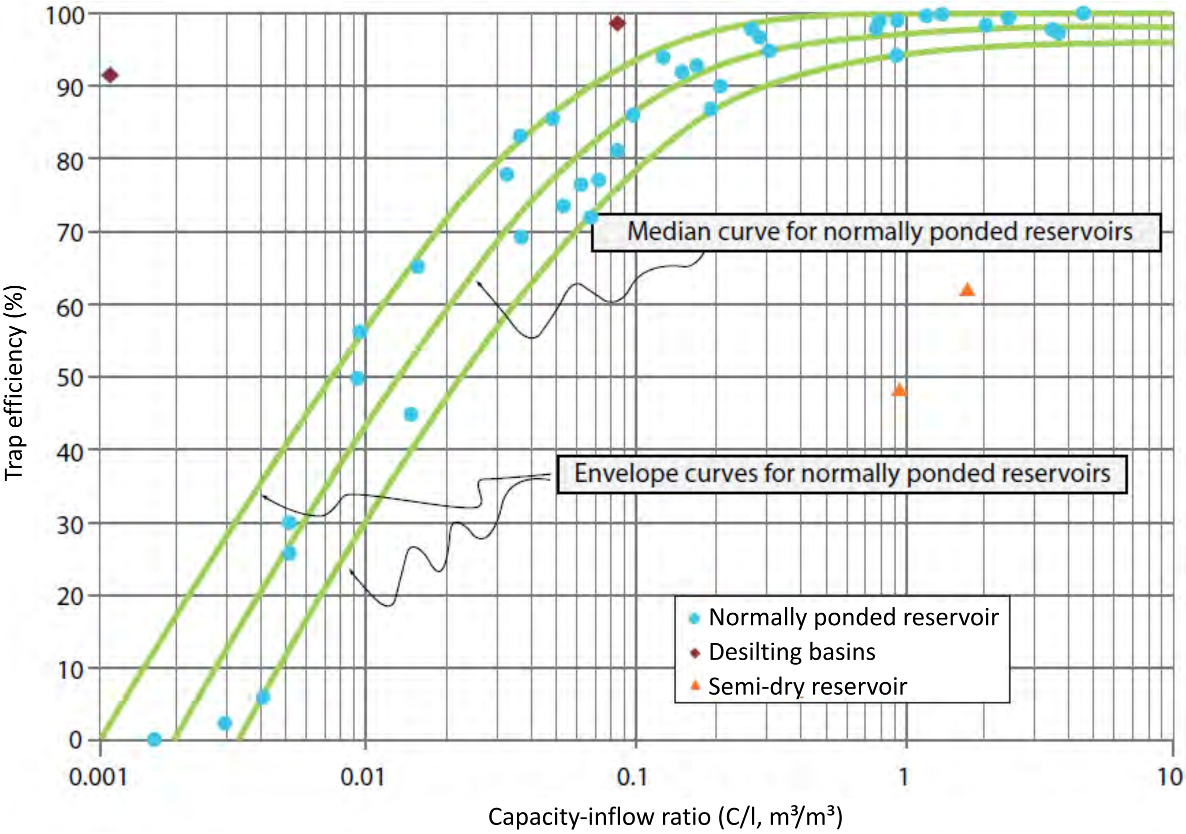
Brune's curves are widely used in estimating sedimentation of reservoirs. Brune developed curves relating trap efficiency to the ratio of reservoir volume to annual average inflow (Figure E.1). Trap efficiency depends on sediment grain size. The trap efficiency of coarse sediments (sand and gravel) is greater than the trap efficiency of fine sediments (silt and clay). Brune's curves include curves for coarse and fine sediments and a median curve.

Under the full development pathway, sediment grain size was assumed to follow the median curve in the Brune trap efficiency curves. Additional models were run with curves for fine and coarse sediments.

Initial reservoir volume determines initial trap efficiency. When the reservoir is filled with sediment, reservoir volume decreases, which decreases trap efficiency.

The model has annual time steps to take into account that trap efficiency decreases as reservoirs fill with sediment. Thus, it tracks the gradual build-up of sediment in each reservoir over its design lifetime (normally 100 years) based on the following simplified generalized assumptions:

Figure E.1: **Brune's Curve for Trap Efficiency of Normally Ponded Reservoirs**



Source: Brune 1953 in Efthymiou et al. 2017.

Note: C/I = capacity/inflow; m³/m³ = capacity and inflow use of same units , cubic meters.

Table E.1: Source of Bulk Density Assumptions for Sekong Sediment Transport Mode

Operational condition	Initial weight (kilograms per cubic meter)		
	W_C	W_M	W_S
Continuosly submerged	416	1,120	1,554
Periodic drawdown	561	1,140	1,554
Normally empty reservoir	641	1,150	1,554
Riverbed sediment	961	1,170	1,554

Source: Annandale et al. 2016.

Note: W_C = weight of clay; W_M = weight of silt; W_S = weight of sand

- The entire catchment has an assumed constant and homogeneous sediment yield of 280 tons per square kilometer per year, as predicted for the Kon Tum massif (Kondolf, Rubin and Minear 2014).
- An average bulk density of 1.5 tons per cubic meter was used to convert incoming load to sediment volumes, based on a predominance of sand being trapped (Table E.1).
- Different curves for fine, coarse, and mixed sediment fractions can be applied in the model, as Brune documented, and the volume of sediment trapped is subtracted from the available free water volume of the reservoir for the following year.
- All reservoirs were assumed to be at highest regulated water level when most of the sediments arrive in the monsoon season. A sensitivity test reducing the reservoir level of the largest five reservoirs to the lowest regulating water level showed negligible change in sediment accumulation and transport downstream.
- In the full development case, no flushing of sediments was assumed, so Brune's curves were applied with no modifications. In a mitigation analysis, the effect of applying sediment management by flushing through bottom outlets was studied.
- A compaction factor of 1.0 was applied in the full development case for coarse sediments (no compaction assumed), but a compaction factor of 0.8 was applied for very fine sediments to represent the long-term compaction of finer sediment normally experienced in deeper reservoirs. Sensitivity tests demonstrated that this had negligible effect on the transport downstream.

E.1.2 Model Overview

The model includes 17 reservoirs. Figure E.2 shows a schematic overview of the reservoirs and the relationship between them.

E.1.3 Key Data for Reservoirs

Key data used for the model include total reservoir volume (dead and active volumes), catchment area, and annual inflow. Data used are shown in Table E.2.

Figure E.2: Schematic Overview of Reservoirs Included in Model

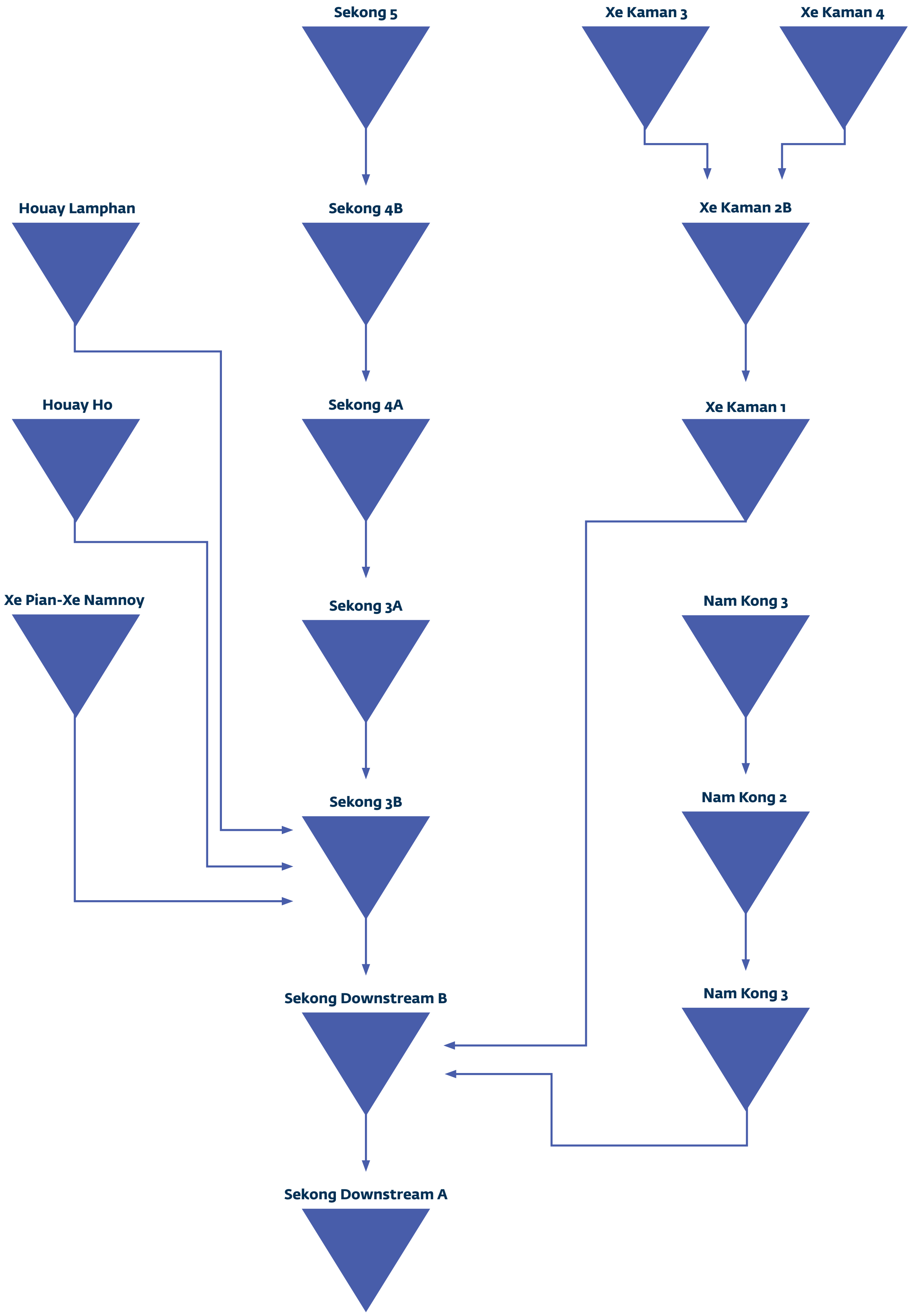


Table E.2: Key Data for Reservoirs Used in Sediment Simulations

Name	Catchment area (km²)	Mean annual inflow (m³/s)	Total reservoir volume (m³)	Capacity-inflow ratio (%)
Houay Lamphan Gnai	237	11	481	134
Houay Ho	192	10	674	225
Xe Pian–Xe Namnoy	820	43	1,072	80
Sekong 5	2,518	125	3,300	84
Sekong 4B	2,758	132	634	15
Sekong 4A	5,182	227	655	9
Sekong 3A	5,800	209	187	3
Sekong 3B	8,733	316	168	2
Sekong Downstream B	9,594	399	105	1
Sekong Downstream A	18,800	796	92	0
Xe Kaman 3	712	30	142	15
Xe Kaman 4	216	10	19	6
Xe Kaman 2B	1,740	68	349	16
Xe Kaman 1	3,580	149	4,804	102
Nam Kong 3	646	29	500	55
Nam Kong 2	861	37	71	6
Nam Kong 1	1,250	42	679	51

Note: Reservoir volume is total (active reservoir plus dead storage) initial reservoir volume for each hydropower plant.
km2 = square kilometers; m³/s = cubic meters per second; m³ = cubic meters.

E.2 Summary of Results

E.2.1 Sediment Inflow and Outflow for Each Reservoir

Modeled sediment transport for each reservoir for the full development pathway with medium-size sediments can be seen in Table E.3. The last column shows reduction in sediment transport downstream of the reservoir.

E.2.2 Sediment Transport per Pathway

Reduction in sediment transport from each reservoir in the three development pathways is summarized in Table E.4.

There is a very slight increase after 2030 as reservoirs gradually fill with sediment, the free water volume is reduced, and trap efficiency declines slightly.

Table E.3: Sediment Transport (1,000 Tons per Year) for Each Reservoir in Natural Condition (1998) and After Full Development (2030)

Name	1998 In/out	2025		Reduction %
		In	Out	
Houay Lamphan Gnai	66	66	-	100
Houay Ho	54	54	-	100
Xe Pian–Xe Namnoy	207	207	-	100
Sekong 5	705	705	-	100
Sekong 4B	772	67	6	99
Sekong 4A	1,451	685	94	94
Sekong 3A	1,624	267	90	94
Sekong 3B	2,445	584	267	89
Sekong Downstream B	2,686	508	317	88
Sekong Downstream A	5,264	1,545	992	81
Xe Kaman 3	199	199	19	90
Xe Kaman 4	60	60	11	81
Xe Kaman 2B	487	258	22	95
Xe Kaman 1	1,002	538	-	100
Nam Kong 3	181	181	3	98
Nam Kong 2	241	64	18	93
Nam Kong 1	350	127	3	99
Sekong at Lao PDR–Cambodia border	**6,415**	**2,143**		**67**

Note: "-" means no sediment outflow from respective reservoirs.

Table E.4: **Reduction in Sediment Transport per Reservoir per Pathway**

Name	Full development	Present	Conservative development	Intermediate development
	% reduction			
Houay Lamphan Gnai	100	100	100	100
Houay Ho	100	100	100	100
Xe Pian–Xe Namnoy	100	100	100	100
Sekong 5	100	0	0	100
Sekong 4B	99	0	0	99
Sekong 4A	94	0	0	53
Sekong 3A	94	0	0	47
Sekong 3B	89	13	13	45
Sekong Downstream B	88	12	12	41
Sekong Downstream A	81	29	32	46
Xe Kaman 3	90	90	90	90
Xe Kaman 4	81	0	81	81
Xe Kaman 2B	95	37	95	95
Xe Kaman 1	100	100	100	100
Nam Kong 3	98	98	98	98
Nam Kong 2	93	93	93	93
Nam Kong 1	99	64	99	99
Sekong at Lao–Cambodia border	**67**	**24**	**26**	**38**

E.2.3 Sensitivity Analysis

E.2.3.1 Coarse and Fine Sediments

Brune's curves include envelope curves for fine and coarse sediments. The study assumed that most sediments in the Sekong Basin are of medium grain size, but if fine sediments were to predominate (silt and clay), more sediment would be transported, whereas if there were more coarse sediments (sand), less would be transported. The difference in sediment transport per reservoir is summarized in Table E.5. Compared to a modeling based on medium sediments, the variation is greater for fine sediments than for coarse sediments.

E.2.3.2 Compaction Factor

A smaller compaction factor means that a reservoir fills up faster and thus reaches equilibrium sooner. The study conducted a simulation with a compaction factor of 0.8 that had little effect on sediment transport, because many reservoirs are very large. The sediment transport in the furthest downstream reservoir would increase by a negligible 0.7 percent in 2100.

E.2.3.3 Reservoir Water Level

In the initial simulations, all reservoirs were assumed to be at full supply level. The study conducted additional simulations with the five largest reservoirs at minimum operational water levels. In theory, lower reservoir water levels should transport more sediment, but the model showed only a small increase of 2.7 percent in the furthest downstream reservoir. In any case, assuming full supply level is much more realistic because most reservoirs will be full when the heaviest sediment load arrives.

Table E.5: Sediment Transport Downstream from Each Reservoir as Percentage of Natural Condition Using Brune's Curves for Fine and Coarse Sediments

Name	Fine sediments (%)	Coarse sediments (%)
Houay Lamphan Gnai	96	100
Houay Ho	96	100
Xe Pian–Xe Namnoy	95	100
Sekong 5	95	100
Sekong 4B	98	100
Sekong 4A	87	96
Sekong 3A	89	96
Sekong 3B	82	93
Sekong Downstream B	78	92
Sekong Downstream A	69	86
Xe Kaman 3	81	96
Xe Kaman 4	70	88
Xe Kaman 2B	90	98
Xe Kaman 1	98	100
Nam Kong 3	94	100
Nam Kong 2	87	95
Nam Kong 1	97	100
Sekong at Lao–Cambodia border	**56**	**71**

APPENDIX F
SUPPORTING CUMULATIVE IMPACT ASSESSMENT ANALYSIS OF AQUATIC ECOLOGY AND FISH

F.1 Approach and Methodology

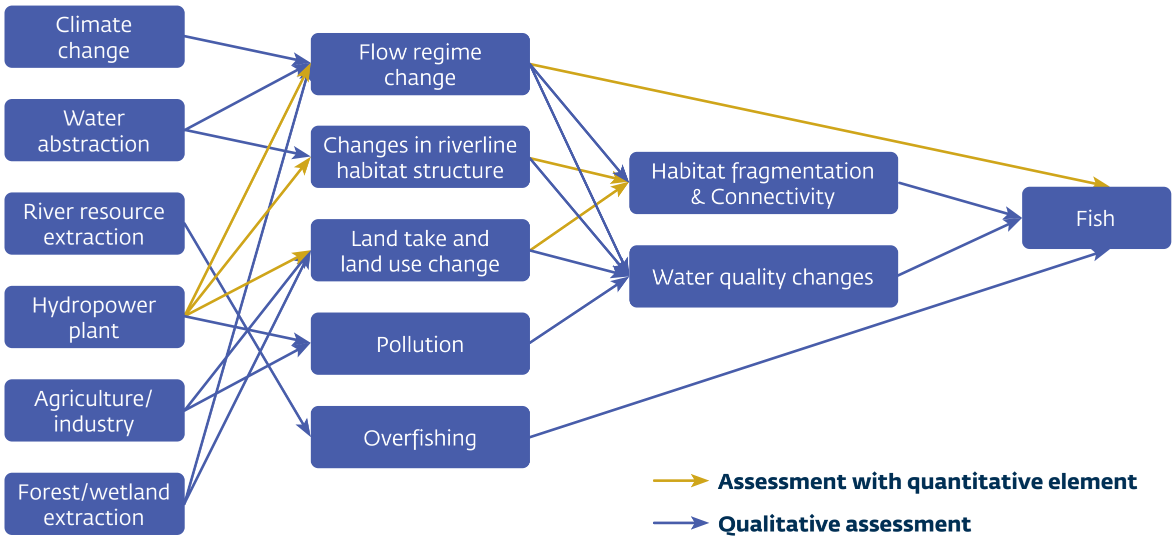
Figure F.1 illustrates the impact pathway network for fish. Part of the impact assessment was analyzed quantitatively using geographic information system (GIS) data and results from hydrological modeling. The yellow arrows in Figure F.1 indicate which parts of the impact pathway use this quantitative method. The method for the quantitative analysis is described in Sections F.1.1 to F.1.4.

F.1.1 Selection of Indicator Species

An initial list of fish species in the Sekong Basin was derived by creating a geographic overlap of reported species ranges from the International Union for Conservation of Nature (IUCN) with the Sekong Basin boundaries. This was done in ArcGIS (a geographic information system for working with maps and geographic information), in which IUCN species ranges were overlaid on the Sekong Basin. The result was an ArcGIS attribute table in which all fish species with ranges in the Sekong Basin were recorded. These data were subsequently supplemented with data from the Integrated Biodiversity Assessment Tool database.[1] Then a list was created of species that were critically endangered and endangered according to the IUCN Red List status (IUCN 2017). The list was supplemented with the 15 super-endemic species reported by Meynell (2014) and served as the basis for the district consultations.

The final fish species to be included in the cumulative impact assessment were selected by assigning points to each species according to characteristics that are important ecologically (super-endemic, IUCN status, and conservation) and socio-economically (important food fish and conservation) as well as sensitive to the proposed developments (migratory behavior) (Table F.1). These criteria were presented to stakeholders during the interim workshop on October 30 and 31, 2018. After the workshop, the method and list of fish species were discussed and agreed upon with the Champassak Provincial Agriculture and Forestry Office and Sekong Provincial Ministry of Natural Resources and the Environment.

Figure F.1: **Impact Pathway Network for Fish**



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[1] IBAT Alliance (http://www.ibat-alliance.org).

Table F.1: Scoring Criteria for Selection of Fish Species

Characteristic	Points	Reasoning
Critically endangered	2.0	Important for conservation
Endangered	1.0	Important for conservation but not critical
No data or other status	0.5	Because they occur in the basin, but their condition is unclear
Super-endemic	2.0	Highly important for conservation
Migratory	1.0	Sensitive to decreased connectivity
Importance for stakeholders	2.0	Important for food, livelihoods, and cultural reasons

The final score for each fish species was calculated by summing scores for each characteristic (Table F.2). For instance, a fish species that was critically endangered (two points), migratory (one point), and important to local communities for food (two points) received five points. Fish species with three points or more were added to the final list, resulting in a list of 12 species. The list was then shortened because several species had a very small distribution overlap with the Sekong Basin—in the far southern tip only.

To be able to conduct a quantitative analysis of the effect of flow alteration and habitat fragmentation, species ranges need to be in the range of the hydrological model and in the range where potential developments take place. Giant salmon carp (*Aaptosyax grypus*), Julien's golden carp (*Probarbus jullieni*), Mekong giant catfish (*Pangasianodon gigas*), Mekong freshwater stingray (*Hemitrygon laosensis*), and *Schistura bairdi* were therefore eliminated from the shortlist.

Discussions with stakeholders revealed that *Probarbus jullieni* was still observed in the middle and lower ranges of the Sekong Basin, indicating that the IUCN ranges do not appear to reflect the current range of this species, but because available data on the specific range details are limited, a quantitative analysis was not possible for this species.

The final list now includes seven fish species (Figure F.2) with distinct characteristics such as IUCN status, importance for local food or conservation, and being migratory or super-endemic (Table F.3).

Table F.2: Scoring for Selection of Fish Species

Scientific name	Common name	IUCN Red List status	Super-endemic	Importance for stakeholders	Migratory	Sum of points
Aaptosyax grypus	**Mekong giant salmon carp**	**2.0**			**1**	**3.0**
Catlocarpio siamensis	**Giant carp**	**2.0**		**1**	**1**	**4.0**
Datnioides pulcher	Siamese tiger perch	2.0				2.0
Devario salmonata		0.5	2			2.5
Hemitrygon laosensis	**Mekong freshwater stingray**	**1.0**		**1**	**1**	**3.0**
Laubuca caeruleostigmata	Flying minnow	1.0				1.0

Scientific name	Common name	IUCN Red List status	Super-endemic	Importance for stakeholders	Migratory	Sum of points
Pangasianodon gigas	**Mekong giant catfish**	**2.0**		**1**	**1**	**4.0**
Pangasianodon hypophthalmus	**Striped catfish**	**1.0**		**1**	**1**	**3.0**
Pangasius sanitwongsei	**Giant pangasius**	**2.0**		**1**	**1**	**4.0**
Poropuntius bolovenensis		1.0			1	2.0
Poropuntius consternans		**1.0**		**2**		**3.0**
Poropuntius deauratus	Yellow tail brook barb	1.0				1.0
Poropuntius lobocheiloides		1.0				1.0
Poropuntius solitus		1.0				1.0
Pristis	**Large tooth Sawfish**	**2.0**			**1**	**3.0**
Probarbus jullieni	**Jullien's golden carp**	**1.0**		**1**	**1**	**3.0**
Probarbus labeamajor	Thick-lipped barb	1.0			1	2.0
Schistura bairdi		**1.0**	**2**			**3.0**
Schistura bolavenensis		**1.0**	**2**	**2**		**5.0**
Schistura clatrata		0.5	2			2.5
Schistura fusinotata		0.5	2			2.5
Schistura imitator		0.5	2			2.5
Schistura khamtanhi		0.5	2			2.5
Schistura nomi		0.5	2			2.5
Schistura rikiki		0.5	2			2.5
Schistura spiloptera		1.0				1.0
Schistura tizardi		0.5				0.5
Serpenticobitis octozona		0.5				0.5
Sewellia breviventralis	Butterfly loach	2.0				2.0
Sewillia diardi		0.5	2			2.5
Sewillia elongata		0.5	2			2.5
Sewillia speciosa		0.5	2			2.5
Urogymnus polylepis		1.0		1		2.0

Note: Selected species in bold.

Figure F.2: International Union for Conservation of Nature–Reported Ranges of Selected Fish Species in the Sekong Basin

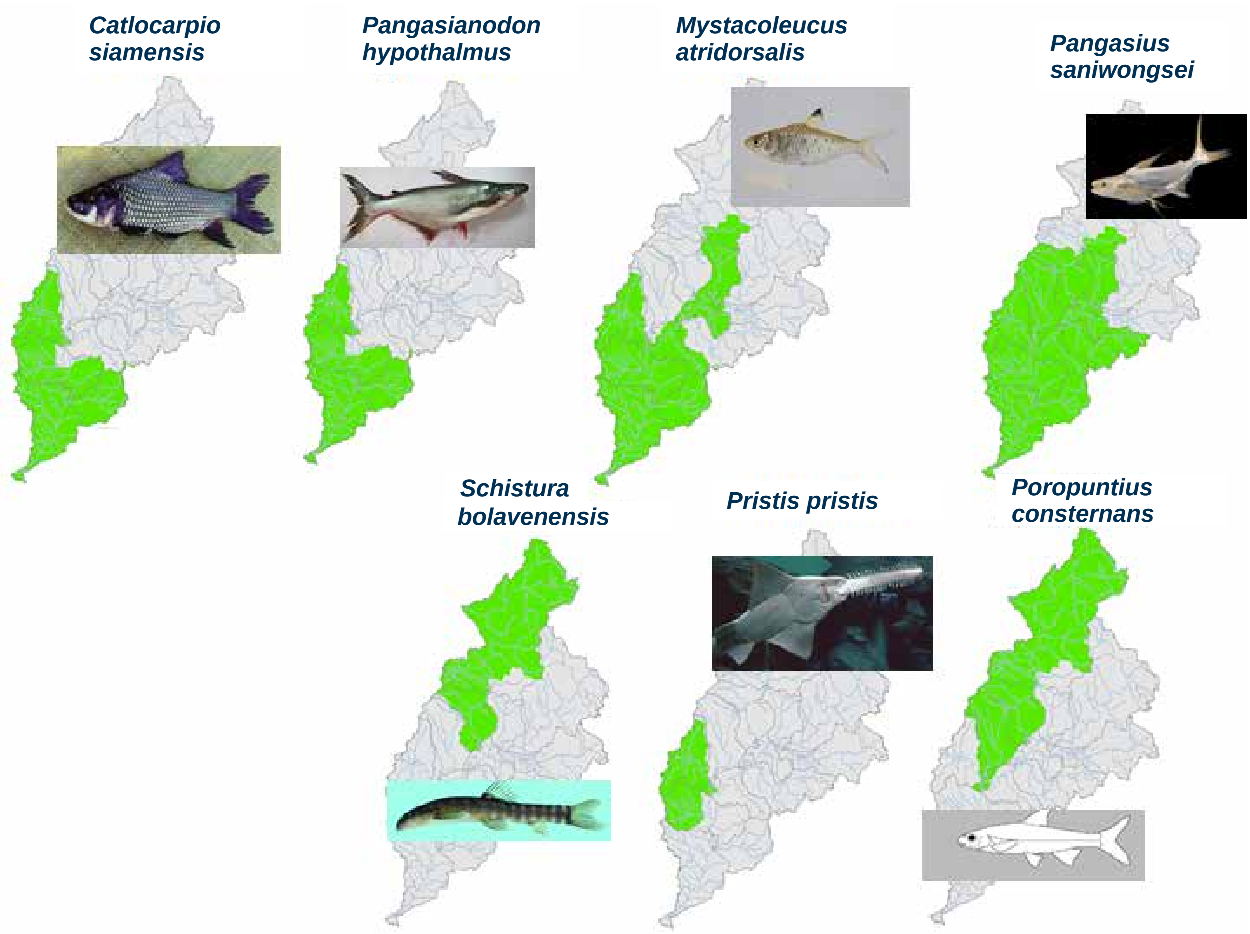


Table F.3: Fish Species Included in Analysis

Scientific name	English name	Lao name	IUCN Red List status	Super-endemic	Migratory
Schistura bolavenensis	n.a.	Pa eet	Endangered	Yes	No
Catlocarpio siamensis	Giant carp	Pa kaho	Critically endangered	No	Yes
Pangasius sanitwongsei	Giant pangasius	Pa leum	Critically endangered	No	Yes
Mystacoleucus atridorsalis	n.a.	Pa teb	Least concern	No	Yes
Pangasianodon hypophthalmus	Striped catfish	Pa souy	Endangered	No	Yes
Poropuntius consternans	n.a.	Pa chad	Endangered	No	No
Pristis	Large-tooth sawfish	Pa kheo luaey	Critically endangered	No	Yes

Note: n.a. = not applicable.

F.1.2 Assessment of Pathways

Some parts of the cause-and-effect network for fish can be calculated quantitatively if model data or GIS data are available on which calculations can be made and from which effects can be calculated as opposed to qualitatively described. This includes the effect of hydropower operation on flow regime, which is calculated using hydrological modeling, and changes in riparian habitat structure, land take, and land use, which is calculated using GIS data. Because each fish species has a different geographical range, the effects are determined for each separately. The final rating of the impact score of the corresponding pathway is then derived using an unweighted average of scores for all selected fish species. The methods for quantitative analysis of the pathways are described in the following section.

F.1.3 Assessment of Effect of Flow Regime Alteration on Fish

Climate change and hydropower development can alter the flow regime. These changes in flow regime have been calculated using hydrological modeling (Appendix B). Several indicators were selected to quantify the differences in flow between the present situation and all future development pathways (Table F.4). These indicators describe the main aspects of the flow curve—magnitude, duration, frequency—that are ecologically relevant and that the proposed development pathways affect (Richter et al. 1996). The magnitude indicators show the amount of water under average, very low, and very high flow conditions. Duration is the length of time during which there are low- or high-flow conditions. Frequency is how often there are very low- and very high-flow conditions; 1991 was excluded from the calculation of indicators because it included a period during which model values were not correctly calculated for several months.

The impact score is calculated as an absolute percentage of change between the present situation and the pathway. The direction of change (increase or decrease) is not reflected in the outcome value of the hydrological indicator because increases and decreases in flow magnitude reduce the abundance and diversity of fish species (Poff and Zimmerman 2010). Therefore, the direction of change of the indicators is ignored in the calculation.

The impact score was calculated for each model calculation point that falls within the distribution range of the species (Figure F.2). Subsequently, the total deviation was calculated as the median of all calculation points. The deviation percentages of the magnitude indicators were calculated according to the formula:

$$\text{abs}((\text{Value}_{\text{scenario}} - \text{Value}_{\text{present}})/(\text{Value}_{\text{present}}/100))$$

Table F.4: Hydrological Indicators Used to Calculate Changes in Flow Discharge Characteristics

Flow characteristic	Very low flow	Low flow	Average flow	High flow	Very high flow
Magnitude	Twentieth percentile of annual minimum discharge		Median of median annual discharges		Eightieth percentile of annual maximum discharge
Duration		Average number of days per year with discharge < the 25th percentile of present situation		Average number of days per year with discharge > the 75th percentile of present situation	
Frequency	Non-exceedance frequency of 20th percentile of present situation of annual minimum discharge				Exceedance frequency of 80th percentile of present situation of annual maximum discharge

Duration indicators were calculated as percentages of deviation scaled to the maximum amount of deviation possible. The maximum duration difference between the present situation and the scenario is 274 days (365 days in the year - 91 days, which corresponds to the number of days less than the 25th percentile and greater than the 75th percentile in the present situation). The following formula was used:

$$\mathrm{abs}((\mathrm{Value}_{\mathrm{scenario}} - \mathrm{Value}_{\mathrm{present}})^{*}100/274)$$

The frequency indicators were calculated using the following formula:

$$\mathrm{abs}((\mathrm{Value}_{\mathrm{scenario}} - \mathrm{Value}_{\mathrm{present}})/(\mathrm{Value}_{\mathrm{present}}/100))$$

For each indicator, this percentage is translated into impact based on the description in Table F.5.

Table F.5: Impact

Impact	%
Negligible	0–5
Slight	5–15
Moderate	15–30
Large	30–50
Severe	>50

The final impact score is an average of all indicator impact scores per fish species.

F.1.4 Habitat Fragmentation and Loss of Habitat

Physical blocking of rivers by dams and changes in aquatic habitats can fragment aquatic habitat. Physical blockage of dams that hamper connectivity was assessed in terms of reduction in the largest unblocked habitat expressed in river kilometers (see, for example, *Poropontius consternans*, Map F.1) and degree of fragmentation of the species habitat. The length of unblocked river and the number of areas in which a species range is fragmented was calculated using ArcMap 10.4.1, then the difference in percentage reduction in the longest unblocked river section and percentage increase in fragmentation between the present situation and all other development pathways was assessed. A large reduction in the connected areas could pose a risk to the carrying capacity of the population if too little habitat remained available for a viable population. This is especially the case for migratory fish, which cover a large range between habitats.

Habitat fragmentation and reduction caused by changes in aquatic habitats were assessed according to differences between impounded and free-flowing areas. Reservoirs are deep and relatively stagnant and therefore provide a habitat different from that of free-flowing rivers with alternating pools and riffles. Reservoirs create two types of effects: they cause fragmentation, and they reduce the amount of preferred habitat. The percentage of river transformed from free flowing to reservoir was used as an indicator. Again, this is species specific, but because reservoirs have an additive effect on fragmentation, the fish-preferred habitat is blocked (and a different type of habitat is produced), which should be an addition to the fragmentation score.

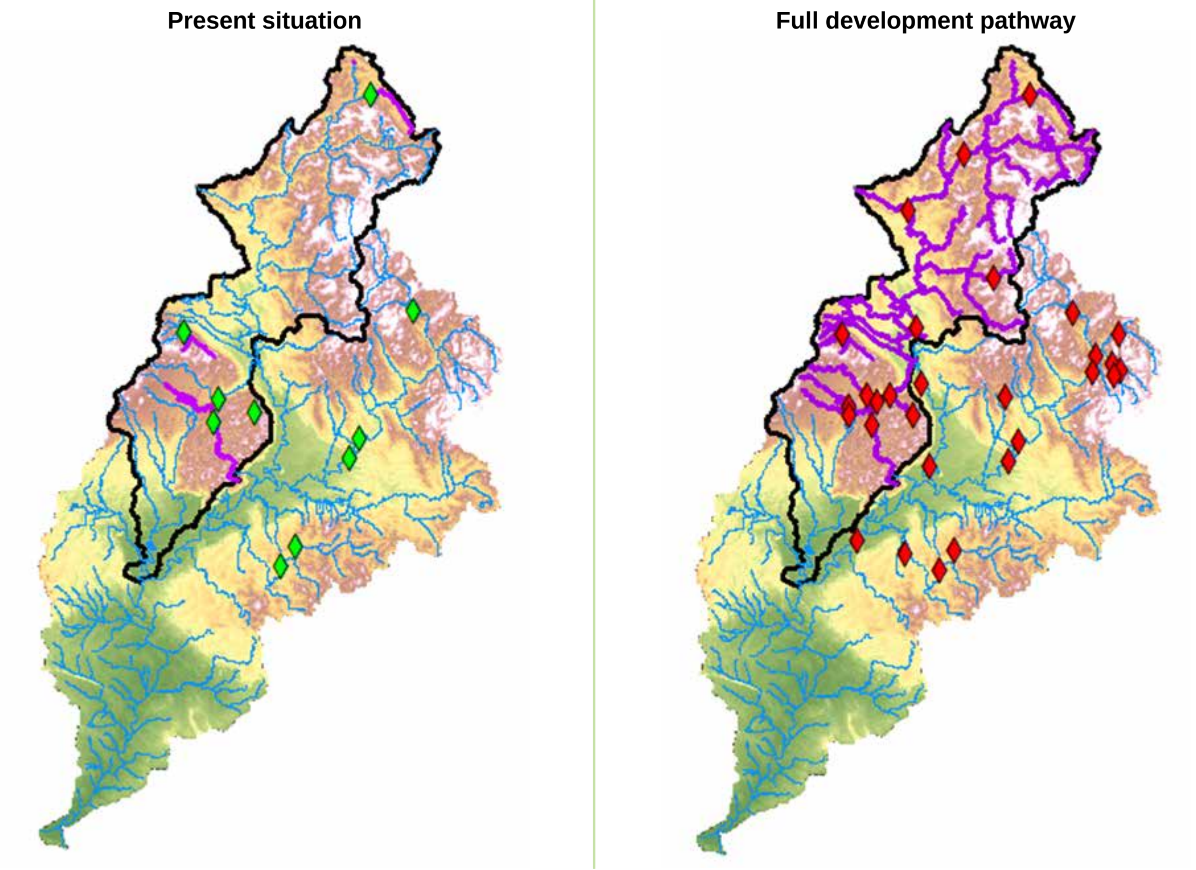
Three types of indicators are calculated:

1. Reduction in largest unblocked area, which is an indicator of potential reduction in the carrying capacity of a population, called *connectivity*
2. Reduction in number of areas in which a species range is split up
3. Reduction in habitat caused by reservoirs

The connectivity score is the score of indicator 1, and the fragmentation score is the sum of indicators 2 and 3. The final score is the average of the connectivity and fragmentation scores. The percentage was translated into an effect, as described in Section F.1.3.

Flow alteration can also fragment habitat, which can lead to dis-connectivity between floodplains and channels or within channels. The effect of flow alteration on habitat fragmentation is estimated using the low-flow indicators of hydrological alteration (Table F.4).

Map F.1: Method for Assessing Connectivity Changes Affecting *Poropuntius consternans*



Note: The historical species range of *P. consternans* is demarcated with a black line, and tributaries without dams are shown in blue. Areas upstream of dams that are no longer accessible to *P. consternans* are depicted in purple. In the present situation, most of the current range is connected and accessible, whereas under the full development pathway, only a small area in the southern part of the range remains connected.

F.2 Cumulative Impact Assessment Analysis and Results

F.2.1 Effect of Flow Regime Change on Aquatic Ecology

Climate change, water abstraction, and hydropower plants can alter flow. The most dominant driver of flow alteration is reservoir dams. Table F.6 shows the details of all calculated hydrological indicators for all fish species and all pathways. The hydrological indicators depict the absolute values of differences under each pathway compared with the present situation. For details on the methodology, see Section F.1.3.

The hydrological indicators show large deviations in very low and very high flows. There are large differences between species and between pathways (Table F.7). Because all pathways involve dam construction, they all harm fish species to varying degrees. The largest effects are for the full development pathway, whereas the conservative pathway has the fewest negative effects. On average, all pathways, although mostly full development, affect *Schistura bolavenensis* most. This fish species is super-endemic and is an important species for food.

Water extraction, which irrigation demand dominates, is less important than the effect of dams (Asian Development Bank 2010). In the Sekong Basin, the irrigated area is 3,605 hectares in the wet season and 2,743 hectares in the dry season (Meynell 2014), although expansion of the agricultural sector and increases in water abstraction for drinking water and domestic water are becoming increasingly important (Asian Development Bank 2010; Freshwater Health Index 2018). In the Sekong, Sesan,

Table F.6: Values for Hydrological Indicators per Fish Species for Each Pathway

Species and pathway	Amount of change in magnitude of different flows			Amount of change in duration of different flows		Amount of change in frequency of different flows		Average score
	Low flow	Average flow	High flow	Low flow	High flow	Low flow	High flow	
Pangasius sanitwongsei								
Full	62.6	0.8	13.5	12.0	4.4	80.0	40.0	30.5
Conservative	13.0	0.1	0.3	0.5	0.1	20.0	0.00	4.9
Intermediate	44.0	0.9	8.9	6.4	1.4	80.0	20.0	23.1
Schistura bolavenensis								
Full	40.5	2.4	27.5	22.3	6.7	80.0	80.0	37.1
Conservative	0.00	0.00	0.0	0.0	0.0	0.0	0.00	0.0
Intermediate	40.8	2.3	20.1	14.7	3.6	100.0	60.0	34.5
Poropuntius consternans								
Full	40.5	2.4	21.9	15.7	5.2	80.0	70.0	33.7
Conservative	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
Intermediate	40.8	2.3	16.2	9.8	3.2	80.0	40.0	27.5
Mystacoleucus atridorsalis								
Full	64.7	1.4	15.4	13.9	5.4	90.0	40.0	33.0
Conservative	26.2	0.2	1.2	0.8	0.2	40.0	20.0	12.7
Intermediate	45.6	1.6	9.7	6.9	2.8	80.0	20.0	23.8

Table F.7: Effect of Flow Regime Change on Aquatic Ecosystem and Fish Stocks

Pressure or pathway	Present situation	Full development	Intermediate development	Conservative development
Climate change	Slight	Slight	Slight	Slight
Water extraction	Slight	Slight	Slight	Slight
Catchment changes	Slight	Moderate	Moderate	Slight
Hydropower dams and reservoirs	Moderate	Large	Moderate	Slight
Impact score	Slight	Large	Slight to moderate	Slight

and Srepok basins, irrigation is planned for 270,000 hectares of land in addition to the current 60,000 hectares (Asian Development Bank 2010). These developments could place additional pressure on water resources and hence the aquatic ecosystem, including fish stocks, especially in the dry season (Freshwater Health Index 2018). Therefore, under the present situation, the effect of water abstraction is considered low, but for future situations, it is considered low moderate, mainly in the dry season.

The flow regime is further affected by climate change (Table F.7). Projections for the Sekong Basin predict a slight increase in flow during the wet season and a larger decrease in the dry season (see Appendix B). Decrease in flow in the dry season can especially harm fish by shrinking their habitat. Therefore, a similar effect is given to climate change as to water abstraction: low in the current situation and low moderate in future scenarios.

Absolute indicator values were used for the assessment, but the direction of change of these indicators provides insight into the type of alteration that takes place in the river system. The magnitude of low flows increases, and the magnitude of high flows decreases. A reduction in high flows will result in a reduction in channel-floodplain connectivity, which harms species that depend on these connections, although any direction of change in flow parameters can decrease abundance and diversity of fish species (Poff and Zimmerman 2010). Therefore, the values of the indicators provide insight into several ecologically relevant aspects of the flow and can be used to assess the effect of flow alteration on fish species.

F.2.2 Habitat Fragmentation and Connectivity

Dams block rivers, which causes habitat fragmentation and loss of connectivity. Dams decrease the length of river that species can use, fragment ranges, and transform aquatic habitats from lotic (flowing) to lentic (stagnant) conditions.

These changes were analyzed quantitatively based on ArcGIS data (Figure F.3, Table F.8, and Figure F.4). For several fish species, the longest stretch of connected river in their distribution range is between dams. This is the case for *Poropuntius consternans* and *Schistura bolavenensis* under the full development pathway, in which the longest stretch is between Sekong 3A and 3B. These species are the most affected fish species, especially in the full and intermediate development pathways. Both species are important for food, and *Schistura bolavenensis* is a super-endemic species. In the intermediate and full development pathways, the longest connected area for *Schistura bolavenensis* is between the A Loui and Sekong 5 dams.

Figure F.3: **Increase in Fragmentation for Each Fish Species Under Different Development Pathways**

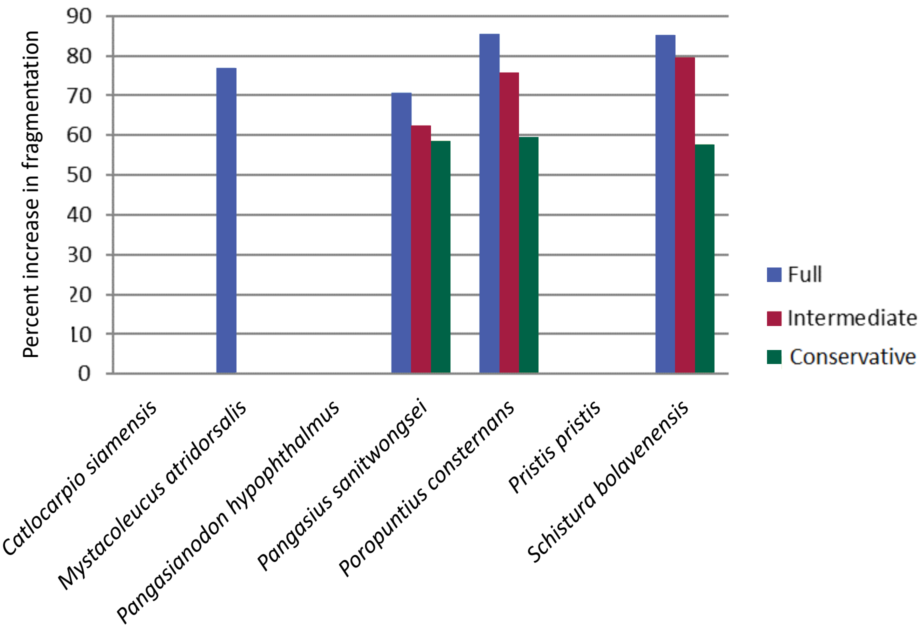
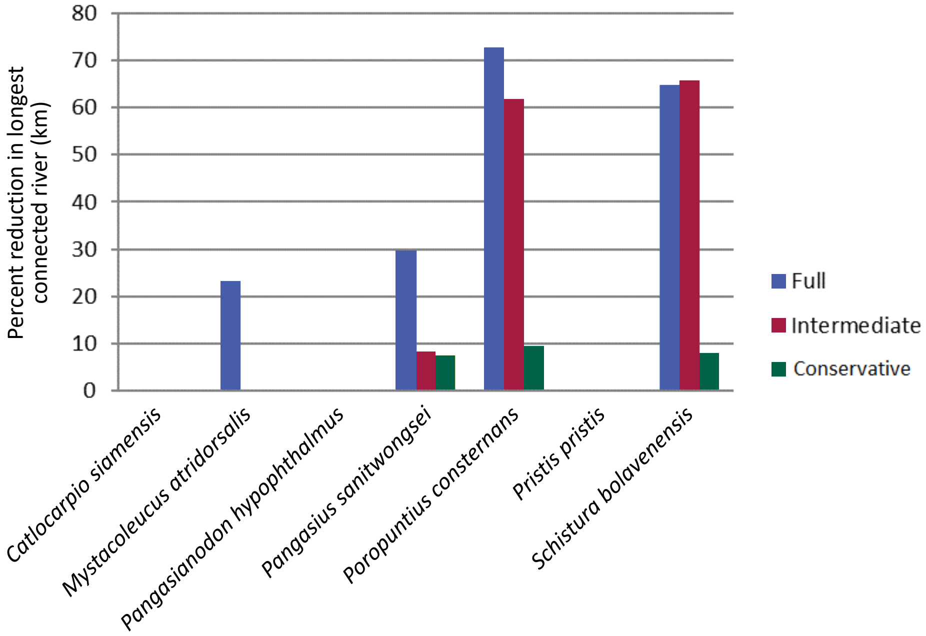


Table F.8: Effect on Ranges of Critical Fish Species of Hydropower Development Under Different Development Pathways

Indicator	*Mystacoleucus atridorsalis*	*Pangasius sanitwongsei*	*Poropuntius consternans*	*Schistura bolavenensis*
Full development pathway				
Dams in range	Sekong Downstream A, Sekong Downstream B, Sekong 3B	Sekong 3B, Sekong Downstream B, Sekong Downstream A, Xe Katam, Xe Katam–Xe Namnoy 1, Xe Namnoy 1, Houay Ho, Houay Makchan, Xe Pian, Xe Pian–Xe Namnoy, Nam Kong 3, Nam Kong 2, Nam Kong 1	Sekong 4B, Sekong 4A, Sekong 5, Houay Lamphan, Sekong 3A, Houay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Katam, Xe Pian, Xe Pian–Xe Namnoy, A Loui, Dak E Mule	Sekong 4B, Sekong 4A, Sekong 5, Houay Lamphan, Sekong 3A, Houay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Katam, Xe Pian, Xe Pian–Xe Namnoy, A Loui, Dak E Mule
River converted to reservoir (kilometers)	3,340	112.2	327.5	327.5
Reduction to total range (%)	1.8	4.1	18.8	23.8
Intermediate development pathway				
Dams in range	No dams	Xe Katam, Xe Katam–Xe Namnoy 1, Xe Namnoy 1, Houay Ho, Houay Makchan, Xe Pian, Xe Pian–Xe Namnoy, Nam Kong 3, Nam Kong 2, Nam Kong 1	Sekong 4B, Sekong 4A, Sekong 5, Houay Lamphan, Kouay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Kamtam, Xe Pian, Xe Pian–Xe Namnoy, A Loui, Dak E Mule	Sekong 4B, Sekong 4A, Sekong 5, Houay Lamphan, Kouay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Katam, Xe Pian, Xe Pian–Xe Namnoy, A Loui, Dak E Mule
River converted to reservoir (kilometers)	0.00	78.8	312.1	312.1
Reduction to total range (%)	0.00	4.2	11.5	17.9
Conservative development pathway				
Dams in range	No dams	Xe Katam, Xe Katam–Xe Namnoy 1, Xe Namnoy 1, Houay Ho, Houay Makchan, Xe Pian, Xe Pian–Xe Namnoy, Nam Kong 3, Nam Kong 2, Nam Kong 1	Houay Lamphan, Houay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Katam, Xe Pian, Xe Pian–Xe Namnoy, A Luoi, Dak E Mule	Houay Lamphan, Houay Makchan, Xe Katam 2, Xe Namnoy 1, Xe Katam, Xe Pian, Xe Pian–Xe Namnoy, A Luoi, Dak E Mule
River converted to reservoir (kilometers)	0.00	78.8	136.1	136.1
Reduction to total range (%)	0.00	4.2	5.0	7.8

Figure F.4: Decrease in Connectivity for Each Fish Species Based on Blockage by Dams



Note: Species not shown do not have dams in their range. km = kilometers.

The final impact scores for fragmentation and connectivity in all development pathways are presented in Table F.9. This shows an average score for all fish species. For details on the calculations, see Section F.1.4. Water abstractions are considered less important than habitat fragmentation and connectivity and are therefore not taken into account.

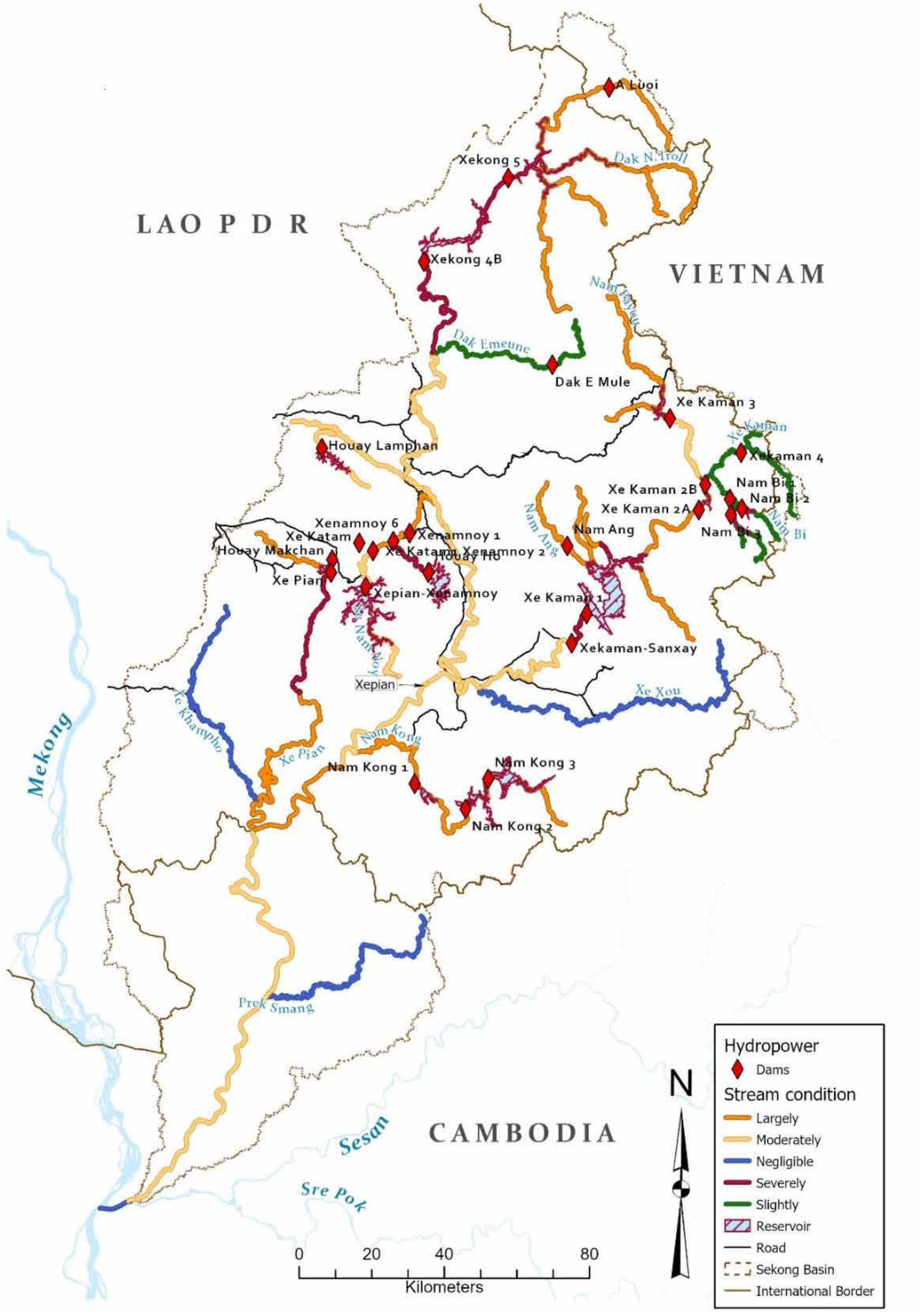
The summary of river modification for various river sections under each development pathway is illustrated in Maps F.2, F.3, and F.4 and under the present situation in Map F.5. The colors show the degree of modification assessed as a combined score averaged over modifications to flow regime, sediment transport, and fish connectivity.

Table F.9: Impact Scores for Habitat Fragmentation and Connectivity

Pressure or pathway	Full development	Intermediate development	Conservative development
Connectivity	**27**	**19**	**4**
Fragmentation			
Subscore 1	39	26	23
Subscore 2	7	4	2
Total score	**46**	**30**	**28**
Final % (average)	**36**	**25**	**14**
Impact score	**Large**	**Moderate**	**Slight**

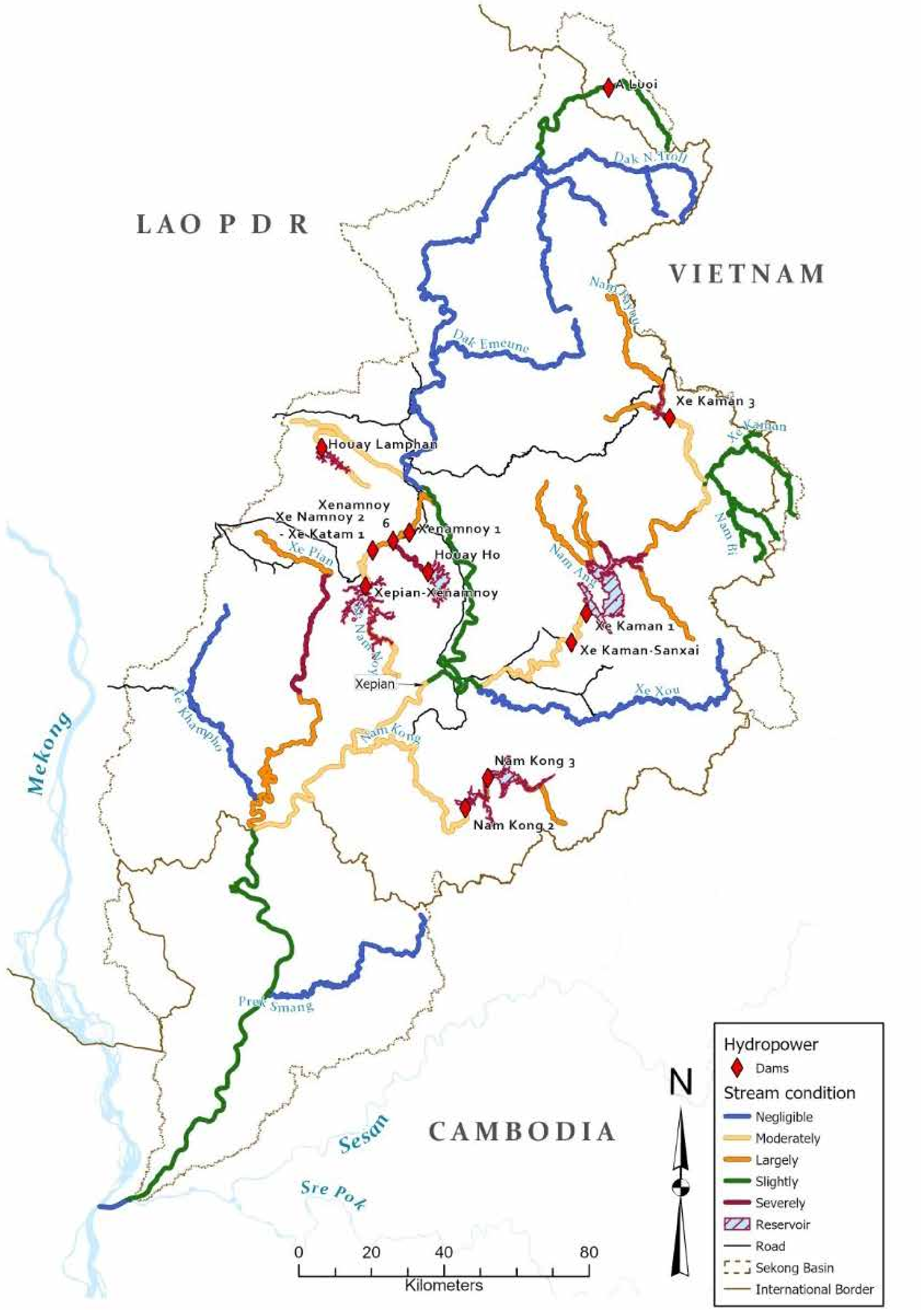
Map F.2: Degrees of River Modification Under Full Development Pathway

Map F.3: Degrees of River Modification Under Intermediate Development Pathway



Map F.4: Degrees of River Modification Under Conservative Development Pathway

Map F.5: Degrees of River Modification in Present Situation



APPENDIX G
HYDROPOWER MODELING AND POWER OPTIMIZATION ASSESSMENT

G.1 Reservoir Operation

To achieve the greatest power generation, reservoirs should be operated so that there is as little spill as possible and the reservoir water level is kept as high as possible. There is some tension between these two goals: it is necessary to lower the reservoir water level to have available volume to store incoming water and so avoid spill. Optimization involves determining the reservoir guide curve that is the best compromise between the two goals.

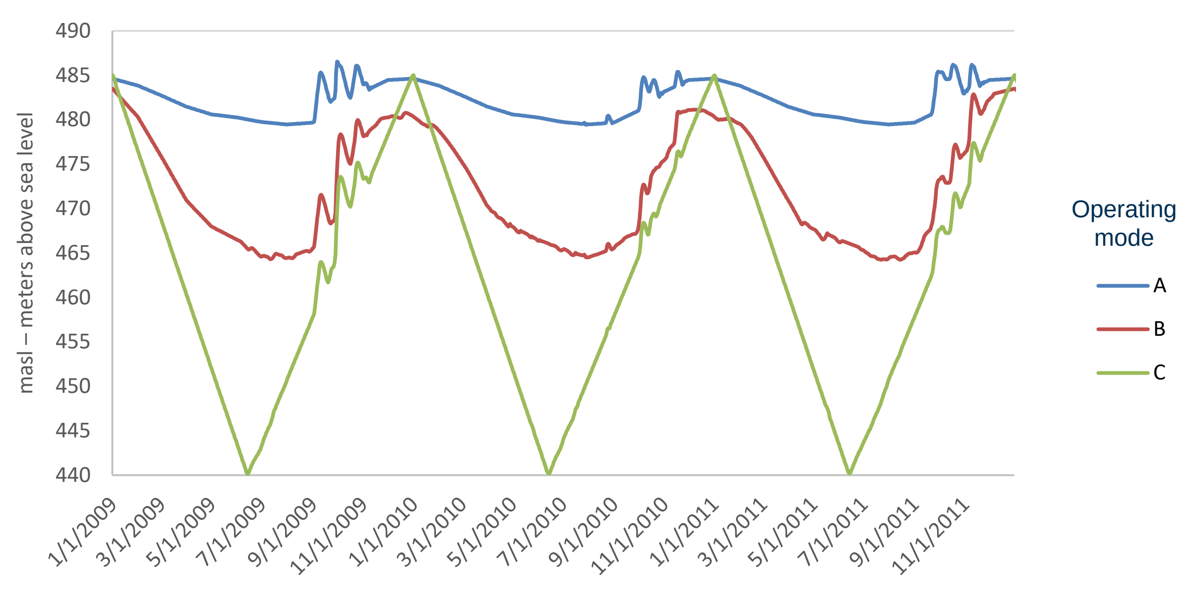
Operation rules may not precisely reflect the outcome of optimization. Other factors besides the guide curve are also important: for instance, guaranteeing power during high-demand periods, providing a stable output, varying prices for energy in wet and dry seasons, and time of day pricing. Environmental releases may also affect power production potential.

For a cascade of dams, different operation regimes may be beneficial. A large upstream reservoir may be used to store all water in the wet season to be used in the dry season, reducing generation at the upstream power plant but benefiting downstream plants.

We analyzed three modes of operation: (1) maximization of energy output (keep water level as high as possible without major spills) (mode A), (2) maximization of firm energy and power (mode B), and (3) dry season generation (mode C) (Figure G.1).

In mode A, the power plant is run close to a run-of-river project, with use of the reservoir restricted to avoid major spilling in the wet season. In mode B, the aim is to run the power plant at a constant output, with the firm power as high as possible. This is favored when the price for firm power is high. This mode could also include

Figure G.1: Modeled Reservoir Water Level at Sekong 5 for Different Modes of Operation



Note: Mode A = maximization of energy output; mode B = maximization of firm energy and power; mode C = dry season generation.

peaking generation but with little to no seasonal variation. In mode C, the reservoir is emptied in advance of the monsoon, and wet season inflow is used to fill the reservoir. This generates as much power as possible in the dry season. This could be feasible if there are seasonal variations in power price or to maximize the power output of a cascade with run-of-river power plants and an upstream reservoir.

If one considers an individual reservoir hydropower plant such as Sekong 5, mode A generates more power than mode B, which generates more power than mode C because loss of head more than counteracts the reduction in spill from active use of the entire reservoir volume. We do not know the details of the power purchase agreements for the the hydropower plants (HPPs) in the Sekong River Basin, but based on available information, it is likely that Sekong HPPs will be operated to maximize firm power (mode B).

Only the larger reservoirs are suited for seasonal storage. In the Sekong River Basin, these include Sekong 5, Houay Lamphan Gnai, Houay Ho, Xe Pian–Xe Namnoy, Xe Kaman 1, Nam Kong 1, and Nam Kong 3. Smaller reservoirs could be used for peaking operation but cannot be optimized for firm power generation. In our model, reservoirs with volume of less than 10 percent of annual flow are operated as run-of-river hydropower. This applies to all mainstream Sekong projects except Sekong 5.

G.2 Technical Assumptions

It has been necessary to make a number of assumptions regarding hydropower calculations because information is lacking about technical parameters for each project. We have assumed that there is a constant release of 2 percent of average flow for all mainstream hydropower plants to provide flow in fish passes, navigation locks, and other releases not producing energy. We have also assumed that reservoir volume curves increase linearly from low- to high-regulated water level. In reality, there will be more water stored in the upper, wider portion of the reservoir than in the lower, narrower portion, but this makes little difference to the results.

The efficiency of all hydropower plants was set to 0.87. This includes efficiency of electromechanical equipment and all head loss in the system.
We assumed that units are designed for operation at peak efficiency or maximum output with reasonably high efficiency. We also assumed intermittent operation in low-flow periods for run-of-river HPPs, meaning that efficiency is kept high. We used full supply levels according to information that the Ministry of Energy and Mines provided.

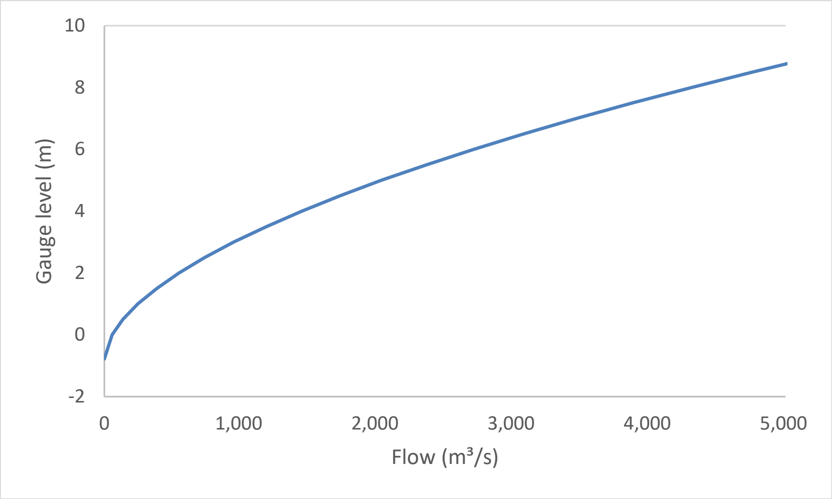
G.3 Tailwater Curves

For low-head hydropower plants, the elevation of the tailwater is important because it greatly affects available head for generation. We have tailwater curves for Sekong 4A and 4B, although we are not certain whether they are correct because the locations of the dams in the feasibility studies do not correspond to the latest official locations. For the other projects, we did not have access to tailwater curves. The water level of the downstream reservoirs will affect most of the Sekong mainstream projects. The downstream reservoirs in the model do not affect Sekong Downstream B and A, but the two upper projects will most probably be affected to some degree.

Because the Sekong mainstream reservoirs are long and narrow, we have assumed that there is a gradient in the water levels. For simplicity, we assumed that the tailwater level of an HPP is 1 meter higher than the headwater level at the downstream dam. This will gradually become the case, if not higher, because sediment accumulation at the upstream end of each of the reservoirs backs up river levels in the reaches approaching the reservoir.

For higher flows and for Sekong Downstream B and A, we generated tailwater curves based on the Siem Pang gauging station, located on the Sekong in Cambodia. We adjusted the curve for each project based on the difference between the width of the Sekong River at the project site and the width at Siem Pang (see Figure G.2). We tried to ensure that the average tailwater level based on the tailwater curve matched the given tailwater elevation or median head in the feasibility studies (Figure G.3).

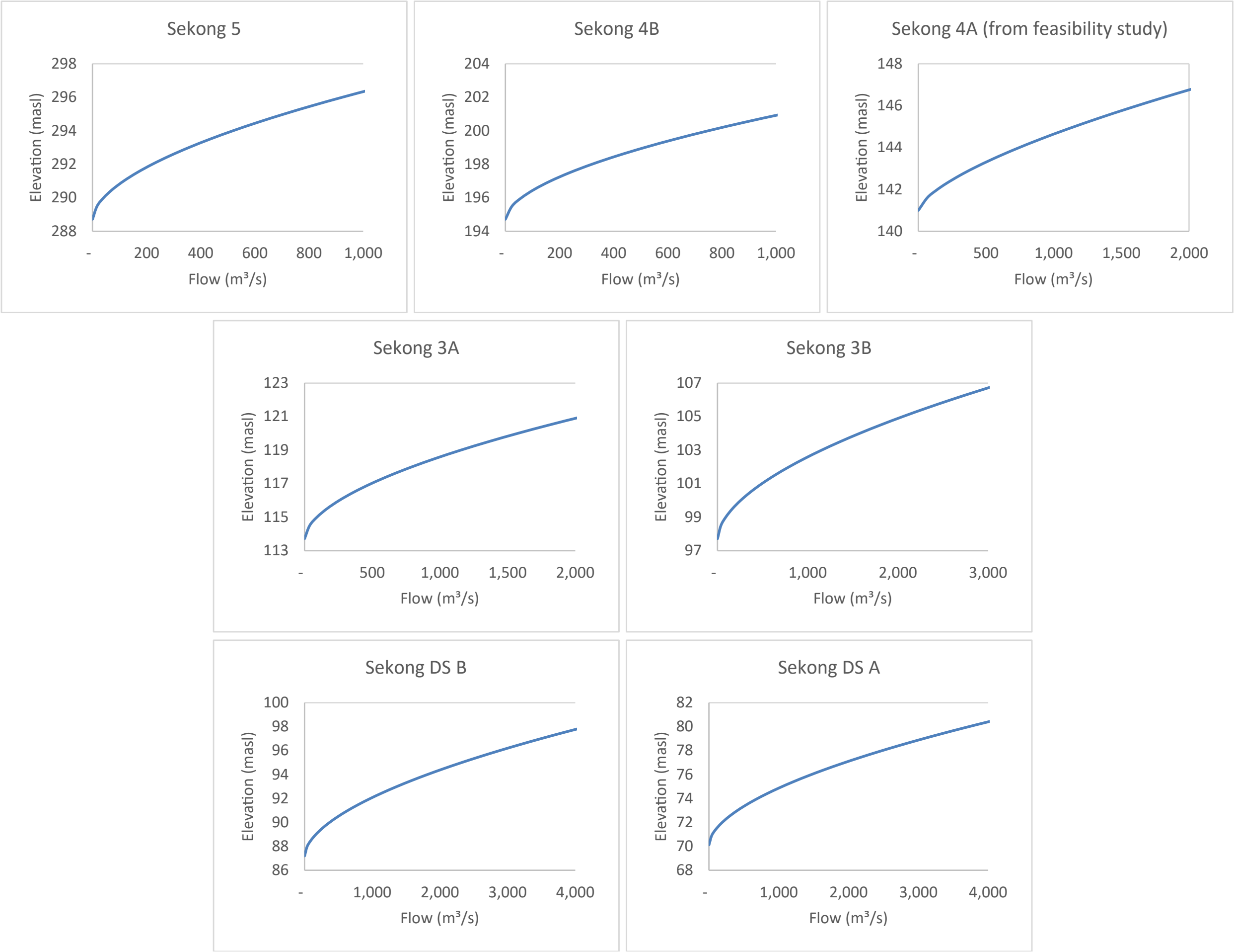
Figure G.2: Siem Pang Rating Curve



Source: http://cam-crds.nis.gov.kh/site/docs/CCpolicy/Cambodian_Water_Resources_Profile_FINAL_21-04-14.pdf.

Note: m = meters; m³/s = cubic meters pers second.

Figure G.3: Assumed Tailwater Curves



Note: masl = meters above sea level; m³/s = cubic meters per second; DS = downstream.

G.4 Sekong Mainstream Power Generation

Simulations have been done for 1991 to 2014 (Table G.1). To avoid having the initial conditions of the model affect the model results, the presented numbers are averages of 1992 to 2014.

There are several potential reasons for the differences in power generation between our model and the results of the feasibility studies. First, there are significant differences in assumed annual inflow at each dam site. In general, the model uses 15 to 20 percent lower annual inflow than the feasibility studies assume. Second, the production figures given in feasibility reports are assumed not to involve the upstream regulation benefits of the future Sekong 5 project. Third, some feasibility studies do not include downstream reservoirs in their calculated tailwater level, thus overestimating available head. There are probably also differences in number and type of units and assumed efficiency curves and operating rules. We had to make a simple assumption to fit all projects (0.87 constant).

To reduce the effect of the first factor, we adjusted the feasibility study energy output figures proportionally to correspond to the reduced inflow in our model. The results are shown in the final column in Table G.2, which shows that, in most cases, we are obtaining more production from the same adjusted mean inflow with the exception of Sekong 3A and 3B, for which our model shows 6 to 7 percent less production. From the feasibility studies of Sekong 3A and 3B, we believe the generation estimated for these projects is too high because they included the period from 1979 to 1989, which had higher flows than observed today. The regulation of flows from Sekong 5, Xe Kaman, Nam Kong, and other reservoirs is probably the reason for the larger modeled power production of Sekong Downstream A. Sekong 4B, being directly downstream of Sekong 5, also receives considerable benefits from the Sekong 5 reservoir. Sekong 4A most probably has a different tailwater curve because it stems from the old dam location.

The comparison between our model and the feasibility study results shows there is reasonable agreement; it is likely that variation is due to uncertainties and assumptions inherent in the model.

There is little difference between modes A and B (Figure G.4) (the blue line covers the red), but mode C is somewhat different. There is a considerable contribution from the reservoirs in all scenarios and relatively little spill. The rated discharge of the hydropower plants is also relatively high compared with the flow in the river, which reduces spill. Therefore, the average production figures do not change from mode to mode.

Table G.1: **Sekong Mainstream Power Generation**

Hydropower project	Model results			Figures reported in project feasibility studies
	Maximize generation	Maximize firm power	Seasonal storage	
	(GWh/year)			
Sekong 5	1,239	1,200	1,159	1,500
Sekong 4B	736	756	757	750
Sekong 4A	734	749	752	780
Sekong 3A	368	370	371	460
Sekong 3B	307	310	310	400
Sekong Downstream B	176	180	181	210
Sekong Downstream A	423	438	439	380
Total	**3,983**	**4,003**	**3,970**	**4,480**

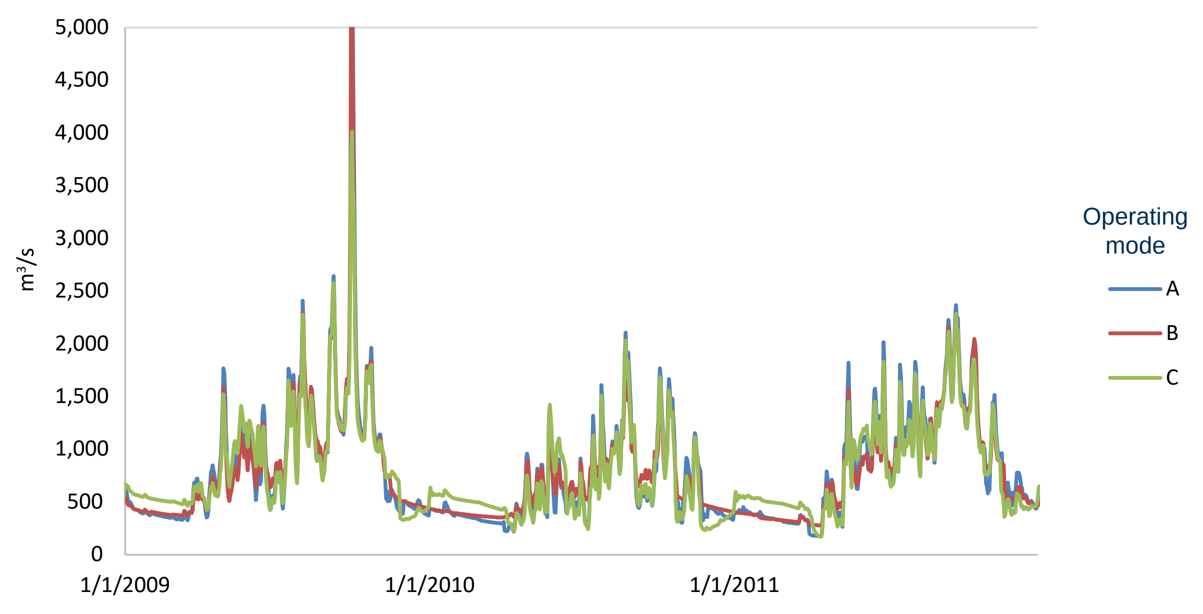
Note: GWh = gigawatt-hours.

Table G.2: Flow Comparison

Hydropower project	Estimated average flow, feasibility study	Average flow HEC-ResSim model	Model flow versus feasibility study	Adjusted improvement on feasibility study energy with equal annual inflow
	(m³/s)		%	
Sekong 5	125	91	74	10
Sekong 4B	132	117	89	14
Sekong 4A	227	184	81	18
Sekong 3A	247	213	86	-7
Sekong 3B	335	276	83	-6
Sekong Downstream B	399	316	79	8
Sekong Downstream A	796	798	100	15

Note: HEC-ResSim = Hydrologic Engineering Center - Reservoir System Simulation ; m³/s = cubic meters per second.

Figure G.4: Flow at Sekong Downstream A for Modeled Scenarios



Note: Design flow for Sekong Downstream A is 1,105 m³/s. Mode A = maximization of energy output; mode B = maximization of firm energy and power; mode C = dry season generation; m³/s = cubic meters per second.

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