Study on the Impacts of Mainstream Hydropower on the Mekong River

Final Report

Ministry of Natural Resources and Environment

Final Report

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Final Report

Prepared for: Ministry of Natural Resources and Environment

Government of Viet Nam

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AW	Autumn-Winter crop season
BAR	Baseline Assessment Report
BDP2	Lower Mekong Basin Development Plan 2
cm	centimeter(s)
CPUE	catch per unit effort
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DWT	Dead Weight Tonnage
ECOLab	MIKE software package process module for water quality and ecological modelling
GSO	General Statistics Office of Vietnam
IAA	Impact Assessment Area
IAR	Impact Assessment Report
JICA	Japan International Cooperation Agency
K	potassium
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
LMB	Lower Mekong Basin
m	meter(s)
m/y	meter(s) per year
m^3/s	cubic meter(s)/second
MDS	Mekong Delta Study
MIKE	Name of a water modeling software package, which includes MIKE 11, MIKE FLOOD, MIKE 21C, MIKE HYDRO Basin, MIKE SHE
MRC	Mekong River Commission
Mt	million tonne(s)
N	nitrogen
OAA	other aquatic animals
P	phosphorus
PDR	People's Democratic Republic
SA	Summer-Autumn crop season

SEA	Strategic Environmental Assessment
SWAT	Soil and Water Assessment Tool
USD	United States dollar
VND	Vietnamese dong
WS	Winter-Spring crop season

Executive Summary

Eleven hydropower projects have been proposed for the Mekong River mainstream in the Lower Mekong Basin, which covers riparian areas of Thailand, Lao PDR, Cambodia, and Viet Nam. All the proposed dams will be located in Thailand, Lao PDR, and Cambodia.

Construction and operation of any or all of these proposed projects could potentially have substantial and wide-ranging environmental and socio-economic effects in all four countries. In particular, there is specific concern over the impacts of the mainstream cascade on the downstream floodplains of Cambodia and Viet Nam. This concern led to a strong need to conduct additional studies and analyses using the most current data and best available scientific tools to improve understanding of how the proposed cascade would impact the natural and human environment and the socio-economic status and livelihood of tens of millions of people in the Mekong Delta.

Therefore, the Government of Viet Nam, in close cooperation with the Governments of Lao PDR and Cambodia, initiated the *Study on the Impacts of Mainstream Hydropower on the Mekong River* (also known as the Mekong Delta Study or MDS) **to study the overall impact of the proposed Lower Mekong Basin (LMB) mainstream hydropower cascade on the natural, social, and economic systems of Cambodian and Vietnamese floodplains.** The primary objectives of the MDS were to evaluate changes projected to occur in the hydrological processes of the LMB resulting from construction and operation of the proposed mainstream hydropower cascade, and assess how these changes could potentially impact the human and natural environment in the Cambodian and Vietnamese floodplains.

Other objectives included developing a comprehensive database of relevant environmental, social, and economic conditions for the Lower Mekong River Basin, quantitatively assessing impacts on selected resource areas, seeking basin-wide consensus on the results of the impact assessment, and determining avoidance and mitigation measures through close consultation with stakeholders.

Impacts associated with the major changes caused by mainstream hydropower projects (river flows and inundation patterns, sediment and nutrient loading, salinity intrusions, and dam barrier effects) were assessed separately for six resource areas: fisheries, biodiversity, navigation, agriculture, livelihood, and economics. Inter- and intra-resource area impacts were identified and overall impacts of the various resource areas on the regional and national economy were forecasted. Two additional scenarios were also evaluated to examine the incremental effects of tributary dams and mainstream water withdrawals. In addition, four dam development alternatives were assessed to determine the level of relief that could be obtained from only constructing selected dams in the cascade.

The impact assessment approach was based on internationally recognised standards and accepted practices and principles. Guidelines recommended by the International Association for Impact Assessment, the United States National Environmental Policy Act, and the World Bank International Finance Corporation's Performance Standards on Environmental and Social Sustainability were incorporated, as applicable. **Best available input data and peer-reviewed, scientifically validated impact assessment methods were used to characterise and quantify the impacts.**

The assessment results indicate that **the planned mainstream hydropower cascade (Scenario 1) would cause high to very high adverse effects on some**

of the key sectors and environmental resources in Cambodia and Viet Nam if implemented without mitigations. Cumulative adverse effects of the planned cascade and tributary dams (Scenario 2) and the planned cascade and proposed water diversion schemes in Thailand and Cambodia (Scenario 3) would pose even greater impacts to the Mekong Delta in comparison to Scenario 1 effects. **Under all three scenarios, the most severe adverse impacts are anticipated to result from a combination of the dam barrier effects and the reduction in sediment-associated nutrient loading.** Development alternatives on constructing and operating a fewer number of dams would decrease the projected impacts to varying degrees depending upon which of the 11 proposed dams are constructed.

Notable adverse impacts of the mainstream cascade on the individual resource areas include the following:

- Though low to moderate changes are expected for a normal hydrological year, high to very high short-term adverse impacts on river flow regimes would occur as a result of dam hydropeaking operations and dry-season drawdowns for maximum power production (potential loss of 10-day water volume at Kratie is 60%, and at Tan Chau and Chau Doc the potential loss is 40%). The river course of Cambodia downstream of the cascade is projected to suffer the highest impacts from high fluctuating flows and water level. Amongst the three assessed scenarios and four development alternatives, impacts on flow regimes from Scenario 3 are the worst.

- Sediment and nutrient deposition would decrease as much as 65% at Kratie and Tan Chau – Chau Doc and by smaller amounts off the mainstream, potentially causing a substantial decline in biological productivity, reduction in agricultural production, increase in erosion, and a decrease in the rate of buildup of riparian and coastal sites. Scenario 2 poses the most severe impacts on sedimentation and nutrients in comparison to the other scenarios and development alternatives.

- Salinity intrusion would increase in some coastal areas. Similar to flow impacts, Scenario 3 causes the largest impacts on salinity intrusion.

- Travel routes of long-distance migratory fish (white fish), which account for 74% of the catch of the top 10 commercial fish species, would be completely obstructed. The dams would also block upstream and downstream movements of all other migratory fish and other aquatic animals. **Overall, the proposed mainstream hydropower cascade may lead to approximately 50% decline in capture fishery yields in both Viet Nam and Cambodia.** Tributary dams and diversion may cause additional marginal impacts on fisheries.

- The substantial loss of capture fishery resources would adversely affect the food security, livelihood, social well-being, and economic status of large segments of the population in the Cambodian floodplains and the Mekong River Delta that are directly or indirectly reliant on fishing and associated occupations.

- High to very high adverse effects on biodiversity include the potential for extirpation or global extinction of up to 10% of the fish species from Viet Nam and southern Cambodia, reduced populations of surviving migratory fish species, extirpation of the Irrawaddy dolphin from the Mekong River, reduced distribution and abundance of freshwater mussels, and reduced drift of all other invertebrates.

- Unsafe conditions for the operation of vessels could occur downstream of dams operating for peak daily power production or conducting drawdowns. Low to moderate adverse impacts are projected on navigation elsewhere mainly due to changes in river flow regime and resulting challenges to river navigation not historically encountered.

Overall, in Cambodia a national industry of high importance (fisheries) would suffer very high decline in yields (a loss of approximately 48 to 55%), and widespread adverse impacts are anticipated in the riparian areas between Kratie and Kampong Kor, which would be most severely impacted. Viet Nam would also suffer great losses in fisheries and biodiversity, and would experience adverse impacts in some coastal areas due to increase in salinity incursions.

The projected impacts are based on a robust combination of quantitative and qualitative analyses of the best available data with advanced modeling systems and customised impact assessment tools. **The actual impacts may well be greater than projected** because of the cumulative effects of other natural phenomenon (climate change, sea level rise), on-going developments in the LMB (deforestation, etc.), and the uncertainty related to how the natural systems will respond to the major disruption in the LMB system. Though recognising that biological resources are adaptive by nature and over time might counter and overcome some of the projected impacts, such adaptations cannot fully compensate for the projected effects.

Projected impacts on capture fisheries and biodiversity could be reduced, primarily through avoidance, which could include 1) constructing only selected hydropower projects from the planned cascade, and in particular avoiding construction in the lower cascade, and/or 2) relocating some planned projects off the mainstream to tributaries. Fish passage technologies and/or dam design changes may be considered to mitigate some of the projected losses. However, the **effectiveness of fish passage technologies has not been proven in the context of the Mekong Basin and its highly diverse fish community**. Therefore, it is uncertain what degree of relief fish passage technologies might be able to provide. Also, it is likely that even the best available fish passage technologies may not be able to handle the massive volume of fish migrations, which during peak migration periods can reach up to 3 million fish per hour, and the diversity of migration strategies that characterise the hundreds of fish species in the basin.

In conclusion, the proposed mainstream cascade would cause very high adverse impacts to the Mekong River floodplains and Delta due to the combined interaction of dam barrier effects, highly reduced sediment and nutrient loading, and increase in salinity incursion. Yield of the critically important capture fishery could be reduced by 50%, and up to 10% of fish species in the region could be lost. The large amounts of sediment trapped behind the dams would greatly decrease the delta's capacity to replenish itself making it more vulnerable to sea level rise and saline intrusion, and may worsen coastal erosion. Loss of nutrients trapped along with the sediments will decimate the unmatched productivity of the flood-affected parts of the delta system.

In the Mekong River Delta, the food, health, and economic security of the local populations are inseparably intertwined with the integrity of the natural environment. Un-mitigated **mainstream hydropower development in the LMB would cause long-lasting damage to the floodplains and aquatic environment, resulting in significant reduction in the socio-economic status of millions of residents and creating social and economic burdens on local and regional economies**. With regard to the Mekong River Delta as a unique system of national and international heritage, **the planned hydropower cascade would substantially and permanently alter the productivity of the natural system** leading to degradation of all the Delta’s related values.

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1 Introduction

1.1 Report Scope and Study Purpose

The purpose of the MDS was to identify and evaluate potential changes in the hydrological processes as a result of the development of hydropower projects on the Mekong Lower Mekong Basin (LMB) mainstream and assess how these changes would be anticipated to impact the human and natural environments in the downstream floodplains of Cambodia and Viet Nam.

This Final Report of the *Study on the Impacts of Mainstream Hydropower on the Mekong River* (also known as the Mekong Delta Study or MDS) contains an overview of the important findings and major recommendations of the study. The MDS was initiated by the Government of Viet Nam, and its purpose was to identify and evaluate potential changes in the hydrological processes in the Lower Mekong Basin (LMB) as a result of the development of hydropower projects on the Lower Mekong River mainstream and assess how these changes would be anticipated to impact the human and natural environments in the downstream floodplains of Cambodia and Viet Nam.

This purpose supports the overall goal of safeguarding the Mekong Delta and its resources, economies, and natural systems and ensuring the continued well-being of communities and their livelihoods in the Delta region through informed and scientifically supported decision-making on the use and exploitation of the river's resources.

Mainstream hydropower development recently began in the LMB. Construction of the first LMB mainstream hydropower project, located approximately 30 km east of the town of Xayaburi in Northern Lao People's Democratic Republic (PDR), has been ongoing since approximately 2011, and the Government of Lao PDR announced in 2013 their plan to build a second dam, the Don Sahong Hydropower Project, in the Siphandone area of Southern Lao PDR. Nine other mainstream hydropower projects of varying sizes and production capacities and a river diversion scheme have also been proposed for the LMB. Locations and specifications of proposed 11 mainstream hydropower projects are shown in Figure 1.1-1 and summarised in Table 1.1-1.

Construction and operation of any or all of these projects could have substantial and wide-ranging environmental and socio-economic effects in all the riparian areas in four LMB countries, especially in the downstream areas of individual projects, and in the downstream floodplains and Delta of Cambodia and Viet Nam.

The MDS created a set of customised impact assessment tools and established a scientific basis that can be used by the four LMB countries (Thailand, Lao PDR, Cambodia, and Viet Nam) to guide hydropower development on the Mekong River, including consideration of planning, scale, and design of proposed projects to avoid or minimise significant adverse impacts downstream. The MDS results are intended to provide a platform for cooperation amongst the four countries for the sustainable development of water and related resources of the Mekong River Basin.

Table 1.1-1: Locations and preliminary design specifications of existing and proposed LMB mainstream hydropower projects

Project ID	Location	Design specifications									
		Rated Head (m)	**Plant Design Discharge (m^3/s)**	**Installed Capacity (MW)**	**Mean Annual Energy (GWh)**	**Full Supply Level (mamsl)**	**Low Supply Level (mamsl)**	**Live Storage (mcm)**	**Reservoir Area (km^2)**	**Length of dam (m)**	**Height (m)**
Pak Beng	Lao PDR	31	7,250	1,230	5,517	345	340	442	87	943	76
Luang Prabang	Lao PDR	25.1	5,095	1,100	5,437	310	300	734	55.9	823	46.8
Xayaburi	Lao PDR	28.5	5.000	1,260	6,035	275	270	678	49	810	63
Pak Lay	Lao PDR	26	4,500	1,320	6,460	240	235	384	108	630	35
Sanakham	Lao PDR	25	5,918	700	5,015	215	210	206	81	1,144	38
Pakchom	Lao PDR Thailand	22	5,720	1,079	5,318	192	190	441	74	1,200	55
Ban Koum	Lao PDR Thailand	19	11,700	1,872	8,434	115	110	652	133	780	53
Lat Sua	Lao PDR	10.6	10,000	686	2,668	97.5	90	550	13	1,300	27
Don Sahong	Lao PDR	17	2,400	240	2,375	75.1	71	115	290 (ha)	1820-720-2730	10.6-8.2-8.3
Stung Treng	Cambodia	8.8	N/A	900	N/A	52	51	151	211	2.502	10
Sambor	Cambodia	16.5	N/A	2,600	N/A	40	38	1,450	620	18,002	56

Figure 1.1-1: Locations of proposed LMB mainstream hydropower projects

1.2 Study Context

Numerous prior studies and reports have evaluated and discussed potential effects of tributary and mainstream hydropower development in the LMB, including the Strategic Environment Assessment (SEA) of Hydropower on the Mekong Mainstream (ICEM 2010) and the Lower Mekong Basin Development Plan 2 (BDP2) (MRC 2011), both of which were initiated by the Mekong River Commission (MRC). The SEA took a higher-level strategic perspective that was focused on providing policy options for mainstream hydropower development and it provided input to the MRC's Procedures for Notification, Prior Consultation and Agreement process. The BDP2 evaluated costs and benefits of different basin-wide hydropower development scenarios, including full mainstream and 2030 tributary development. These studies also evaluated the cumulative effects of mainstream hydropower development on people and resources throughout the LMB, including the Mekong Delta.

The tools and analyses used to characterise hydropower development impacts for the entire LMB are not the most appropriate to better understand and evaluate specific impacts in the Mekong Delta region. This is because the environment in the delta differs considerably from the rest of the LMB in many ways. For example, river flows in the Vietnamese portions of the Mekong Delta are highly controlled by a series of canals dikes and related infrastructures. These water management structures must be accounted for in delta-specific analyses and hydrological models. Models of the Mekong Delta must also consider tidal fluctuations, salinity intrusion, and other influences of the marine and coastal environment. In addition, the Delta differs from the rest of the LMB because it is highly developed (more urbanised) and densely populated, and land use is dominated by extensive agricultural production.

The MDS was initiated to develop customised tools and methods that address the Delta-specific conditions in order to improve understanding of the mainstream hydropower development impacts on the Mekong Delta and to help inform the Vietnamese government and other riparian countries. Accordingly, the study was designed to identify and characterise important potential effects of mainstream hydropower development specifically on the people and resources in the floodplains of southern Cambodia and Viet Nam.

The MDS was focused on assessing impacts from hydropower development only. It is acknowledged that factors such as climate change, sea level rise, land subsidence, urbanization and deforestation may alter the MDS impact projections.

The study was *not* intended to comprehensively evaluate the cumulative effects of hydropower development and other changes in the region or to be a comprehensive evaluation of future conditions in the region. As such, the assessment did not consider other factors that contribute to important changes in the region, such as climate change, sea level rise, rapid urbanization, deforestation, and land subsidence. These factors likely affect many of the same people and resources that might be impacted by hydropower development, and future cumulative evaluations are therefore needed to understand the combined effects. The modeling and analysis tools and methods developed for the MDS provide a framework for future evaluations of changes and impacts in the Mekong Delta.

Also, the study assessed *overall, collective* impacts of the entire set of 11 mainstream hydropower projects (Cascade) taken together, and collective effects of various subsets of those projects (Dam Development Alternatives 4-7). Evaluation of potential impacts of individual mainstream hydropower projects was beyond the scope of this study.

1.3 Study Objectives and Outputs

The MDS had the following three main objectives:

1. Develop a comprehensive database on hydrology; sediment; ecology; navigation; and environmental, natural and socio-economic conditions in the LMB that can be used to assess impacts of hydropower projects to people and resources in the floodplains and Delta of Viet Nam and Cambodia.

2. Quantitatively assess impacts of mainstream hydropower projects on the downstream system including (i) the flow regime, (ii) transport of sediments and nutrients, (iii), water quality, (iv) fisheries, (v) biodiversity, (vi) navigation, and (vii) related socio-economic issues.

3. Support efforts towards achieving consensus on the results of the impact assessment of mainstream hydropower projects on the Mekong Delta and determine avoidance, mitigation, and enhancement measures through close consultation with stakeholders.

1.4 Study Area

The MDS Impact Assessment Area (IAA) was limited to downstream floodplains of Cambodia and Viet Nam (Figure 1.4-1). It encompasses approximately 106,350 square kilometers (km^2) and includes 13 provinces in Viet Nam and 14 provinces in Cambodia. The northern boundary of the IAA lies to the south of the location proposed for the lowermost hydropower project in the mainstream cascade (Sambor Dam). The southern boundary of the IAA is the Mekong River coastal zone, which is formed by confluence of the Mekong River tributaries with the East Sea.

The MDS did not consider effects (positive or negative) of mainstream hydropower development that would primarily occur upstream of the IAA. It is true that mainstream hydropower development in the LMB will produce important ancillary beneficial effects such as flood control, improved irrigation during the dry season, additional employment opportunities associated with increased power generation, and resulting economic and social benefits. But these beneficial effects are most likely going to accrue in the upper reaches of the LMB, and very few of these benefits will be transferred downstream to the people and resources in the IAA.

The MDS evaluated impacts to people and resources downstream of the proposed cascade and therefore it does not address adverse and beneficial effects that would primarily occur upstream of the IAA.

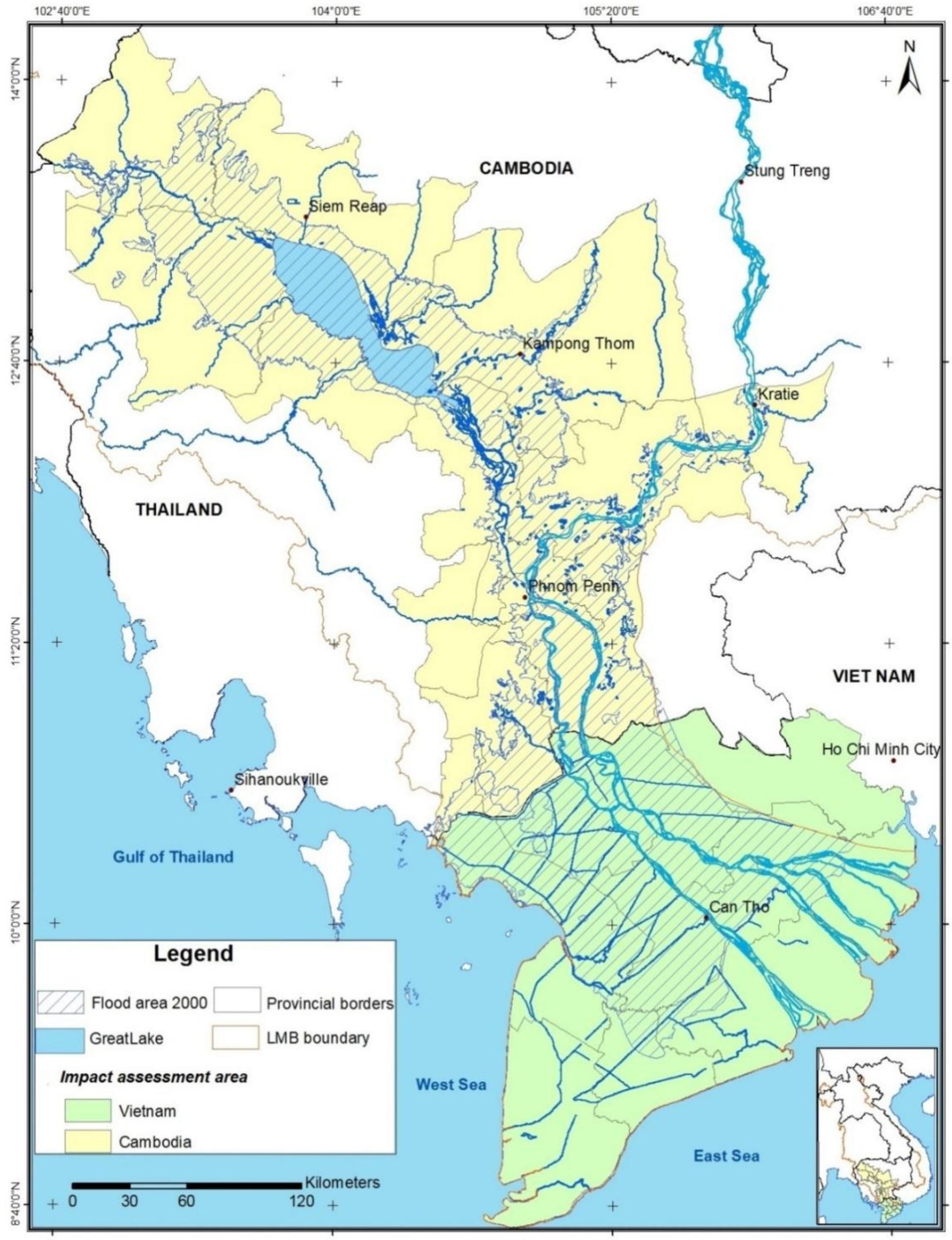

Figure 1.4-1: MDS impact assessment area

1.5 Study Implementation

The study was conducted by an independent consultant team of international and national experts over a 30-month period. It was completed in four overlapping phases:

- **Inception Phase** – Key activities completed during this phase included identification of critical issues to be addressed during the impact assessment, development of modelling and impact assessment methods, review of available historical data and data gap analyses, and preparation of study plans for six research studies to gather new data through field surveys to fill in the most critical data gaps.

- **Baseline Assessment Phase** – This phase included conducting detailed review and evaluation of available relevant historical data and new data gathered by the research studies to characterise existing baseline conditions. Hydrological, hydraulic, sediment transport, river morphology, salinity and nutrient transport models were developed, calibrated, and verified during this phase.

- **Impact Assessment Phase** – This phase defined and characterised likely impacts of the proposed Cascade on selected components of the natural, social, and economic systems of the downstream floodplains.

- **Avoidance, Enhancement and Mitigation Phase** – Avoidance, enhancement and mitigation measures were identified and evaluated to assess implementation capacity.

During each phase, robust consultation workshops were organised at the national and regional levels to describe progress and results and seek consensus from key stakeholders in member countries, non-governmental organisations and community residents in Lao PDR, Cambodia, and Viet Nam. A team of international subject matter experts assembled by the World Bank and the United States Department of Interior International Technical Assistance Program, with support from USAID, provided comments on MDS work products on an on-going basis. Program Management Support for the MDS was provided by Australia's Department of Foreign Affairs and Trade.

During the stakeholder consultation meetings, results from different phases of the study were presented and discussed. Minutes were prepared for each meeting, including questions and answers. Draft work products from each phase were reviewed and updated after the meeting to address comments, provide clarification, and include recommendations, as appropriate.

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2 Impact Assessment Overview

2.1 Approach

> ***The MDS impact assessment approach was based on internationally accepted practices and principles.***

The MDS impact assessment approach was based on internationally accepted practices and principles. Guidelines recommended by the International Association for Impact Assessment (IAIA 1994), the United States National Environmental Policy Act (40 Code of Federal Regulations, Parts 1500-1508), and the World Bank International Finance Corporation's Performance Standards on Environmental and Social Sustainability (IFC 2012) were incorporated, as applicable

The assessment included characterization of the (1) nature [direct, indirect, positive, negative]; (2) duration [short-term, long-term, temporary, permanent]; and (3) geographic scale [regional, national, hydro-ecological zones] of impacts. As permitted by data availability and reliability, impacts were quantified when possible. Where quantification was not possible (or advisable) because of the lack of adequate and reliable data, potential impacts were assessed in a qualitative manner.

2.2 Impact Drivers and Resource Areas

Construction and operation of mainstream hydropower dams could cause important changes to the following four important physical characteristics of the Mekong River ecosystem:

- Hydrology and water quantity
- Sediment loading
- Water quality (nutrients and salinity)
- Barriers to movement.

> ***Potential direct and indirect impacts of four drivers were assessed on six resource areas.***

Those changes would cause or drive effects to people and resources in the IAA. Therefore, changes likely to occur in these drivers under various scenarios were projected through model simulations and analysed to predict changes likely to occur in the IAA due to mainstream hydropower development. Note that the IAA is located downstream of the southernmost proposed mainstream dam (Sambor); thus, the study did not directly quantify or consider changes or impacts upstream of dams, including effects of the creation of reservoirs.

The following six important components of the natural, social, and economic systems (henceforth called Resource Areas) in the IAA were selected for the impact assessment and potential effects caused by changes in the drivers described above were evaluated for each resource area:

- **Fisheries** – Fisheries, and to a lesser extent aquaculture, production in the Delta and Cambodian floodplain are primarily driven by the flow regime of the Mekong River, nutrient dynamics linked to transport and deposition of sediments, and barriers to migration (e.g., Dugan et al. 2010, Halls et al. 2013). The primary focus of the fisheries impact assessment was to quantify the combined effects of these factors on the total yield of capture fisheries in the IAA. Potential impacts on aquaculture were also evaluated.

- **Biodiversity** – The structure, function, and diversity of aquatic and floodplain habitat in the LMB is strongly influenced by the annual flood pulse (Dudgeon 2000, Lamberts and Koponen 2008, Arias et al. 2013). The availability and quality of habitat for aquatic and terrestrial species are largely driven by the timing, extent, and duration of flooding. Timing, extent and duration of flooding and associated transport of sediment also influence primary and secondary productivity. The analysis of biodiversity was therefore focused on determining how the modifications of flows, inundation patterns, and water quality would affect migratory aquatic species.

- **Navigation** – Daily and seasonal changes in river flows could affect the size and capacity of vessels that can operate in the IAA, and would influence when those vessels could safely operate. In addition, changes in riverine and coastal morphology could affect navigation and increase costs of maintaining navigation routes and facilities, and the presence of dams could increase the length of time required for transport via inland water routes.

- **Agriculture** – Changes in flow volumes and patterns could impact agricultural productivity, when crops can be grown (that is, the cropping calendar), and land use in the IAA. Decreases in sediment and nutrient transport and changes in salinity concentrations could also affect agricultural productivity and increase the direct and indirect costs of growing crops.

- **Economics** – The economic impact assessment builds on results from the agriculture, fisheries, navigation and biodiversity impact assessments. These economic analyses applied a range of economic parameters (e.g., prices, profit, and employment) to the estimated changes in quantities of goods and services to generate a series of economic indicators. The assessment geographically spanned the entire IAA and produced results at the commune level – the smallest level governmental organisation – where possible. In addition, economic multipliers were used to indicate how directly affected commercial sectors lead to wider impacts across the economies in the Delta and the rest of each nation.

- **Livelihood** – Impacts on the livelihoods of people and communes from hydropower development can take several forms. First, results of the economic analysis can be used to estimate changes in household incomes for fishers and farmers. In addition, the fishery impact analysis can be used to predict changes in the fish available for home consumption. Finally, hydrologic modeling results can be directly applied to determine the numbers of households that could be affected by increased salinity during low flow periods, and alternatively, higher flood levels during peak flow periods. Together these indicators provide a composite measure of livelihood impacts in different parts of the Impact Assessment Area. These estimated impacts may eventually be implemented in a broader vulnerability assessment.

2.3 Scenarios

Potential impacts associated with the following three Scenarios (Table 2.3-1) were identified and characterised by the MDS:

Potential impacts of three unmitigated scenarios were evaluated by the MDS. These scenarios were intended to bracket the range of potential effects in order to demonstrate the need to ensure sound planning, design, and operation of the mainstream hydropower projects.

- **Scenario 1: Mainstream hydropower cascade** – This scenario was used to determine the *overall* effects of 11 planned LMB mainstream hydropower projects operating simultaneously. The design characteristics of each proposed dam was based on information contained in the MRC's BDP2 Report (MRC 2011). **To ensure that all potential effects of the mainstream dams were identified and assessed, no mitigation measures, such as sediment management and fish passage facilities, were included in the design**. Thus the impacts identified by the analysis of this scenario could be lower if fewer dams are constructed or if customised, site-specific mitigation measures are incorporated into the design of the mainstream dams.

- **Scenario 2: Mainstream hydropower cascade plus additional (tributary) dams** – This scenario was used to determine the cumulative effects of the proposed mainstream cascade (Scenario 1) and selected LMB tributary dams. A total of 72 tributary dams mainly consisting of projects under construction up to 2012 and dams planned through 2030 were included in this assessment.

- **Scenario 3: Mainstream hydropower cascade plus water diversions** – This scenario was used to determine the cumulative impacts of the proposed mainstream cascade (Scenario 1) and planned water diversion projects in Thailand and Cambodia. Two main water diversion schemes were included in this scenario, namely 1) inter-basin transfer of about 290 to 350 cubic meters/second (m^3/s) of flow into the Ing and Kok basins in Thailand, and 2) LMB intra-basin transfer of 12 to 100 (m^3/s) of flow in Cambodia for irrigation schemes.

Table 2.3-1: Hydropower development Scenarios analyzed by the MDS

Scenario ID and Description		Mainstream Dams											Other Factors	
		Pak Beng	Luang Prabang	Xayaburi	Pak Lay	Sanakham	Pak Chom	Ban Kum	Lat Sua	Don Sahong	Stung Treng	Sambor	Tributary Dams	Water Diversions
1	All Mainstream Dams	X	X	X	X	X	X	X	X	X	X	X		
2	Scenario 1 + Tributary Dams	X	X	X	X	X	X	X	X	X	X	X	X	
3	Scenario 1 + Water Diversions	X	X	X	X	X	X	X	X	X	X	X		X

The above scenarios were intended to identify the full range of potential effects in order to demonstrate the need to ensure sound planning, design, and operation of the mainstream hydropower projects. For each scenario, potential impacts were identified by comparing model simulated conditions likely to occur under a given scenario to normal (average) year hydrological conditions.

For each scenario, potential impacts were identified by comparing model simulated conditions likely to occur under that scenario to normal year hydrological conditions and dry year drawdown (worst-case) conditions.

The methods used to operate dams can also have important effects on downstream resources and therefore alternative dam operations were also considered in the MDS. For example, operating dams to meet peak daily power demands (i.e., hydropeaking) can cause large daily fluctuations that affect downstream fisheries and other resources. Because hydropeaking is very likely to occur for at least some dams (e.g., daily peak power production is required in the Power Purchase Agreement for Xayaburi Dam, Chitnis 2013), all the mainstream dams were modelled as operating in this manner. Hydropeaking was conservatively defined as a daily cycle of 8 hours of peak power production (during which the storage reservoir is drawn down and discharges are large) followed by 16 hours of low power production (during which the storage reservoir is filled up and discharges are small). Impacts likely to be caused by hydropeaking operations were separately identified.

In addition, where appropriate and relevant, the following two sensitivity analyses were also conducted using selected indicators:

1. **Dry year, dry season drawdown** – Simultaneous drawdown operations at all mainstream dams during the dry season of a dry year.

2. **High sediment discharge** – Represented by 2008 sediment loading (wet year following start of operation of Chinese dams).

Under each scenario, impacts were separately projected for each resource area for portions of Cambodia and Viet Nam within the IAA (Figure 1.4-1). Where appropriate, impacts were further broken down and evaluated at the provincial level. For Lao PDR, which is outside the IAA, a high-level overview of impacts for each resource area was derived, based primarily on findings from the BDP2 (MRC 2011) and the SEA (ICEM 2010).

Impacts of the main drivers on each resource area were assessed and evaluated using pre-selected indicators. Quantitative indicators were selected, where possible. If a quantitative analysis could not be conducted, for example because of the lack of suitable data, qualitative indicators were used. To summarise the effects of each scenario, the relative level of effect on each indicator was ranked on a scale of 0 (no impact) to 4 (very high impact) (Table 2.3-2).

Impacts on individual resource areas were assessed using selected indicators. Quantitative indicators were used where possible.

Rankings of changes caused by hydropower development were defined in relation to the characteristics of the resource and the types and magnitudes of effects. For example, effects to fisheries were defined based on the loss of capture fisheries resources and the potential effects of that loss on the people that depend on those resources, and effects to biodiversity were defined based on the potential for the extirpation of species from the IAA.

Table 2.3-2: Scale for characterizing changes associated with the mainstream hydropower cascade

Rank	Level of Impact	Impact Description
0	No	No noticeable or measureable adverse effects
1	Low	Low but detectable level of adverse effects to a resource
2	Moderate	Moderate localised or widespread decrease in the level, value, or function of a resource
3	High	High widespread decrease in the level, value, or function of a resource
4	Very High	Very high decrease in the level, value, or function of resource

2.3.1 Dam Development Alternatives

Likely impacts associated with four Dam Development Alternatives (Alternatives) were also identified and evaluated to provide information on possible relief from impacts that could be obtained by constructing and operating only selected projects (Table 2.3-3).

Table 2.3-3: Hydropower dam development alternatives analysed by the MDS

Dam Development Alternatives	Mainstream Dams										
	Pakbeng	**Luang Prabang**	**Xayaburi**	**Paklay**	**Sanakham**	**Pak Chum**	**Ban Kum**	**Lat Sua**	**Don Sahong**	**Stung Treng**	**Sambor**
4			X						X		
5	X		X						X	X	
6	X		X						X	X	X
7	X		X			X	X	X	X	X	

2.4 Baseline conditions

In order to predict potential impacts of a given scenario or alternative, a set of baseline conditions were identified for all drivers and resource areas. Changes likely to occur under the given scenario or alternative were determined by comparing model simulation output to the baseline conditions.

2.4.1 Selection of baseline hydrologic years

The hydrological baselines used in the MDS analyses to evaluate effects of mainstream hydropower dams represent the hydrological conditions in normal (average) and dry hydrologic years. For the MDS a hydrological year is defined as the 12-month period from 1 December of one calendar year to 30 November of the following calendar year. For example, the 2007 hydrological year extended from 1 December 2006 to 30 November 2007.

2.4.1.1 Normal (average) hydrological baseline year

The hydrological baseline year for average hydrologic conditions was selected by analysing river flows at Kratie and flooding characteristics for hydrological years from 1985 to 2013. The distribution of the peak flow measured at Kratie for the period from 1924 to 2013 was plotted, along with duration of flow measured as total flood volume, and discharge. **Based on this evaluation, the 2007 hydrological year best represented the average annual flood volume, and it was therefore selected for representing normal hydrologic year baseline conditions in the IAA**.

2.4.1.2 Dry hydrological baseline year

To identify the representative dry year for an evaluation of a drawdown during the dry season, information on peak flow and flood volume, discharge, and drought characteristics were examined. This evaluation indicated that 1998 was the hydrologic year with the lowest flood volume, in combination with a low discharge, and low dry-season flows. **Thus, 1998 was selected as the representative dry hydrologic year**, and it was used to conduct a sensitivity analysis for selected hydrology, flooding, and salinity indicators.

In addition to evaluating dry year hydrologic conditions, additional assumptions for this sensitivity were imposed on dam operations that resulted in an extended period of low-water conditions that would be caused by a **drawdown** to temporarily maximise electricity output. This effect was explored to evaluate the extent to which extreme conditions could add further impacts to resources and people in the impact assessment area.

2.4.1.3 High sediment and nutrient loading baseline year

The year 2008 was selected as the baseline year to represent high sediment and nutrient loading conditions. Impacts resulting from changes in sediment and nutrient loadings under a given Scenario or Alternative were determined by comparing relevant indicators for that Scenario or Alternative with 2007 baseline conditions and with 2008 conditions.

2.4.2 Simulation of baseline conditions

Baseline conditions for selected key indicators of river system flows and velocities, sediment loading and transport, and water quality were projected using model simulations. Those baseline model simulations were based on historical data and on the results, observations, and findings of sediment and water quality characterization field surveys conducted by the MDS in 2014.

Baseline conditions for key indicators of the six resource areas were quantitatively and/or qualitatively characterised using historical data and the results, observations, and findings from four research studies (fisheries, biodiversity, livelihood and navigation) that were conducted in 2014.

The 2013 update of baseline conditions for water flow and sediment transport captured and considered the present development level of the Chinese dams. This includes six dams already in operation, especially the two largest dams, namely Xiaowan and Nuozhadu.

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3 Impact Assessment Findings

Important results, key findings, and major recommendations for future studies are discussed below for the four drivers and six resource areas that were evaluated by the MDS.

3.1 Hydrology and Water Quantity

3.1.1 Input data

Input data on precipitation, evaporation, water levels, discharges, salinity and nutrients for hydrology and hydraulics model setups were obtained from multiple sources including the MRC database. Where appropriate, input data were supplemented by updated information generated through the sediment and nutrient surveys conducted by the MDS in 2014. The input data set represents the most updated compilation of relevant hydro-meteorological data. For additional information, refer to MDS Impact Assessment Report (IAR), Volume 1, Chapter 3.

3.1.2 Methodology summary

The Baseline and Scenarios' simulations have been carried out using the entire state-of-the-art suite of models developed for the entire Mekong catchment, namely SWAT (Soil and Water Assessment Tool) and MIKEBasin for hydrology, MIKE11 for hydraulics for the Mekong Mainstream and Delta, and MIKE21 for the Great Lake and the Coastal for hydraulics). The advantage of the compatibility and interlinking between different MIKE models have been explored in order to cover the entire Mekong Basin geographically, and being able to simulate water flow within the same model framework that has been developed for earlier successful applications world-wide (e.g., for the Ganges Brahmaputra Basin and Delta, for the Yangtze River in China and for the Everglades in the United States).

The MDS inherited the SWAT set-up used by the MRC. The setting up of the MIKEBasin inherited the regional/national knowledge embedded in the IQQM model (Integrated Quantity and Quality Model) used by the MRC. Similarly, the MIKE11 Mainstream model inherited the river cross section information from the ISIS model used by the MRC. Finally, the MIKE11 Delta model constitutes a further development of models for the Cambodian part of the Delta under the JICA (Japan International Cooperation Agency) Water Utilization Program Study and for the Vietnamese part of the Delta developed by the Southern Institute for Water Resources Planning. The model system developed is considered to be well calibrated and validated in accordance with the existing international standards and fully taking into account the existing regional modelling standards set by the MRC. The model therefore guarantees the highest quality possible not only for basin-wide planning purposes, but also for detailed impact assessment activities at a smaller level.

Hydropower dams are designed to store and control the release of water. Operation of dams can therefore change (among other hydrological factors) the downstream volume of water, water levels, location of areas inundated, and timing of inundation and drying. The design of dams strongly influences these changes, as dams built to store large amounts of water to be released during periods of low flow can cause much larger seasonal changes in water volumes and water levels than a run-of-river dam, as mistakenly expected for the case of the Mekong mainstream dams.

The operation of dams also effects downstream hydrology. For example, large daily fluctuations in water levels can occur when water levels (and thus electricity production) are increased daily during periods of peak energy demand. The consequences of two modes of operating dams, daily operation for peak-demand power production (hydropeaking) and active storage operation were considered in the MDS. The following key indicators were modeled to characterise impacts on hydrology and water quantity:

- Deviation of average flow and volume loss in dry season (dry season month and 10-day interval in dry season)
- Deviation of water level in dry season (dry season month; 10-day interval in dry season and max fluctuation)
- Deviation of flood volumes (seasonal change)

For additional information, refer to the MDS IAR, Volume 1, Chapter 3.

3.1.3 Key results

3.1.3.1 Impacts on water levels and flows

Impacts associated with water levels and flows under the three Scenarios and other Development Alternatives are summarised in Tables 3.1-1, 3.1-2, and 3.1-3 and discussed below.

Scenario 1 – normal year

During the wet season, the cascade could influence onset of high flows by a few days due to increase in propagation of the flood wave that is caused by increased water depths due to the presence of the dams in different parts of the river. During the dry season, the daily hydropeaking operations could generate high fluctuations in water flows and water levels immediately downstream of each dam. Within the IAA, fluctuations in flow rates and water levels at Kratie, situated only 31 kilometers (km) downstream of the last dam in the cascade, are around 16,000 m^3/s and 2 meters (m), respectively. Water level and flow rate fluctuations dissipate rapidly with distance downstream of Phnom Penh.

Scenario 1 – dry year, dry season drawdowns for increased power production

Dry year, dry season drawdowns and subsequent filling of the reservoirs could have short-term (weeks) high impacts on flow rates and water levels in the Mekong Delta (Figure 3.1-1).

Scenario 2

Changes in water flows and water levels during normal year and dry year, dry season drawdowns are of the same order of magnitude as reported for Scenario 1.

Table 3.1-1: Comparison of dry year indicators for water flows and water levels for Laos under Scenarios 1, 2 and 3 and Alternatives 4 through 7

Location	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Luang Prabang	Dry season	Drop down in Volume for 10 days	Bill.m^3	-0.44	-0.34	-0.66	0.00	-0.21	-0.21	-0.21
			%	-49.2	-38.18	-74.05	0.00	-31.46	-31.46	-31.46
		Drop down in Volume for 1 month	Bill. m^3	-0.54	-0.62	-1.34	0.00	-0.23	-0.23	-0.23
			%	-19.0	-21.92	-47.51	0.00	-11.84	-11.84	-11.84
		Drop in Water Level for 10 days	m	-2.70	-2.47	-2.92	0.01	-1.04	-1.04	-1.04
		Drop in Water Level for 1 month	m	-2.26	-1.95	-2.61	0.02	-0.91	-0.91	-0.51
		Magnitude of WL Fluctuation	m	1.71	1.73	1.77	0.02	0.95	0.95	-0.45
	Flood season	Volume change in flood season	Bill. m^3	-0.03	-0.47	-0.95	0.00	-0.15	-0.15	-0.15
			%	-0.30	-0.70	-0.52	0.00	-1.41	-1.41	-1.41
Vientiane	Dry season	Drop down in Volume for 10 days	Bill.m^3	-0.60	-0.55	-0.82	-0.27	-0.40	-0.40	-0.48
			%	-62.0	-56.08	-84.59	-31.92	-47.30	-47.30	-56.46
		Drop down in Volume for 1 month	Bill. m^3	-1.32	-1.41	-2.03	-0.26	-0.46	-0.46	-0.57
			%	-42.8	-45.77	-65.81	-8.92	-15.95	-15.95	-19.69
		Drop in Water Level for 10 days	m	-1.83	-1.59	-3.00	-0.78	-1.19	-1.19	-1.50
		Drop in Water Level for 1 month	m	-1.31	-1.34	-2.32	-0.25	-0.47	-0.47	-0.61
		Magnitude of WL Fluctuation	m	1.18	1.53	1.63	0.42	0.53	0.53	1.23

Location	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
	Flood season	Volume change in flood season	Bill. m^3	-0.06	-0.51	-1.01	-0.13	-0.30	-0.30	-0.38
			%	-0.9	-1.75	-1.31	-1.12	-2.54	-2.54	-3.18
Pakse	Dry season	Drop down in Volume for 10 days	Bill. m^3	-0.75	-0.39	-0.98	-0.27	-0.42	-0.42	-0.70
			%	-51.8	-32.27	-67.36	-20.13	-31.28	-31.28	-51.73
		Drop down in Volume for 1 month	Bill. m^3	-1.79	-1.13	-2.58	-0.45	-0.74	-0.74	-1.12
			%	-43.1	-27.25	-62.19	-11.34	-18.80	-18.80	-28.40
		Drop in Water Level for 10 days	m	-0.69	-0.37	-1.00	-0.21	-0.34	-0.34	-0.66
		Drop in Water Level for 1 month	m	-0.54	-0.31	-0.87	-0.12	-0.21	-0.21	-0.39
		Magnitude of WL Fluctuation	m	1.40	1.39	1.32	0.06	0.08	0.08	1.15
	Flood season	Volume change in flood season	Bill. m^3	-0.15	-1.17	-1.06	-0.10	-0.25	-0.25	-0.66
			%	-1.30	-2.53	-1.89	-0.56	-1.28	-1.28	-3.44

Note: The indicators capture the short-term changes during filling of the reservoirs after drawdown for maximum power production.

Table 3.1-2: Comparison of dry year indicators for water flows and water levels for Cambodia under Scenarios 1, 2 and 3 and Alternatives 4 to 7

Location	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Kratie	Dry season	Drop down in Volume for 10 day	Bill. m^3	-1.15	-1.05	-1.33	-0.21	-0.46	-0.85	-0.58
			%	-59.5	-54.44	-68.77	-12.40	-22.53	-50.82	-28.36
		Drop down in Volume for 1 month	Bill. m^3	-2.60	-1.98	-3.39	-0.44	-0.92	-1.77	-0.98
			%	-46.5	-35.36	-60.72	-8.10	-17.06	-32.96	-18.19
		Drop in Water Level for 10 days	m	-1.66	-1.12	-1.6	-0.23	-0.51	-1.22	-0.67
		Drop in Water Level for 1 month	m	-1.14	-0.54	-1.30	-0.15	-0.34	-0.82	-0.38
		Magnitude of WL Fluctuation	m	2.15	2.31	2.19	0.06	0.18	1.79	0.31
	Flood season	Volume change in flood season	Bill. m^3	-0.66	-1.76	-2.02	-0.11	-0.31	-0.62	-0.85
			%	-1.10	-2.17	-1.62	-0.27	-0.74	-1.50	-2.04
Phnom Penh	Dry season	Drop down in Volume for 10 days	Bill. m^3	-1.11	-1.02	-1.20	-0.22	-0.46	-0.81	-0.61
			%	-47.0	-43.15	-50.79	-8.94	-18.65	-36.48	-24.65

Location	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
		Drop down in Volume for 1 month	Bill. m^3	-2.28	-1.55	-3.22	-0.37	-0.82	-1.81	-0.87
			%	-32.4	-22.02	-45.78	-5.38	-11.94	-26.50	-12.68
		Drop in Water Level for 10 days	m	-0.35	-0.32	-0.39	-0.08	-0.16	-0.25	-0.22
		Drop in Water Level for 1 month	m	-0.23	-0.15	-0.35	-0.04	-0.09	-0.20	-0.09
		Magnitude of WL Fluctuation	m	0.18	0.15	0.13	0.03	0.05	0.12	0.07
	Flood season	Volume change in flood season	Bill. m^3	-0.54	-1.47	-1.87	-0.07	-0.26	-0.60	-0.76
			%	-0.90	-1.86	-1.40	-0.17	-0.60	-1.36	-1.73

Table 3.1-3: Comparison of dry year indicators for water flows and water levels for Viet Nam under Scenarios 1, 2 and 3 and Alternatives 4 to 7

Location	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Tan Chau - Chau Doc	Dry season	Drop down in Volume for 10 days	Bill. m^3	-1.06	-0.97	-1.18	-0.23	-0.45	-0.77	-0.61
			%	-39.50	-36.07	-44.03	-8.28	-16.50	-28.15	-22.20
		Drop down in Volume for 1 month	Bill. m^3	-2.10	-1.31	-3.21	-0.34	-0.77	-1.81	-0.83
			%	-25.60	-16.03	-39.15	-4.25	-9.56	-22.59	-10.30
		Drop in Water Level for 10 days	m	-0.13	-0.12	-0.15	-0.03	-0.06	-0.09	-0.08
		Drop in Water Level for 1 month	m	-0.08	-0.05	-0.13	-0.01	-0.03	-0.07	-0.04
		Magnitude of WL Fluctuation	m	0.03	0.02	0.03	0.01	0.02	0.04	0.02
	Flood season	Volume change in flood season	%	-0.24	-0.93	-1.24	-0.04	-0.16	-0.31	-0.43
			Bill. m^3	-0.50	-0.97	-0.73	-0.09	-0.27	-0.60	-0.79

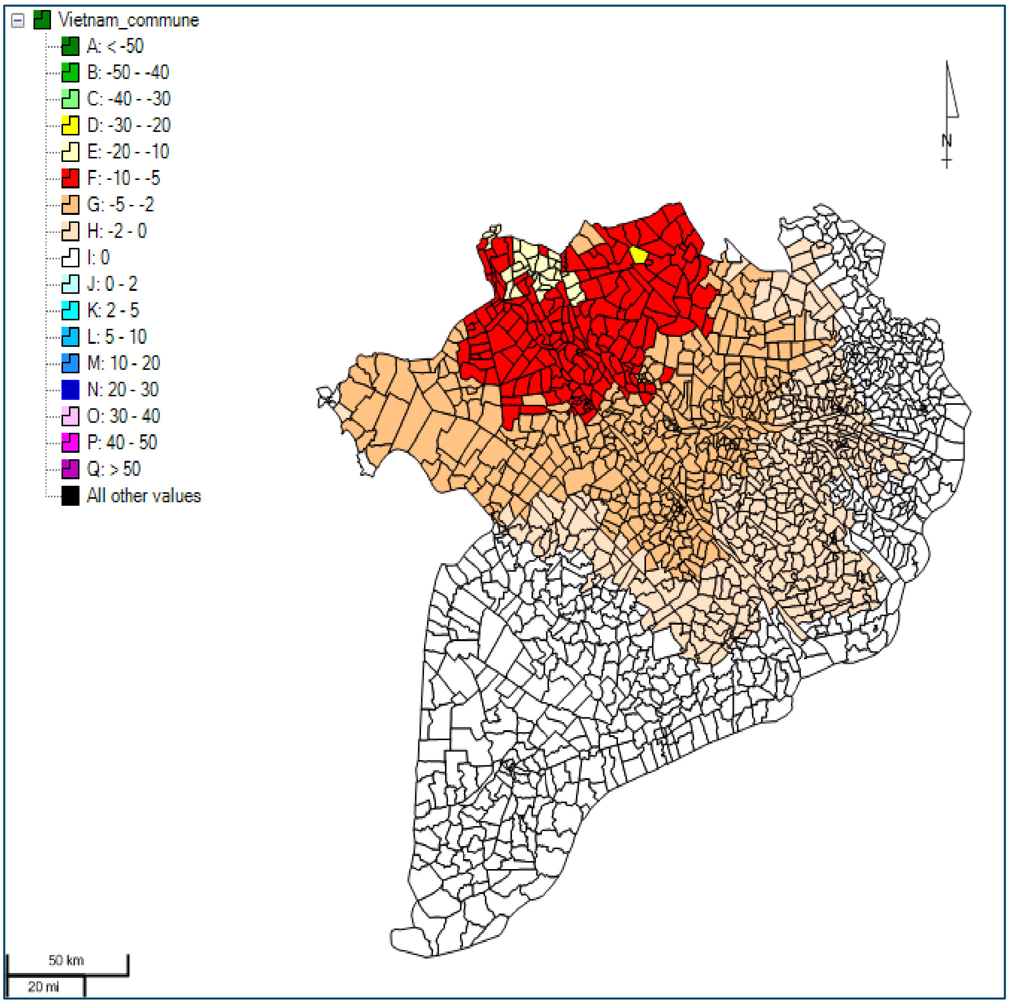


Figure 3.1-1: Changes in minimum water levels in the Vietnamese Delta during dry year, dry season filling subsequent to drawdowns for increased power production

Scenario 3

Changes in water flows and water levels during dry year dry season drawdowns are aggravated due to the inclusion of water diversions in Thailand.

Development Alternatives 4-7

Alternative 6 is expected to have slightly lower impacts than Scenario 1, and other Development Alternatives (4, 5 and 7) are likely to cause lower impacts than Scenario 1.

3.1.4 Dam Break

The impact of a dam break at Sambor (the most downstream dam with the largest regulatory reservoir of the Mekong mainstream cascade) has been simulated using the model setup and inputs as advised by the U.S. Army Corps of Engineers. Additional information can be found in IAR Volume 1, Chapter 3. It was noted that this emergency case was conducted for Scenario 1 only.

Figure 3.1-2 shows the simulated flood peak level increase caused by a dam break at Sambor during the maximum flood leading to maximum outflow due to overtopping failure. The floodwave shows an increase of about 8.5 m just downstream the Sambor Dam at Kratie.

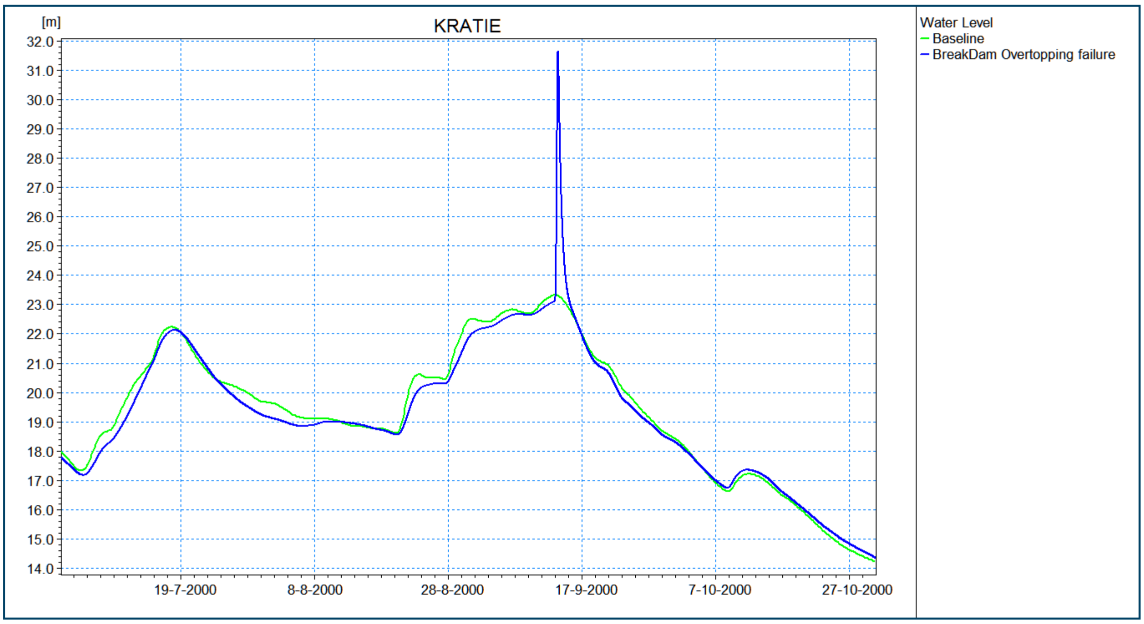


Figure 3.1-2: Flood peak level generated by a Sambor Dam Break for the maximum flood event just downstream the dam

Figure 3.1-3 shows the simulated flood peak level increase caused by a dam break at Sambor for the maximum flood event and maximum outflow due to overtopping failure. The floodwave shows an increase of about 0.6 m at Phnom Penh.

Figure 3.1-4 shows the flooding in the Mekong Delta with an increase at Tan Chau and Chau Doc of about 0.4 m.

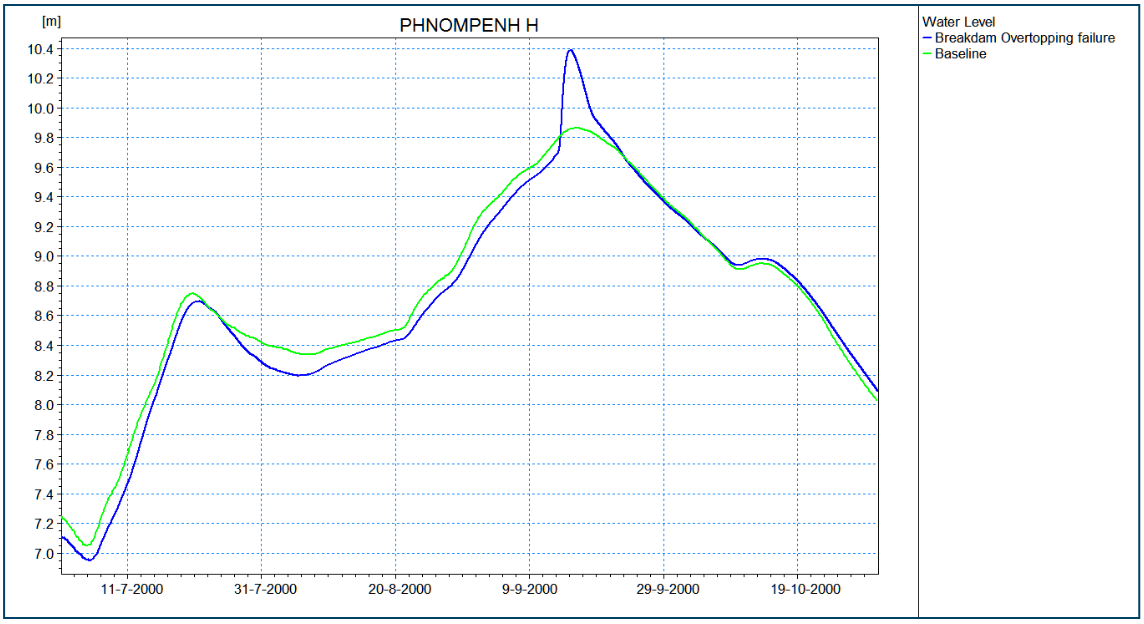


Figure 3.1-3: Flood peak level generated by a Sambor Dam Break for the maximum flood at Phnom Penh

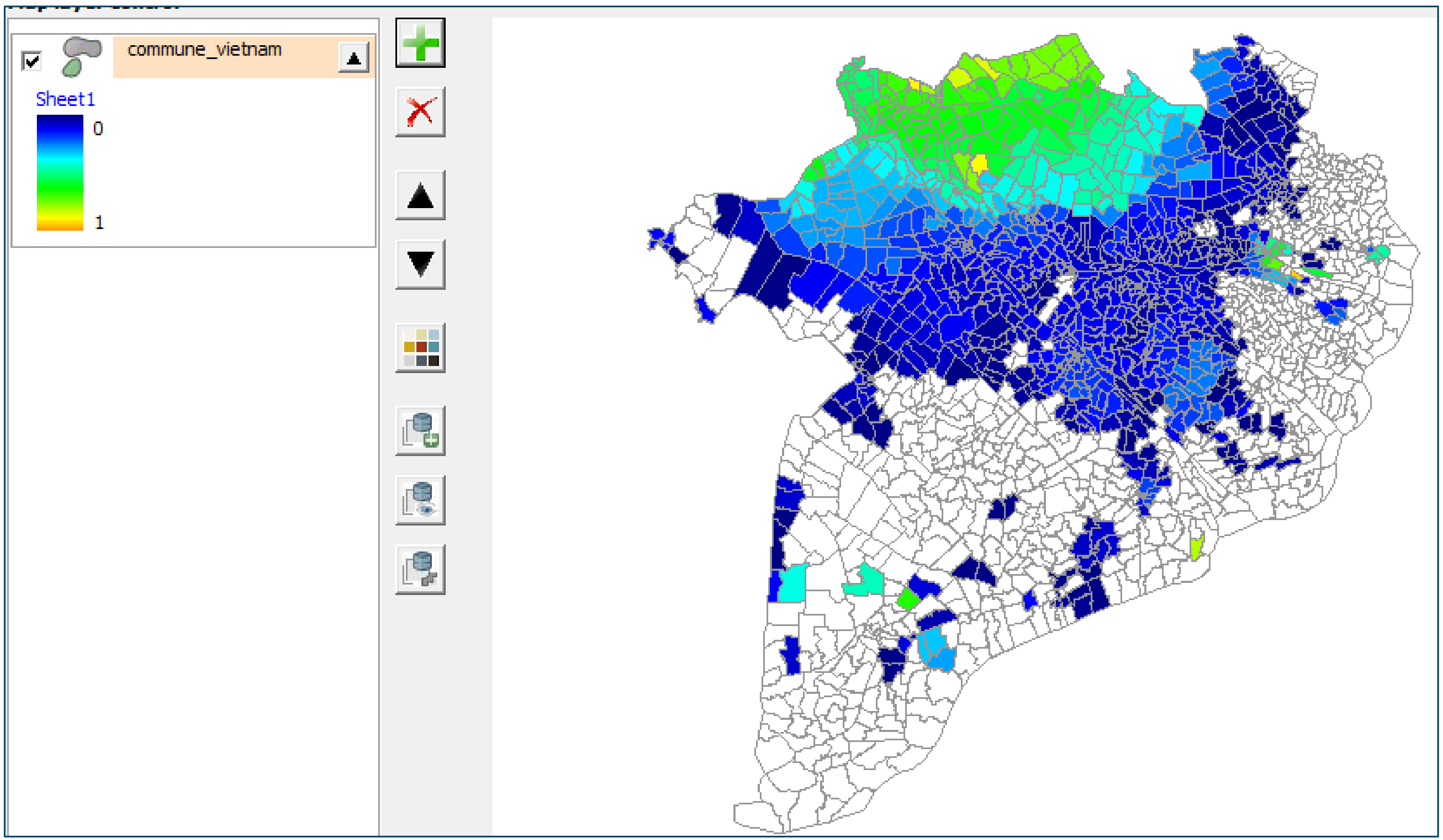


Figure 3.1-4: Flooding in the Mekong Delta due to the dam-break

3.1.5 Discussion of key results

Although the introduction of all 11 mainstream dams (Scenario 1) together with additional tributary dams (Scenario 2) or water diversion (Scenario 3) may cause modest reduction of water levels against the Baseline during normal or hydropeaking operation of the dams (correspond to the representative normal year of 2007) in the dry season, short-term high impacts might be expected during the dry season of the representative dry year of 1998 with a 10-day maximum drop in water level at Kratie up to 1.66 m, and 0.13 m at Tan Chau in Scenario 1, up to 1.12 m, and 0.12 m in Scenario 2 and up to 1.60 m, and 0.15 m in Scenario 3, respectively.

Alternative 6 is expected to have slightly lower impacts than Scenario 1, and other Development Alternatives (4, 5 and 7) are likely to cause lower impacts than Scenario 1, with short-term high impacts expected during the dry season of the representative dry year of 1998 with the 10-day maximum drop in water level at Kratie and Tan Chau ranging from 1.22 m and 0.09 m (Alternative 6), 0.67 m and 0.08 m (Alternative 7), 0.51 m and 0.06 m (Alternative 5), to 0.23 m and 0.03 m (Alternative 4), respectively.

Regarding water flows, similar to water levels, while water flow reductions between the Baseline and Scenarios in the dry season during normal or hydro-peaking operation of the dams (correspond to the representative normal year) seem to be modest, short-term very high impacts might occur during the dry season of the representative dry year during filling of the reservoir after release for maximum power production with the 10-day maximum loss of water volume at Kratie being approximately 60% in Scenario 1, 55% in Scenario 2, 68% in Scenario 3 and at Tan Chau and Chau Doc approximately 40%, 36 % and 44% for Scenarios 1, 2 and 3, respectively, compared to the Baseline. Changes in flows are considered small in flood season.

Similar to water levels, Development Alternative 6 is expected to have slightly lower impacts than Scenario 1, and other Development Alternatives (4, 5 and 7) are likely to cause lower impacts than Scenario 1, while short-term high impacts might be expected during the dry season of the representative dry year of 1998 with the 10-day maximum drop in water volume at Kratie and Tan Chau ranging from 51% and 28% (Alternative 6), 28% and 22% (Alternative 7), 23% and 17% (Alternative 5), to 12% and 8% (Alternative 4), respectively.

With regard to the high fluctuation of water levels, due to the foreseen daily operation of the planned hydropower schemes during the dry season, the water levels downstream at Kratie are expected to have high variations (maximum 2.15 m in Scenario 1, 2.31 m in Scenario 2 , 2.19 m in Scenario 3, and 1.79 m in Alternative 6) against the Baseline, while the variations of other Development Alternatives are considerably lower compared to Scenario 1 with variations of 0.31 m (Alternative 7), 0.18 m (Alternative 5) and 0.06 m (Alternative 4). Further downstream, the daily fluctuations would dissipate to a low level at downstream Phnom Penh and continue declining to very low when reaching Chau Doc and Tan Chau at the Cambodian-Vietnamese border.

Concerning flow impact on the river course of Lao PDR, operation of the mainstream dams would likely cause wide fluctuation of the water levels immediately downstream and short-term, high reduction of river flow during the dry season of the representative dry year. For example, at Vientiane the magnitude of water level fluctuation is 1.18 m in Scenario 1, 1.53 m in Scenario 2,1.63 m in Scenario 3 , 0.42 m in Alternative 4, 0.53 m in Alternatives 5 and 6, and 1.23 m in Alternative 7; and the 10-day maximum loss in water volume is about 62% in Scenario 1, 56% in Scenario 2, 85% in Scenario 3, 32% in Alternative 4, 47% in Alternatives 5 and 6, and 57% in Alternative 7. Changes during the flood season are considered small.

The above assessments are based on consideration of the present development level of the Chinese dams, when six Chinese dams were already in operation, especially the two largest dams namely Xiaowan and Nuozhadu. Additionally, with regard to the probable construction of 14 Chinese dams on the Lancang River (eight for the first stage and six for the second stage), impacts of the cascade at its full development have been considered. Apparently the Chinese cascade, especially the two largest dams namely Xiaowan and Nuozhadu, causes impacts on the river flow. The impacts gradually dissipate downward along the mainstream. Upon reaching the Mekong Delta, impacts caused by additional Chinese dams are expected to be slightly higher (from 1.5 to 3%) than those reported above (i.e., at the present development level), and a similar conclusion can also be drawn for Development Alternatives 4 through 7.

To illustrate the level of impact of full mainstream hydropower development for 14 dams in China, the 10-day maximum loss of water volume caused by full Chinese cascade development at Kratie is estimated to be approximately 60% for Scenario 1, 58% for Scenario 2, and 70% for Scenario 3 for the dry year during filling after drawdown for maximum power production in the dry season, against the losses of 60%, 55% and 68%, respectively, for the present development level. Similarly, the volume loss at Tan Chau and Chau Doc is approximately 41% for Scenario 1, 37% for Scenario 2, and 47% for Scenario 3 of full Chinese cascade development, against 40%, 36% and 44% of the present development level, respectively.

Table 3.4-1 shows the ranks assigned to hydrological impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7.

3.2 Sediment Transport

3.2.1 Input data

Changes in sediment transport and deposition within the IAA under various hydropower development Scenarios and Alternatives were estimated relative to baseline conditions using the Mainstream Sediment Transport Model and the Delta Sediment Transport Model. Input data for both models were sourced from the MRC's Information and Knowledge Management Programme/Discharge and Sediment Measuring Program and nation water quality monitoring programs. The input data set represents the most updated compilation of relevant sediment data. For additional information, refer to the MDS IAR, Volume 1, Chapter 3.

3.2.2 Methodology summary

Similar to hydrology and water quantity, for sediment transport, the Baseline and Scenarios' simulations have been carried out using the entire state-of-the-art suite of models developed for the entire Mekong (MIKE11 for sediment transport for the Mekong Mainstream and Delta, and MIKE21 for the Great Lake and the Coastal for sediment transport). The advantage of the compatibility and interlinking between different MIKE models have been explored in order to cover the entire Mekong Basin geographically, and being able to simulate sediment transport within the same model framework. The model system developed is considered to be well calibrated and validated in accordance with the existing international standards and fully taking into account the existing regional modelling standards set by MRC. The model therefore guarantees the highest quality possible not only for basin-wide planning purposes, but also for detailed impact assessment activities at smaller level. This is the first time that such an entire suite of models has been applied for the Mekong river basin, including the first-ever simulation of sediment for the entire Mekong Basin.

Dams might reduce the flow of sediment by physically blocking (trapping) the movement of riverbed material and increase the settling rate of suspended particles. A decrease in sediment transport might also cause a reduction in deposition of sediment onto floodplains, decreasing soil buildup in those areas. To quantify changes in sediment transport and deposition, the following indicators were used:

- Yearly total sediment loss
- Change in rates of river bank/bed erosion and deposition
- Decreased growth rate of Ca Mau tip
- Change in sediment concentrations

For additional information, refer to the MDS IAR, Volume 1, Chapter 3.

3.2.3 Key results

3.2.3.1 Bed Load Impacts

The mainstream reservoirs retain nearly all the bed material load causing a loss of bed material load downstream of the reservoirs in Lao PDR and Cambodia.

Estimated deposition rates are 18 million tonnes (Mt)/year at Pakbeng, 5 Mt/year at Xayabury, 22 Mt/year at Bankum and 12 Mt/year at Sambor. Downstream of Sambor there is almost no upstream bed material load (Figure 3.2-1).

However, bed erosion will take place downstream Sambor, and restore the bed material load. At Tan Chau and Chau Doc, the bed material transport will be the same in Scenarios 1 and 2, and Development Alternatives 4 through 7, approximately 3.7 Mt at Chau Doc and 9.1 Mt at Tan Chau. In Scenario 3, the bed load transport will have a low decrease to 3.6 Mt at Chau Doc and 8.8 Mt at Tan Chau due to the reduction of water flow from diversions in Thailand.

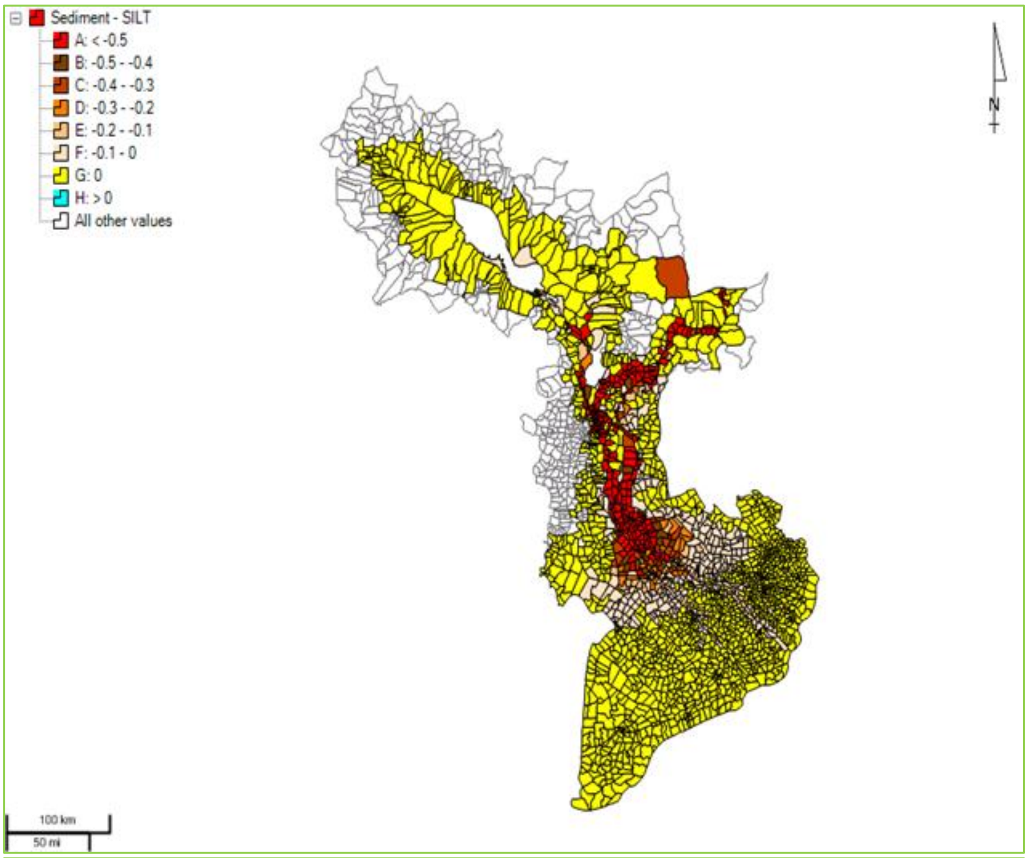
3.2.3.2 Wash load Impacts

In a year with higher sediment transport, such as 2008, reductions in silt transport under all three Scenarios relative to Baseline conditions are similar to the reductions under a normal year. Transport of clay is only marginally affected under all three Scenarios for both 2007 and 2008 conditions (Table 3.2-1). Wash load transport changes and distribution under Scenarios 2 and 3 are comparable to changes projected to occur under Scenario 1. The impacts on wash load transport at Kratie, Tan Chau and Chau Doc of Alternative 6 are similar to Scenario 1, while lower impacts are expected in Development Alternatives 4, 5 and 7 compared to Scenario 1.

Table 3.2-1: Comparison of annual wash load transport estimates at Kratie and Tan Chau + Chau Doc under the three Scenarios and four Development Alternatives relative to Baseline conditions

Scenario	Unit	Kratie	Tan Chau + Chau Doc
Baseline	*Mt/year*	52.6 ÷ 68.8	32.1 ÷ 42.3
Scenario 1	*Mt/year*	22.5 ÷ 25	13.9 ÷ 15.3
	% loss	57.2 ÷ 63.7	56.7 ÷ 63.8
Scenario 2	*Mt/year*	21.3 ÷ 23.3	13.7 ÷ 15.1
	% loss	59.5 ÷ 66.1	57.4 ÷ 64.4
Scenario 3	*Mt/year*	21.8 ÷ 24.4	13.7 ÷ 15.2
	% loss	58.6 ÷ 64.5	57.3 ÷ 64.0
Alternative 4	*Mt/year*	51.4 ÷ 66.9	31.3 ÷ 41
	% loss	2.4 ÷ 2.8	2.5 ÷ 3.1
Alternative 5	*Mt/year*	51 ÷ 66.4	31 ÷ 40.7
	% loss	3 ÷ 3.5	3.4 ÷ 3.8
Alternative 6	*Mt/year*	22.7 ÷ 25.2	14 ÷ 15.4
	% loss	56.9 ÷ 63.4	56.4 ÷ 63.5
Alternative 7	*Mt/year*	50.7 ÷ 66.1	30.8 ÷ 40.4
	% loss	3.6 ÷ 3.9	4.1 ÷ 4.5

Figure 3.2-1: Cumulative transport and trapping of bed load under Scenario 1 (average for 1985-2008)



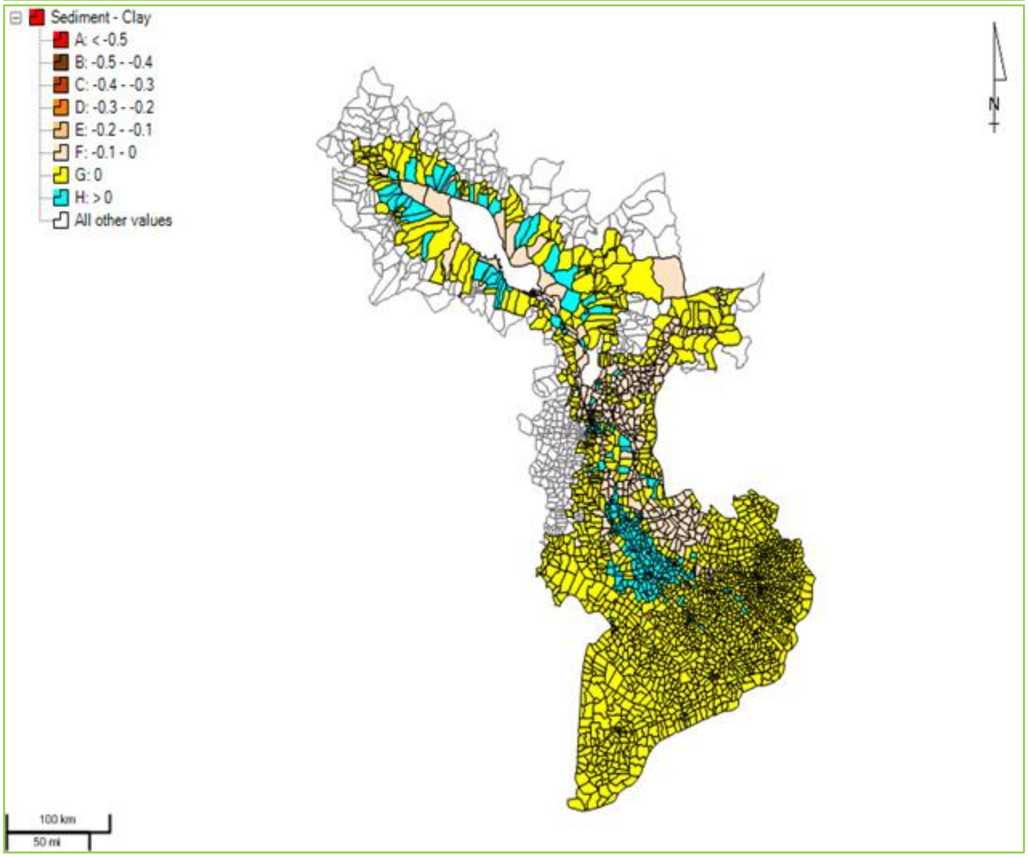
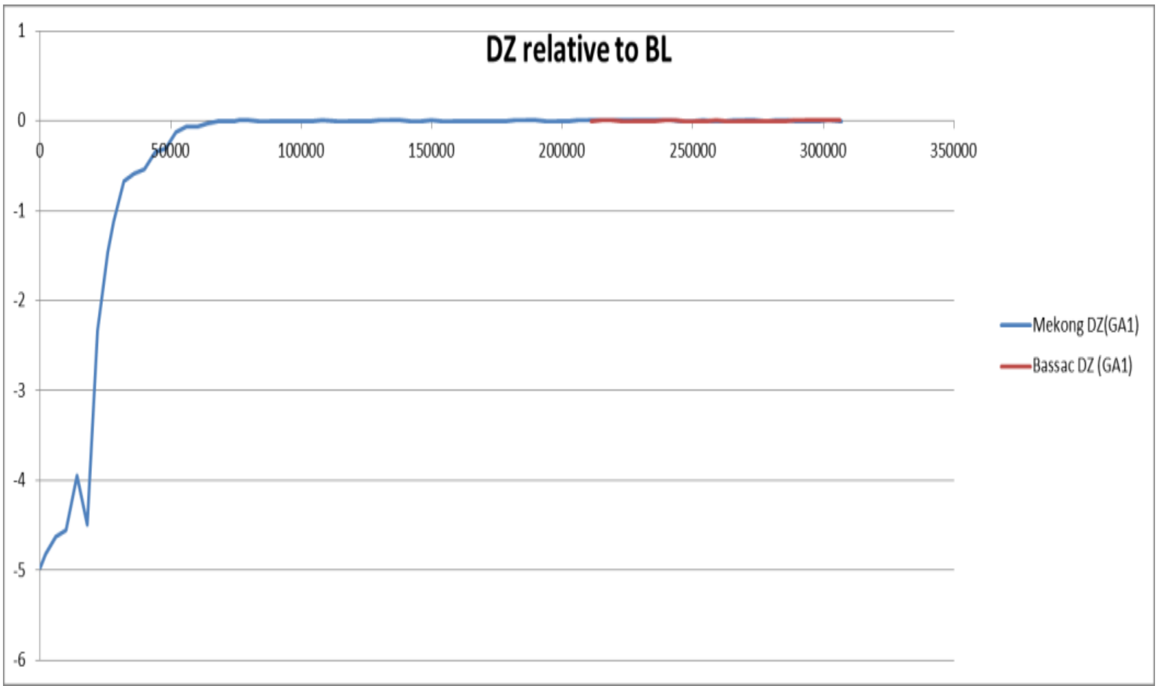


Figure 3.2-2: Impacts in wash load transport in the IAA: Comparison between Scenario 1 and Baseline 2007: Silt (upper) and Clay (lower).

3.2.3.3 Impacts on erosion

Trapping of sediments in the upstream dams will cause downstream scouring of the river bed. Bed transport simulations for Scenario 1 indicate that downstream of Kratie, up to 5 m deep scour could occur (Figure 3.2-3) and the river bed degradation will progressively move around 50 km downstream over a 23 year period, this is equivalent to a downstream propagation rate of the estimated 1.5 to 2 km/yr. In Scenarios 2 and 3 as well as in Alternative 6, the bed erosion depth and propagation rates are considered to be the same as in Scenario 1.



Note: The blue curve shows the depth of river bed erosion after a 23-year baseline simulation period.

Figure 3.2-3: River bed erosion simulated for the period from 1985 to 2008 for Scenario 1 with mainstream dams

In Alternatives 4 and 5, the bed erosion is considered to be nearly similar to the Baseline, meaning a small change. In Alternative 7 the bed transport simulations indicate that downstream of Kratie, up to 3 m deep scour could occur with the same downstream movement rate of 1.5 to 2 km/yr as for Scenarios 1 through 3. River bed degradation may lead to river bank failures.

It is worth noting the scope of this Study only preliminarily analyses the risk on bank erosion/deposition. Therefore, detailed analyses on bank erosion/deposition would be an important subject for further detailed studies in the future.

The high capture of silt and low capture of clay by the planned mainstream hydropower schemes give expected reductions in silt concentrations in the Delta impact area, and consequently reduction in silt deposition rates in the upstream part of the Vietnamese Delta that is normally affected by seasonal flooding during the wet season.

A reduction in sediment loads would result in reduction of the accretion and increase of erosion at and near the river mouths, with an estimated rate reduction by 4 to 12 m per year (m/y) in comparison with the present accretion and erosion rates (see Figure 3.2-4), causing the loss of land under all three Scenarios. Further away to the southwest, impacts on erosion/accretion rates are less than 0.5 m/y, and the growth rate of the Ca Mau tip is expected to be reduced by approximately 1 m/y in all three Scenarios. The recently measured accretion and erosion rates are continuously affected not only by changes in sediment transport to the Delta coastline, but also by emerging sea level rise and subsidence caused by groundwater abstraction in the Delta. However, exact rates of these future changes were not assessed in the MDS.

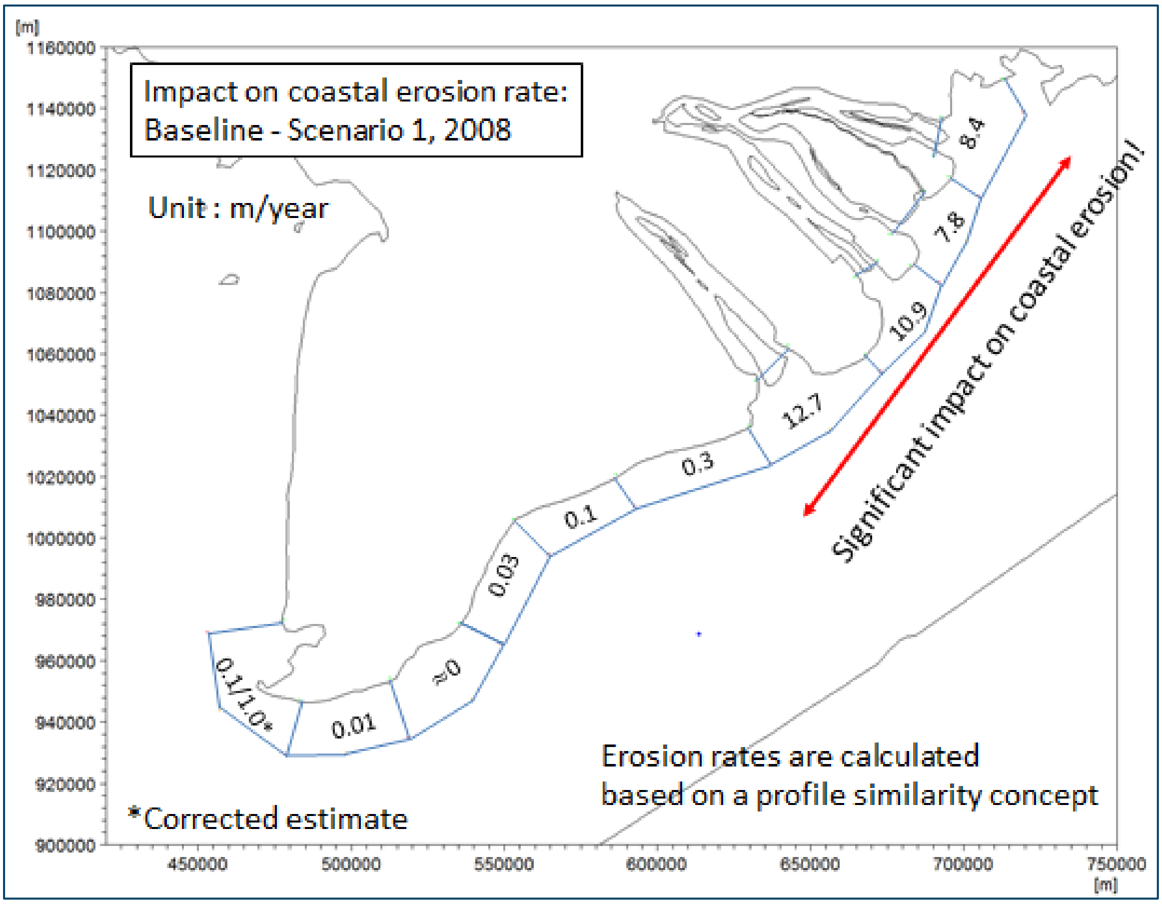


Figure 3.2-4: Estimated changes in erosion rates along the Mekong Delta coastline, year 2008.

3.2.4 Discussion of key results

Concerning sedimentation, all bed load is considered to be trapped in the reservoirs at the present design. The impacts to bed load transport to the Mekong Delta of Alternative 6 is similar to of the bed load transport in Scenario 1, while about half-lesser impacts than Scenario 1 might be expected in Alternative 7, and no detectable impacts on bed load transport to the Mekong Delta are expected in Development Alternatives 4 and 5.

The total transport of silt and clay in Scenario 1 at Kratie is reduced from 58 to 63% in Scenario 1, from 59 to 66% in Scenario 2, and from 59 to 65% in Scenario 3, while at Tan Chau + Chau Doc the reductions are nearly the same for all three Scenarios, from 57 to 64%, depending on hydrological years considered. The impacts to wash load transport to the control points of the Mekong Delta (Kratie, Tan Chau and Chau Doc) of Alternative 6 is similar to Scenario 1, while lower impacts are expected in Development Alternatives 4, 5 and 7 compared to Scenario 1.

The high capture of silt and low capture of clay by the planned mainstream hydropower schemes give expected reductions in silt concentration levels in the Delta impact area, and consequently reduction in silt deposition rates in the upstream part of the Vietnamese part of the Delta that is impacted by seasonal flooding during the wet season.

A reduction in sediment loads would result in reduction of the accretion and increase of erosion at and near the river mouths, with an estimated rate reduction from 4 to 12 m/y in comparison to the present accretion and erosion rates, causing the loss of land under all three Scenarios. Further away to the southwest, the impacts on erosion/accretion rates are less than 0.5 m/y, and the growth rate of the Ca Mau tip is expected to be reduced by approximately 1 m/y in all three Scenarios. The recently measured accretion and erosion rates are continuously affected not only by changes of sediment transport to the Delta coastline, but also by emerging sea level rise and subsidence caused by groundwater abstraction in the Delta. However, exact rates of these future changes were not assessed in this MDS.

In the upper reach of the lower Mekong mainstream, the mainstream reservoirs retain nearly all the bed material load and parts of the wash load. Coupling with the fluctuation of flows it is likely to cause high rates of river bed and bank erosion downstream of the dam sites and along the mainstream. On the mainstream courses in the Mekong Delta, the risk of erosion is high due to the lack of upstream bed material load and the reportedly increasing sand mining. The scope of this Study only preliminarily analyses the risk on bank erosion/deposition. Therefore, the detailed analyses on bank erosion/deposition would be an important subject for further detailed studies in the future.

Furthermore, similar to flow effects, the existing Chinese cascade at the present development level, especially the two largest dams namely Xiaowan and Nuozhadu, already traps most of the bed load and a large part of the wash load in China, leading to high impacts (reductions) on the sediment transport right downstream of the cascade downward. According to the MRC monitoring network, the wash load from China is presently low, and the main sources of silt and clay to the downstream are contributed from the tributaries primarily at the Golden Triangle downstream. The reduction in bed load from China is compensated by river bed erosion downstream. Therefore, a full development of Chinese dams likely causes serious impacts on sediment transport in the upper reach (Lao PDR and Thailand) but modest increases in the sediment transport reductions at the gateway of the Mekong Delta compared to the present dam development level when considering Scenarios 1, 2 and 3. A similar conclusion can also be drawn for Development Alternatives 4 through 7.

See Table 3.4-1 for ranks assigned to sediment impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7.

3.3 Water quality (nutrients and salinity)

The ECOLab Model templates were integrated into the Mainstream Sediment Transport Model to simulate nutrient transport. Changes in salinity distribution were projected using data from the Delta Salinity Model, which are based on application of the MIKE11 advection-dispersion model in combination with the Delta Hydrodynamic Model.

3.3.1 Input Data

Input data for the nutrient and salinity modeling were sourced from the MRC and national institutions and were supplemented by data obtained from the MDS Sediment and Nutrient Surveys conducted in 2014. The input data set represents the most current compilation of relevant water quality data. For additional information, refer to the MDS IAR, Volume 1, Chapter 3.

3.3.2 Methodology summary

The Ecolab module attached to the MIKE11 models for Mainstream and Delta (see Section 3.1.2) was employed to simulate nutrients on the Mekong mainstream and the Mekong Delta. The salinity intrusion in the Mekong Delta was simulated by the MIKE11 model for the Delta. This is the first time that such an entire suite of models has been applied for the Mekong river basin, including the first-ever simulation of nutrients for the entire Mekong mainstream and Mekong Delta.

A decrease in sediment transport would also cause a reduction in the transport and deposition of nutrients attached to the sediment. The floodplains of the Mekong River receive large annual influxes of nutrients during floods, which influences agricultural production and the primary productivity of other plants and secondary productivity of animals.

Dams could also cause a change in salinity concentrations in coastal areas (i.e., salinity intrusion) by increasing or decreasing the volume of fresh water flowing to the coast. Salinity intrusion is an important factor affecting agricultural production and the availability of fresh water during the dry season in coastal parts of the Vietnamese Delta.

The following key indicators were modeled to quantify changes in nutrient transport and deposition and salinity intrusion:

- Yearly total N and P loss Change in deposition of nutrients
- Max increase of salinity intrusion length
- Area of increased salinity intrusion.

For additional information, refer to the MDS IAR, Volume 1, Chapter 3.

3.3.3 Key results

3.3.3.1 Nutrient Concentrations

As a result of decline in sediment transport and deposition, nutrient transport is also projected to show high impact under all three Scenarios relative to baseline conditions (Table 3.3-1). Under Scenario 1, very high impacts due to substantial reduction in nutrient deposition rates are projected to occur in An Giang, Kien Giang, Dong Thap provinces in Viet Nam under both 2007 and 2008 conditions (Figure 3.3-1). Scenario 2 and 3 impacts are comparable to Scenario 1. The impacts to total transport of nutrients for Alternative 6 are similar to those for Scenario 1, while lower impacts are expected in Development Alternatives 4, 5 and 7 compared to Scenario 1.

3.3.3.2 Salinity intrusion

Changes in river water flow regimes directly influence the extent of salinity intrusion in the Mekong Delta, especially during dry years. These changes are further exacerbated by dry season hydropeaking operations of the cascade for increased power production (Figure 3.3-2).

Results indicate that under Scenarios 1 and 3, medium to high impacts may occur due to an increase in salinity intrusion. Short-term, localised, very high impacts (on the order of weeks) may result due to increase in salinity intrusion, from dry season drawdowns conducted in dry years. Salinity intrusions may increase further into the delta by 12.0 km and 10.0 km on the Mekong and Bassac branches, respectively.

Under Scenario 2, there is a decrease in salinity intrusion even during dry years because inclusion of the tributary dams causes to some degree transfer of water from the wet season to the dry season.

The impacts on salinity (for both normal year and dry year) of Development Alternatives 4 through 7 follow the pattern similar to the impacts of flows to the Mekong Delta, meaning that Alternative 6 would have slightly lower impacts than Scenario 1, and the other Development Alternatives (4, 5 and 7) are likely to cause lower impacts than Scenario 1.

Under Scenario 3, diversion of water in Thailand causes increased salinity intrusion in the south-central part of the Delta, while salinity intrusion is reduced in the north-east due to the diversion of water from the Mekong Mainstream to the south-eastern part of the Cambodian Delta. The changes in water discharges have medium to high impacts on the salinity distribution in the Vietnamese Delta.

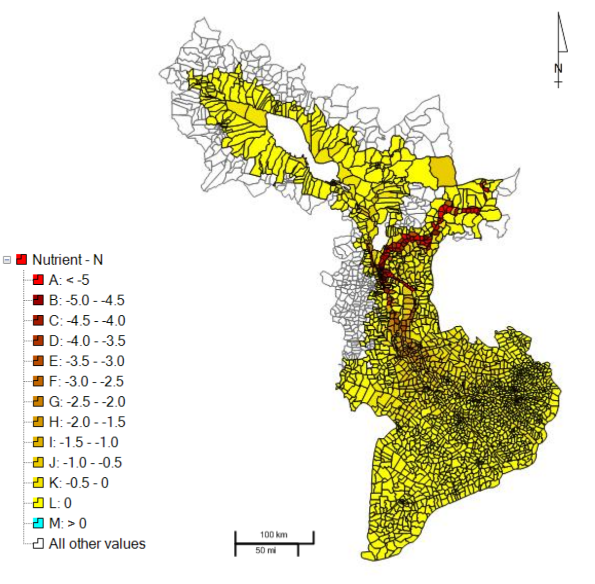
3.3.4 Discussion of key results

3.3.4.1 Nutrients

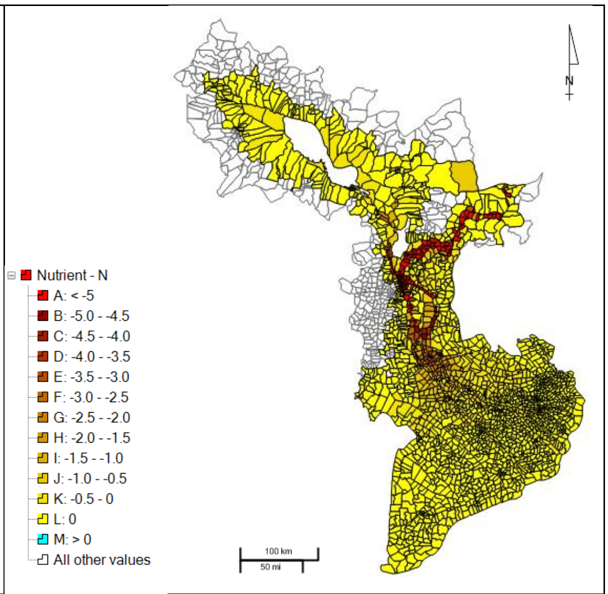
The total transport of phosphorus in at Kratie is reduced from 47 to 53% in Scenario 1, from 49 to 56% in Scenario 2 and from 48 to 56% in Scenario 3 (depending on hydrological conditions considered) compared to the baseline, while at Tan Chau + Chau Doc the reductions are from 46 to 53% in Scenario 1, from 47 to 54% in Scenario 2, and from 48 to 56% in Scenario 3. The impacts to total transport of phosphorus of Alternative 6 are similar to Scenario 1, while lower impacts are expected in Development Alternatives 4, 5 and 7 compared to Scenario 1.

Table 3.3-1: Comparison of annual transport of nutrients attached to silt and clay annually at Kratie and Tan Chau + Chau Doc under Scenarios 1 through 3 and Development Alternatives 4 through 7 relative to baseline conditions

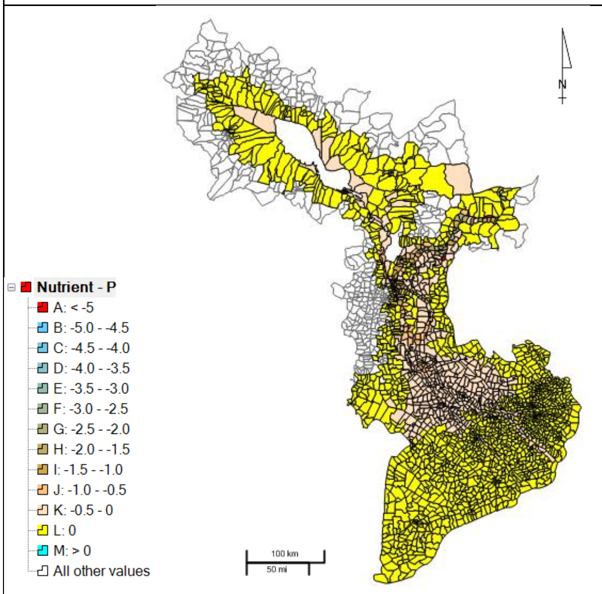
Nutrient	Scenario	Unit	Kratie	Tan Chau + Chau Doc
N	Baseline	1000 tons/year	48.7 ÷ 59.9	29.6 ÷ 36.8
	Scenario 1	1000 tons/year	21.2 ÷ 23.2	12.9 ÷ 16
		% loss	56.5 ÷ 61.3	56.4 ÷ 56.5
	Scenario 2	1000 tons/year	20.6 ÷ 22.7	12.7 ÷ 15.9
		% loss	57.7 ÷ 62.1	57.1 ÷ 56.8
	Scenario 3	1000 tons/year	20.6 ÷ 22.7	12.5 ÷ 15.9
		% loss	57.7 ÷ 62.1	57.8 ÷ 56.8
	Alternative 4	1000 tons/year	48.1 ÷ 58.7	29.1 ÷ 35.9
		% loss	1.2 ÷ 2	1.7 ÷ 2.4
	Alternative 5	1000 tons/year	47.6 ÷ 57.8	28.8 ÷ 35.4
		% loss	2.3 ÷ 3.5	2.7 ÷ 3.8
	Alternative 6	1000 tons/year	21.3 ÷ 23.6	13.1 ÷ 16.5
		% loss	56.3 ÷ 60.6	55.7 ÷ 55.2
	Alternative 7	1000 tons/year	47.2 ÷ 57.1	28.6 ÷ 34.9
		% loss	3.1 ÷ 4.7	3.4 ÷ 5.2
P	Baseline	1000 tons/year	19.1 ÷ 24.4	11.6 ÷ 15
	Scenario 1	1000 tons/year	10.1 ÷ 11.5	6.3 ÷ 7
		% loss	47.1 ÷ 52.9	45.7 ÷ 53.3
	Scenario 2	1000 tons/year	9.8 ÷ 10.7	6.2 ÷ 6.9
		% loss	48.7 ÷ 56.1	46.6 ÷ 54
	Scenario 3	1000 tons/year	9.8 ÷ 10.7	6 ÷ 6.6
		% loss	48.7 ÷ 56.1	48.3 ÷ 56
	Alternative 4	1000 tons/year	18.8 ÷ 23.8	11.4 ÷ 14.6
		% loss	1.6 ÷ 2.5	1.7 ÷ 2.7
	Alternative 5	1000 tons/year	18.6 ÷ 23.6	11.2 ÷ 14.4
		% loss	2.6 ÷ 3.3	3.4 ÷ 4
	Alternative 6	1000 tons/year	10.2 ÷ 11.6	6.4 ÷ 7.1
		% loss	46.6 ÷ 52.5	44.8 ÷ 52.7
	Alternative 7	1000 tons/year	18.4 ÷ 23.5	11.1 ÷ 14.2
		% loss	3.7 ÷ 3.7	4.3 ÷ 5.3



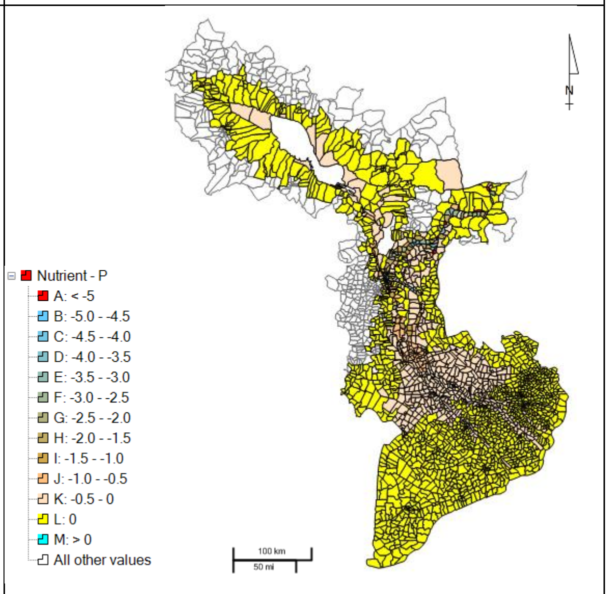
Nitrogen Deposition: Scenario 1 – 2007



Nitrogen Deposition: Scenario 1 – 2008

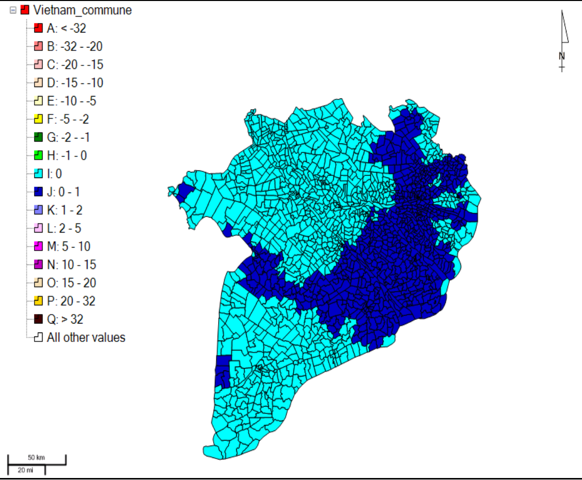


Phosphorus Deposition: Scenario 1 – 2007

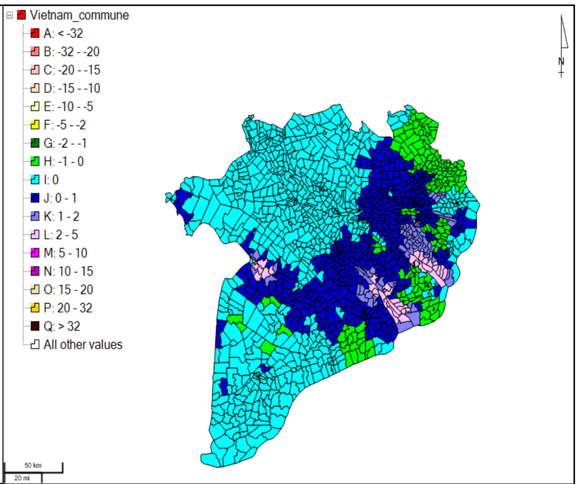


Phosphorus Deposition: Scenario 1 – 2008

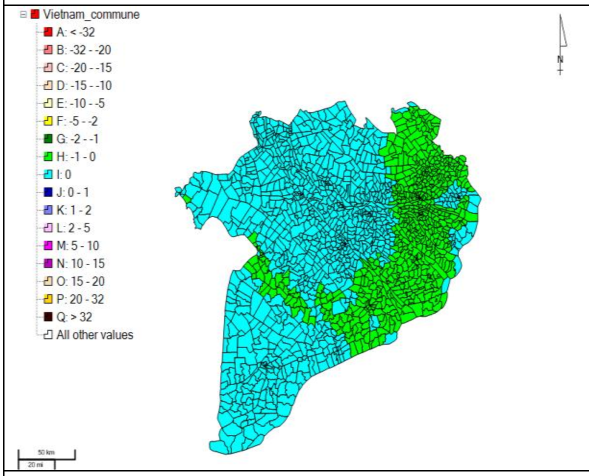
Figure 3.3-1: Changes in annual nitrogen and phosphorus deposition (g/m^2/year) between the Baseline and Scenario 1 for 2007 and 2008



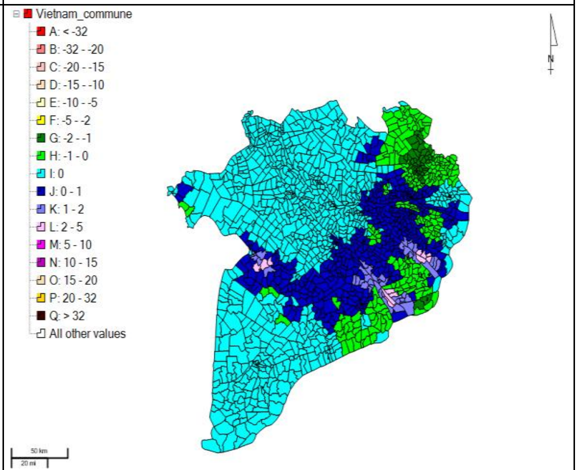
Salinity Scenario 1 – 1998 Average Dry season



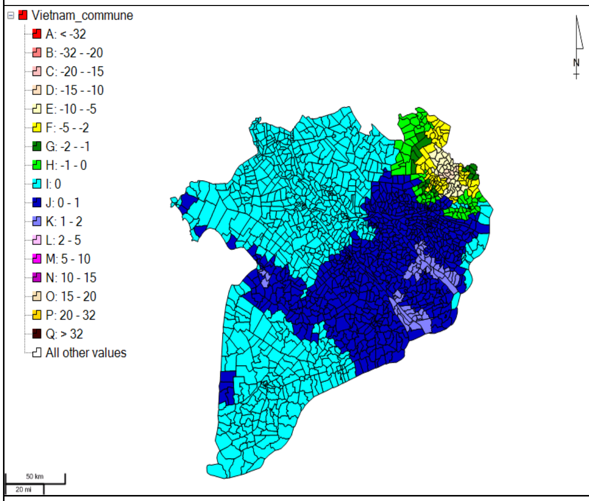
Salinity Scenario 1 – 1998 – Maximum Dry season



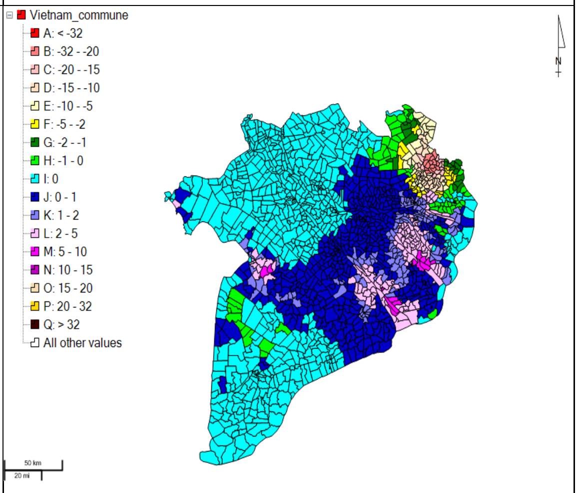
Salinity Scenario 2 – 1998 Average Dry season



Salinity Scenario 2 – 1998 – Maximum Dry season



Salinity Scenario 3 – 1998 Average Dry season



Salinity Scenario 3 – 1998 – Maximum Dry season

Figure 3.3-2: Difference in salinity levels (g/l) between the Baseline and Scenarios 1, 2 and 3 for 1998 (Dry year). Average for dry season (left) and maximum difference during the dry season (right)

Similarly, the total transport of nitrogen at Kratie is reduced from 57 to 62% in Scenario 1, from 58 to 62% in Scenario 2, and from 57 to 62% in Scenario 3 compared to the baseline, while at Tan Chau + Chau Doc the reductions are approximately 57% for all Scenarios. The impacts to total transport of nitrogen of Alternative 6 are similar to Scenario 1, while lower impacts are expected in Development Alternatives 4, 5 and 7 compared to Scenario 1.

Similar to sediment effects, with regard to the high trapping efficiency of the two above-mentioned largest dams in the present development, the impacts on transport of nutrients to the LMB and therefore to the Mekong Delta in Scenarios 1, 2 and 3 with full cascade development in China is considered to be marginally higher compared to the same scenarios with the present dam development, and a similar conclusion can also be drawn for Development Alternatives 4 through 7.

3.3.4.2 Salinity

Generally the changes in salinity are confined to the coastal areas in all three Scenarios as expected. For the dry season in the average year with a low increase of salinity concentrations covering a large area of approximately 7,550 km^2 in Scenario 1 and 11,200 km^2 in Scenario 3, while the salinity concentration is almost unchanged in Scenario 2. For the dry season in the dry year during filling of the reservoir after release for maximum power production, the area with increased salinity in the northern part is up to 14,000 km^2 in Scenario 1, 14,700 km^2 in Scenario 3, 3,866 km^2 in Alternative 4, 4,072 km^2 in Alternative 5, 7,229 km^2 in Alternative 6, and 6.082 km^2 in Alternative 7.

Moreover, very high impacts on salinity in the short term might be expected, especially in middle of the dry season of the representative dry year during filling of the reservoir after release for maximum power production with maximum salinity intrusion that might go further into the Delta by more than 12.0 km and 10.0 km on the Mekong and Bassac branches, respectively.

Impacts on salinity (for both the normal year and dry year) of Development Alternatives 4 through 7 follow the pattern of impacts to flows to the Mekong Delta, meaning that Alternative 6 is expected to have slightly lower impacts than Scenario 1, and other Development Alternatives (4, 5 and 7) are likely to cause lower impacts than Scenario 1.

Corresponding with slightly increased impacts on water flows to the Mekong Delta, introduction of the full Chinese dam would have similar, slightly higher impacts on salinity intrusion compared to the present development level of Chinese dams. Therefore, impacts on salinity of Scenario 1, 2 and 3 at the full Chinese cascade development will be slightly higher compared to the same scenarios with the present dam development, and a similar conclusion can also be drawn for Development Alternatives 4 through 7.

See Table 3.4-1 for ranks assigned to nutrient and salinity impacts under Scenarios 1 through 3 and Alternatives 4 through 7.

Table 3.3-2: Summary of impacts for drivers under Scenarios 1 through 3 and Development Alternatives 4 through 7

	Drivers	Hydrology	Duration	Scenario 1	Scenario 2	Scenario 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Viet Nam	Water	Average year	Dry season	1	0	2	0-1	1	1	1
		Dry year	Dry season	1	0	2	0-1	1	1	1
			Short-term	4	4	4	2	3	4	3
	Sediment	Average year	Yearly	4	4	4	1	1	4	2
	Nutrients	Average year	Yearly	4	4	4	1	1	4	2
	Salinity	Average year	Dry season	1	0	3	0-1	1	1	1
		Dry year	Dry season	2	1	4	0-1	1	1	1
			Short-term	4	4	4	2	3	4	3
Cambodia	Water	Average year	Dry season	1	0	2	1	1	1	1
		Dry year	Dry season	1	0	2	1	1	1	1
			Short-term	4	4	4	1	3	4	3
	Sediment	Average year	Yearly	4	4	4	1	2	4	3
	Nutrients	Average year	Yearly	4	4	4	1	1	4	2

Notes: 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact

3.4 Barriers to movement

Hydropower dams block the passage or increase the travel time of vessels, create barriers to the movement of migratory fish and other aquatic organisms, and fragment aquatic habitat. The direct effects of these physical barriers on navigation, fisheries, and biodiversity were quantitatively evaluated, and indirect impacts of changes in those resource areas were considered in the analysis of economics and livelihood. Key results for the impacts of the barrier effect to navigation, fisheries and biodiversity are presented below for each of these resources areas.

3.5 Fisheries

3.5.1 Input data

Input data used to assess the status and trends in the fisheries and aquaculture sectors in the LMB were sourced from a number of national and regional programs and supplemented by independent data collected under the MDS project. Available, relevant data from MRC fishery programs; local, regional, and national government agencies (such as the General Statistics Office of Viet Nam [GSO]); and peer-reviewed publication were acquired and entered into a database. Critical data gaps were bridged by collecting and analyzing additional data through field surveys and fisher household interviews during 2014 as part of the Fishery Research Study.

Notwithstanding the constraints, the input dataset used for assessing fishery impacts represents the best recent and most comprehensive compilation of relevant fishery data in the IAA. There is, however, an urgent need for collecting additional data in the future that is focused specifically on assessing impacts, particularly as they relate to fish and other aquatic animals (OAA) migration behavior and improving understanding of the complex primary and secondary links between sediment and nutrient loading and biological productivity.

For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.5.2 Methodology summary

A customised impact assessment methodology was developed and used to correlate changes in in flow regime, water quality, and connectivity of the Mekong River on capture fisheries. Both fish and OAAs were included in the analyses. The selected method was based on established fishery assessment principles and it was specifically geared towards the MDS fishery impact assessment objectives. It took into account the type, nature and extent of input data available to support the analyses. This method was previously used in the LMB and other large Delta ecosystems globally. As such, it meets international standards for fishery impact assessment.

Methodology. The fisheries impact assessment was designed to explore the effects of potential changes in flow regime, nutrient dynamics linked to transport and deposition of sediments, and barriers to migration due to hydropower development on fisheries and aquaculture yield, in addition to fish community diversity.

Within the LMB, 10 broad guilds can be defined based on the presence or absence of adult and larvae/juvenile life stages within riverine and floodplain habitats of the system.

To address impacts on fisheries, the following four-step process was followed:

1. Assess the impact of changes in water flow regime, water quality, and connectivity of the Mekong River on capture fisheries.
2. Assess the impact of changes in fish habitat, flow regime, and connectivity on fish community composition.
3. Assess the impact of sediment loss on fisheries production.

4. Assess the impact of changes in water flow regime, water quality, and Mekong River connectivity on aquaculture.

Impacts on capture fisheries

Habitat alteration impacts on fish capture yields. The purpose of this assessment was to quantify impacts on capture yield due to changes in the extent (coverage) of major fish habitats that could result from mainstream hydropower development and other development scenarios using modeling outputs and GIS techniques. The aim was to compare change in water level and inundation periods (effectively the flood pulse) under baseline conditions against those predicted using the MDS hydrology modelling output, and quantify how fishery production potential could be affected. The change in extent of habitat was related to the average productivity of the habitat type based on available data derived from the literature and output of the 2014 MDS Fishery Research study.

Flow modification impacts on fish capture yields. The relationship between hydrological parameters, such as changes to the timing (onset and offset), extent (amplitude), and duration of the flood pulse (area-duration curve), and fish capture yields is examined to predict the impacts influenced by the change in hydrological regime.

Sediment loss impacts on fish capture yields. Without any definitive models for sediment-fish relationships for IAAs, a simple proportional model was used that relates the proportional loss of sediment to loss of primary and secondary fish productivity. Within the Mekong, as with other floodplain systems, the limiting nutrient driving primary production is typically phosphorus; thus, the loss of fisheries production was proportionally related to loss of bio-available phosphorus in the reduced sediment load. In this analysis, a number of qualifying factors were applied.

Longitudinal connectivity disruption impacts on fish capture yields. Dams disrupt fish migration by denying or restricting access to upstream and downstream spawning, nursery, feeding, and refuge habitats. To assess this impact, the project examined the potential changes in fisheries yield as a result of:

- Direct blocking of migration to both upstream and downstream individuals and loss of potentially spawning habitat. The assessment was restricted to the IAA in the Cambodian floodplain and Vietnamese Delta.
- The potential loss in spawning and nursery/feeding areas by reservoir inundation.

Impacts on fish community composition. The impact of hydropower dams on fish species diversity was based on predicted changes in fish community composition as a result of potential loss of species caused by disruption to migration pathways, flooding of potential spawning and nursery areas by the upstream reservoirs, and potential loss of species caused by altering the flooding patterns in wetlands and floodplains.

Impacts on aquaculture

The purpose of this assessment was to quantify changes in aquaculture production in the Mekong Delta that could result from the proposed dam developments due to change in hydrological regime and salinity intrusion.

For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.5.3 Direct impacts

Impacts to capture fisheries

Major direct impacts on capture fisheries under Scenarios 1, 2, and 3 are summarised by key indicators in Tables 3.5-1 and 3.5-2. These impacts were also ranked for all three Scenarios and the four Development Alternatives using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 3.5-3.

Table 3.5-1: Capture fishery impacts summary by indicator – Viet Nam

Indicator	Units	Baseline yield (t)	Scenario yield (t)	Scenario net loss of yield (t)
Scenario 1				
Yield total – Fish	tonnes	692,118	318,004-348,075	344,043-374,114 (49.7-54%)
Yield total – OAAs	tonnes	160,075	137,865	22,840
Yield of economically important species	tonnes	405,650	208,911	196,739
Fish catch diversity[1]	Species at risk	--	33	--
Catch per unit effort (CPUE)[1]	kg/gear/day	Insufficient data to estimate, but general declining trend in catch rate evident in the past 10 years		
Scenario 2				
Yield total – Fish	tonnes	692,118	315,990-345,585	346,533-376,128 (50-54.3%)
Yield total – OAAs	tonnes	160,075	137,430	23,176
Yield of economically important species	tonnes	405,650	208,253	197,397
Scenario 3				
Yield total – Fish	tonnes	692,118	312,331-341,925	350,193-379,787 (50.6-54.9%)
Yield total – OAAs	tonnes	160,075	137,102	23,176
Yield of economically important species	tonnes	405,650	207,642	198,008

[1] CPUE and number of species at risk do not vary between three Scenarios, and thus are not repeated.

Table 3.5-2: Capture fishery impacts summary by indicator – Cambodia

Indicator	Units	Baseline yield (t)	Scenario yield (t)	Scenario net loss of yield (t)
Scenario 1				
Yield total – Fish	tonnes	481,537	223,071-241,919	239,618-258,460 (49.7-53.6%)
Yield total – OAAs	tonnes	105,467	84,466	21,001
Yield of economically important species	tonnes	235,953	119,148	116,805
Fish catch diversity[1]	Species at risk		37	
Catch per unit effort (CPUE)[1]	kg/gear/day	Insufficient data to estimate,		
Scenario 2				
Yield total – Fish	tonnes	481,537	218,774-237,056	244,481-262,763 (50.8-54.6%)
Yield total – OAAs	tonnes	105,467	83,569	21,898
Yield of economically important species	tonnes	235,953	117,826	118,127
Scenario 3				
Yield total – Fish	tonnes	481,537	217,736-236,019	245.518-263.801 (50.9-54. 8%)
Yield total – OAAs	tonnes	105,467	83,444	22,023
Yield of economically important species	tonnes	235,953	117,613	118,340

[1] CPUE and number of species at risk do not vary between the three Scenarios, and thus are not repeated.

Table 3.5-3: Fishery impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7 ranked by level of impact

	Indicator	Scenario 1		Scenario 2		Scenario 3		Alternative 4		Alternative 5		Alternative 6		Alternative 7	
		CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN
Capture fisheries	Loss of fish catch yield	4	4	4	4	4	4	1 – 2	1 – 2	2 – 3	2 – 3	4	4	2 – 3	2 – 3
	Loss of OAAs yield	4	4	4	4	4	4	1 – 2	1 – 2	2 – 3	2 – 3	4	4	2 – 3	2 – 3
	Loss of yield of economically important fish species	4	4	4	4	4	4	1 – 2	1 – 2	2 – 3	2 – 3	4	4	2 – 3	2 – 3
	Species loss in catch composition	4	4	4	4	4	4	1 – 2	1 – 2	2 – 3	2 – 3	4	4	2 – 3	2 – 3
Aquaculture	Change in extent of aquaculture area per species group	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Change in production per aquaculture species group	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Notes:

1. 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact
2. CM = Cambodia; VN = Viet Nam
3. The high to very high impacts are mainly caused due to a combination of the dam barrier effects and substantial declines in sediment and nutrient loadings.

Key observations from data presented in the tables above are listed below:

- Overall, the proposed mainstream hydropower cascade may lead to 48 to 55% reduction in capture fishery yields in both Viet Nam and Cambodia, respectively. The majority of the loss is the result of reduction in yield of white fish species which are the predominant species in the catch and contribute 74% of the catch of the top 10 commercial fish species. These loss estimates do not include any replacement of white fish by other species. At least some of the fish catch that currently consists of white fish will likely be replaced by other, non-migratory fish. However, the proportion replaced cannot be estimated with data currently available. Also, these loss estimates do not include declines in grey and black fish catches that result from indirect impacts associated with decline in white fish yields.

- The major impacts on capture fisheries are due to reduced migration of white fish species. This reduced migration is due to the barriers posed by the dams, especially the most downstream dams of the mainstream cascade. This contributes to a major loss of fish yield under all Scenarios and is potentially exacerbated under Scenario 2 where tributary dams also impede more localised movements of fish.

- Dams acting as physical barriers will also interfere with the downstream drift of fish and OAA eggs and larvae. This blockage is an important trophic loss because it has the potential to impact secondary productivity within non-migratory fish guilds.

- MDS sediment and water quality modelling suggests that sediment and nutrient loading and deposition to the IAA floodplains will be substantially reduced under all three Scenarios. Such a reduction would potentially have substantial adverse impacts on fish productivity that may decline by as much as 50% throughout the IAA. This adverse impact would mostly affect the short-distance migrating white fish, grey fish, generalist and estuarine resident guilds.

- Sediment retention by the proposed Cascade would also be anticipated to have a major impact on coastal fish production and subsequently the Vietnamese fishing sector and fish trade.

- Changes in catch rate and harvest directly due to hydrological (water flow and level) alterations resulting from daily operations under all three Scenarios will be marginal and within the bounds of natural variability of the river's hydrology.

- Hydropeaking operations, however, could potentially cause large daily downstream water fluctuations. These flow modifications could have serious potential environmental impacts on the river between Sambor and potentially as far downstream as Phnom Penh. The regulated flows in this reach could result in losses in fish production, reduction in reproductive output and impede upstream migration of adult fishes. There could also be a loss or local extinction of rhithron fish species from the reach around Kratie–the most downstream reach supporting this fish guild. Large and rapid changes in water levels and velocity within deep pools would also reduce the quality of those important sites as dry season refugia for fish. In addition, the altered hydrology will be disruptive to migration of adult fishes, disrupting their behavioral migration cues and impeding migration cycles. The large daily fluctuations would also make fishing more difficult, which would impact the livelihood of the people dependent upon fishing in this region. Quantifying these effects is challenging due to lack of fisheries data from the river reach around Kratie.

- If drawdowns were conducted under dry year conditions (during both the dry and wet seasons), they could also impact water levels immediately downstream of Kratie and may slightly delay the flood cycle, an important migration cue for some fish species.

- Many freshwater fish species are confined to the Mekong and Chao Phraya basins in Thailand only. Given the level of development in and around Thailand, the Mekong River mainstream has served as a refugium for several regionally endemic species. The proposed mainstream dams may therefore represent complete jeopardy for more than just the five species endemic to the Mekong basin and projected to go globally extinct.

- The impacts of the four Development Alternatives are likely to be similar in terms of type, although the spatial scale and intensity of the impact will vary depending on the dam design and operation, and success of proposed mitigation (especially fish passage) measures. The impact on the Mekong Delta of dams constructed in the middle and lower migration systems (i.e., above Khone Falls to Vientiane and below Khone Falls) will be greater than those built in the upper migration zone in northern Lao. Fish migration will be severely impacted unless bypass solutions are found, especially for downstream migration.

- Development Alternative 4, since it only includes two dams, shows the smallest declines in capture fishery yields (7.0-8.5 and 8-10% in Viet Nam and Cambodia, respectively). Reduction in capture fishery yields in Viet Nam associated with Development Alternatives 5 and 7 are almost the same at approximately 22-28%. In Cambodia, Alternatives 5 and 7 could reduce capture fishery yields by 24-30%. Decline in capture fishery yields under Alternative 6 are almost the same as those projected for Scenarios 1, 2, and 3.

- Capture fisheries impacts for the four Alternatives are projected as: low to moderate under 4, moderate to high under 5, very high under 6, and moderate to high under 7 (Table 3.5-1).

Impacts to Aquaculture

- The cascade is unlikely to cause significant impacts to highly protected aquaculture production in the IAA flood plain because water quality and water levels in the ponds in this culture area are mostly achieved by pumping and does not rely much upon mainstream flows. However impacts on aquaculture may be seen in the areas that may undergo increased salinity intrusion particularly Pangasus culture in the coastal provinces because Pangasus production is exclusively in freshwater environment.

- Impacts to aquaculture are nevertheless widely regarded as more complicated. The need for further study where the aquaculture area is extended over more provinces and when more data on the relationship between environmental drivers and the aquaculture become available is apparent.

Aquaculture operations in the Vietnamese Delta could also be indirectly affected due to loss of coastal fisheries as a result of the decline in sediment and nutrient loading and deposition. This is because the Delta aquaculture sector is partly dependent on local protein sourced from marine 'trash-fish' to feed the aquaculture fish for feedstock.

3.5.4 Indirect and secondary impacts

Indirect and secondary impacts could include the following:

- While flows and water levels are unlikely to change substantially in the Vietnamese Delta, the reduced sediment loading will have an indirect effect on capture fisheries production in the Cambodian floodplains, the Great Lake-Tonle Sap system, Vietnamese Delta, and coastal waters. The extent of this loss of natural nutrient loading is extensive because of sediment trapped in the dams. This could have a substantial effect on primary and secondary production, and ultimately fish production.

- Any loss of capture fishery would indirectly affect the food security, livelihood, social well-being, and economic status of a large segment of the population in the IAA, which relies, either part- or full-time, on fishing and associated occupations. After the fish are caught, they are passed on to collectors, transporters, wholesalers, processors, market sellers, and restaurant owners, and monetary value is added at each step. This monetary value directly increases the participant's purchasing power, allowing more to be spent on food, which in turn increases food security. Adverse impacts on capture fisheries would therefore translate into substantial economic hardships for large groups of individuals and families and at worst may lead to people migrating from rural to urban areas in search of new or different sources of employment.

- Replacing the current contribution of wild-capture fish protein with other sources of protein is likely an expensive and challenging undertaking as the indirect impacts of capture fishery losses on food security simply cannot be easily and fully mitigated. For those families that are either already food insecure or on the brink of it, a reduction in the availability of fish and OAAs, which are their daily staples, could increase malnutrition. People's health could suffer and illness could become more common, and poverty may increase. Poorer families with low resilience capacity will probably bear the major brunt of the impact.

- Capture fishery losses could also potentially impact primarily agricultural communities because many farmers rely on subsistence fishing during peak flood seasons when land cannot be cultivated.

- In any ecosystem, substantial declines in fish populations, especially those of fry and juveniles, gets transferred very quickly through the food chain because young fish serve as prey for many other predator species including reptiles, amphibians, larger fish, aquatic birds, and mammals.

3.5.5 Recommendations for future studies

The robustness of future assessments can be improved by collecting additional data and developing site-specific analytical and modeling tools that are focused on assessing fishery impacts. Recommendations for future studies are listed below:

- Initiate long-term, basin-wide fishery data monitoring programs to collect the following types of information, which will further add to our understanding of the many complex and inter-linked ways in which mainstream and tributary hydropower development could affect fisheries in the IAA and LMB, including the following:
  - Studies of the movement and seasonal habitat use of fish to identify migratory fish species and better understand their movement and habitat requirements.
  - Continue to monitor catch yield and catch species composition of fish and OAA for the main wetland habitat types if not throughout the basin.
  - Undertake food consumption studies to assess the total fish and OOA intake from various sources.
  - Carry out studies to improve the robustness of national statistical reporting data through comparison with consumption data.
  - Assess the reliance of aquaculture production on wild fish and OAA catches in terms of feed inputs.
  - Genetic studies of vulnerable migratory fish species in the Mekong Delta, Tonle Sap, and central Mekong River to better understand population structure and vulnerability of those species.
  - Monitoring of the effects of a decrease in sediment deposition, and associated changes in habitat structure, on benthic invertebrates and other aquatic species.
- Studies of the effects of a change in water-borne nutrient concentrations and deposition on primary productivity within aquatic and wetland habitat, and the secondary effects on the composition, structure, and reproductive output of plant and animal communities.
- Studies that assess the impact of economic development projects, other than hydropower, on fisheries production and diversity.
- Studies that evaluate cumulative impacts of naturally occurring phenomenon such as climate change and sea level rise on ecosystem-wide biodiversity.

3.6 Biodiversity

3.6.1 Input data

The analysis of effects to biodiversity was based on studies conducted in 2014 to characterise wetland biodiversity within the IAA, an updated wetland maps for the entire IAA, and publications and reports by the MRC and others. The available data and knowledge assimilated and synthesised by the MDS met the required sufficiency and quality for analyses at the highest possible level of quantification. For additional information, refer to the MDS BAR and IAR, Volume 2, Chapter 3.

3.6.2 Methodology summary

Four methods were used to evaluate effects to biodiversity over appropriate temporal and spatial scales. These methods were based on scientifically validated and peer-reviewed approaches, and variations of these approaches have been previously used in the LMB for biodiversity impact assessments. As necessary, the methods were tailored for specific application to the IAA and its biodiversity resources based on best professional judgment. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.6.3 Direct impacts

Major direct impacts on biodiversity under Scenarios 1, 2, and 3 are discussed below. These impacts were ranked for all three Scenarios and the four Alternatives using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 3.6-1.

- The dams would block the movements of migratory fish and other aquatic species throughout the LMB, potentially causing:

  - The extirpation or extinction of up to 10% of the fish species that occur in the Mekong River of Viet Nam and southern Cambodia

  - Substantial reduction of any surviving species of migratory fish

  - Extirpation of the Irrawaddy dolphin from the Mekong River

  - Reduction in the distribution and abundance of freshwater mussels and reduction of drift of invertebrates.

- Hydropeaking operations could potentially cause large daily fluctuations in water levels downstream of each dam. In the case of Sambor, which is closest to the IAA, those fluctuations would potentially severely degrade aquatic and riparian habitat from Sambor to south of Kratie.

- Sediment and nutrient deposition would decrease by up to 60% at sites closer to the mainstream and by smaller amounts elsewhere in the IAA, causing an increase in erosion, or decrease in rate of buildup, of riparian and coastal sites, and possibly a large reduction in productivity throughout the IAA.

Table 3.6-1: Biodiversity impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7 ranked by level of impact

Indicator	Scenario 1			Scenario 2			Scenario 3			Alternative 4			Alternative 5			Alternative 6			Alternative 7		
	CF	TS	MD	CF	TS	MD	CF	TS	MD	CF	TS	MD	CF	TS	MD	CF	TS	MD	CF	TS	MD
Change in the extent of open water and floodplain wetlands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Species affected by loss of important open water and floodplain habitat types	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Change in wetlands composition within biodiversity hotspots	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Risk of reduction in biodiversity	2	0	1	2	0	1	2	0	1	0	0	0	0	0	0	2	0	1	0	0	0
Change in primary productivity caused by changes in nutrient deposition	2–3	2	2–3	2–3	2	2–3	2–3	2	2–3	0	0	0	0	0	0	2-3	2	2-3	0	0	0
Loss of riverine habitat caused by changes in sediment transport	2	1	1	2	1	1	2	1	1	0	0	0	0	0	0	2	1	1	0	0	0
Loss of coastal wetlands (mangroves) caused by changes in sediment transport			2			2			2			0			0			2			0
Risk of extirpation	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Notes:

1. 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact
2. CF = Cambodian Floodplains; TS = Tonle Sap; MD = Mekong Delta
3. The high to very impacts are mainly caused due to a combination of dam barrier effects and substantial declines in sediment and nutrient loadings

- Concurrent drawdowns at all mainstream dams for maximizing power production, especially during a dry year, could cause a temporary change in flows in the northern part of the IAA. Such a drawdown could delay the start of wet season flows or change the timing of other important behavioral triggers for aquatic organisms. This could cause short-term alternations in the timing of migration or other behaviors of fish and other aquatic organisms. Any delay or alteration in the timing of migration or reproduction could reduce reproductive fitness in that year if spawning, feeding, or other important life cycle events were then to occur when habitat conditions are sub-optimal. This effect probably would be the most important if the drawdown were to occur near the beginning of the flood season, when many migratory species begin migrating in response to an increase in flows

- Overall, changes in the volume or timing and flows would be within the range of natural variation in the region and thus would no cause significant associated changes in wetlands and aquatic habitat other than those described above.

- The greatest adverse impact of the planned LMB tributary dams (that were assessed under Scenario 2) would be to flood or otherwise adversely modify important spawning and other tributary habitat for migratory fish and other aquatic species. This would further reduce the likelihood of survival of migratory fish in the IAA. It would also cause the reduction or loss of an entirely different set of aquatic species – those found in the tributaries. This reduction in biodiversity would further reduce the resiliency of the natural system to respond to other changes, adding additional risk to the food security of people dependent upon fish for their diet and livelihood. Tributary dams would also cause a small additional decrease in the transport and deposition of sediments and nutrients in the IAA, but would not change the volume or timing of flows or patterns of inundation in a manner that would substantially affect biodiversity.

- Planned diversions assessed under Scenario 3, would cause a small additional decrease in the transport and deposition of sediments and nutrients in the IAA, but would not change the volume or timing of flows or patterns of inundation in a manner that would substantially affect biodiversity. The water withdrawals would not affect movements of migratory fish or other aquatic organisms in the IAA.

- Biodiversity impacts associated with the four Alternatives are also tied to changes in sediment and nutrient loading and dam barrier effects. Alternative 4 would have the smallest effect, as at it has the lowest reduction in sediment and nutrient loading and provides at least some access to riverine and floodplain habitat in Lao PDR and northern parts of Cambodia. Alternatives 5 and 7 would block access to floodplain habitat in Laos but would not prevent movements into habitat in northern Cambodia. Alternative 6 would have the largest effects, as access to all mainstream and tributary habitats north of the IAA would be blocked and it leads to substantial reduction in sediment and nutrient loads into the IAA.

- Overall, biodiversity impacts under the four Development Alternatives are projected to range from none (for most indicators) to very high (risk of extirpation) (Table 3.6-1).

3.6.4 Indirect and secondary impacts

Indirect and secondary impacts could include:

- The loss of numerous ecologically important migratory fish species (which also includes many economically important fish species) could cause substantial shifts in populations of other fish and aquatic organisms in the basin. For example, abundance, and possibly distribution, of some fish species, including invertebrate species, would expand or otherwise change because of a decrease in predation, increase in available resources, or other factors resulting from the extirpation of migratory species. Approximately 25 of the 73 migratory species are carnivorous and the loss of some of those species would cause long-term changes in aquatic biodiversity, such as changes in populations of the fish, mollusks, crustaceans, and other aquatic organisms they feed upon.

It is not possible to predict the nature, magnitude, and trend of the secondary biodiversity effects, but it is very likely that the migratory species that are lost will be replaced primarily by smaller species, non-native species, and possibly by invertebrates. At the very least, it is a reasonable to assert that after the Cascade is constructed and operated for some time, the LMB will likely support fewer overall species of fish and OAAs and, therefore, exhibit less ecological resilience.

- Loss of economically important migratory fish species would directly impact capture fishery yields in the basin in turn potentially affecting the livelihood of a large segment of the population in the IAA that relies either part- or full-time on fishing and associated occupations. This would also have an economic impact and may lead to people migrating from rural to urban areas in search of new or different jobs.

- Creation of dams would alter habitat of riverine species in inundated areas upstream of dams, fragment populations along the river, reduce aquatic drift of plants and invertebrates, and reduce gene flow. This would further reduce the viability of some species and change the composition of aquatic plant and animal populations in the region.

- A reduction in nutrient transport and deposition would case a reduction in the vigor and growth of some plants, a loss of reproductive output, and a shift in species composition. Studies of the effects of a change in nutrient concentrations have documented shifts in the composition, and possibly structure, of plant communities, with a decrease in species adapted to higher soil nutrient contents and an increase in weedy or invasive species adapted to lower soil nutrient content.

3.6.5 Recommendations for future studies

There are important gaps and limitations in data availability and more importantly in the understanding of the complex, multi-faceted, inter-disciplinary ecological processes that dictate and control biodiversity in a large ecosystem such as the LMB.

In general, there is a lack of long-term and detailed information on the types of plants and animals that occur within waters and wetlands of the IAA. Also, limited information is available on movements and habitat use of migratory and other potentially affected species. Finally, very few empirical studies have been conducted to demonstrate how the varied ecological systems in the basin would collectively respond to projected changes in hydrology, sediment and nutrient loading, and water quality. For example there is limited information available to understand how changes in nutrient transport and deposition could directly and indirectly affect wetland productivity, or how the composition of the fish community in the region would respond to the loss of or substantial reduction in populations of numerous migratory fish species.

The robustness of future assessments could be improved by collecting additional data and developing site-specific analytical and modeling tools that are focused on assessing biodiversity impacts. Recommendations for future studies are listed below:

- Initiate short-, mid-, and long-term biodiversity data monitoring programs to collect the following types of information, which will further add to our understanding of the many complex and inter-linked ways in which mainstream and tributary hydropower development could affect biodiversity in the IAA and LMB, including the following:
    - Studies of the movement and seasonal habitat use of fish to identify migratory fish species and better understand their movement and habitat requirements.
    - Genetic studies of vulnerable migratory fish species in the Mekong Delta, Tonle Sap, and central Mekong River to better understand population structure and vulnerability of those species.
    - Monitoring of the effects of a decrease in sediment deposition, and associated changes in habitat structure, on benthic invertebrates and other aquatic species.
- Studies of the effects of a change in water-borne nutrient concentrations and deposition on primary productivity within aquatic and wetland habitat, and the secondary effects on the composition, structure, and reproductive output of plant and animal communities.
- Studies that evaluate cumulative impacts of naturally occurring phenomenon such as climate change and sea level rise on ecosystem-wide biodiversity.

3.7 Navigation

3.7.1 Input data

Input data for the navigation impact assessment were obtained from official government sources including Viet Nam's Ministry of Transportation and the GSO; MRC reports and publications, and a variety of other published sources. Also, a navigation survey was conducted in 2014 to provide updated data on navigation capacity and facilities in the IAA. The data used for assessing navigation impacts represents a comprehensive and updated compilation of relevant information. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.7.2 Methodology summary

A customised approach was developed for assessing and quantifying the impacts. Eight key primary navigation routes in the IAA were selected using a screening process and impacts on navigation capacity caused by declines in water levels, daily water fluctuations, changes in river bank and coastal morphology, and river connectivity were assessed under the three Scenarios. Impacts associated with dam locks, all of which are located outside the IAA, were also evaluated. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.7.3 Direct impacts

Major direct impacts on navigation are discussed below. They were ranked by indicator for all three Scenarios and the four Alternatives using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 3.7-1.

- The main impacts on navigation within the IAA would result from reduction of river channel water depths and high water level fluctuations downstream of the lowermost dam to Kampong Kor caused by hydropeaking. Among the three Scenarios evaluated, the greatest impacts are likely to occur under Scenario 3.
- The section from Kampong Kor to Phnom Penh would be much less impacted and vessels as large as 2,000 DWT (dead weight tonnage) could continue to operate in this area.
- Significant adverse impacts on navigation are unlikely projected downstream of Phnom Penh. Transboundary navigation routes from Phnom Penh to Ho Chi Minh City and the East Sea could be developed per the Master Navigation Plan.
- No detectable impacts on navigation are projected for the Vietnamese Delta.
- Hydropeaking operations, during the dry season causing large fluctuations of discharges and water levels would be a serious safety hazard to vessel operations on the river, and a cause of increased erosion of the channel bank and navigation facilities along that portion of the river.
- The average transit time for a vessel to pass through a lock of about 45 minutes would lead to additional river transportation costs.

Table 3.7-1: Navigation impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7 ranked by level of impact

Indicator	Scenario 1		Scenario 2		Scenario 3		Alternative 4		Alternative 5		Alternative 6		Alternative 7	
	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN
Change in flow regime, water depth in the river changed	3	1	3	1	4	1	2	1	2	1	3	1	2	1
Change in transport capacity	1	0	1	0	1	0	1	0	1	0	1	0	1	0
Physical barriers – Longitudinal connectivity	1	0	1	0	1	0	1	0	1	0	1	0	1	0
Change river morphological condition due to sediment transport	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Notes:

1. 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact
2. CM = Cambodia; VN = Viet Nam
3. The moderate to high impacts in Cambodia are mostly due to dam operational modes such as hydropeaking and the impacts are localised in the areas downstream of Kratie.

- Erosion of the riverbank near Kratie caused by large, rapid water fluctuations and a decrease in sediment transport would be anticipated, that in turn would cause further damages to navigation facilities in that area.
- Navigation impacts associated with the four Development Alternatives are also generally limited to the river section between Kratie and Kampong Cham largely due to fluctuations in water levels and changes in water depths. The greatest impact is associated with Alternative 6 in which the probability is decreased to 81% at Krochreng reducing the number of day not meeting the 95% probability water depth to 69 days.
- Overall navigation impacts for the four Alternatives are projected as: none to moderate under 4 and 5, none to high under 6, and none to moderate under 7 (Table 3.7-1).

3.7.4 Indirect and secondary impacts

Indirect and secondary impacts are mostly related to a marginal increase in economic losses due to increase in the navigation costs in certain river sections, and social and quality of life impacts on people that rely on small boat navigation, especially in the area downstream of Kratie.

3.8 Agriculture

3.8.1 Input data

Historical data on agricultural productivity at the commune level were obtained from government agencies in Viet Nam (GSO), Cambodia and MRCS. Data on water levels, salinity extent, sediment concentrations (silt and clay), and nutrient loading (nitrogen [N], phosphorus [P], and potassium [K]) were provided by the MDS hydrological, sediment, and water quality modeling. Information on nutrient contents in the sediment are also provided by data from the water quality and sediment field surveys conducted by the MDS in 2014 and compared with information from experimental results in the Vietnamese Delta provided in published references. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.8.2 Methodology summary

A customised Excel spreadsheet-based modelling tool (MDS Agri Model) was developed and calibrated for the impact assessment. This model is based on a parametric method (Hoanh 1996) that is used to estimate the variations in crop yield due to changes in water quantity and quality as impacts of the hydropower cascade development. Weekly water level, salinity and sediment (silt and clay) by commune provided by water and sediment models are the primary model input parameters. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.8.3 Direct impacts

Major direct impacts on agriculture are discussed below. They were ranked by indicator for all three Scenarios and the four Alternatives using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 3.8-1.

- Under all three Scenarios, comparable reductions in rice and maize yields have been estimated. However, in Scenario 3 when compared to the 2007 baseline there are additional impacts due to reduction of gravity irrigation in both Viet Nam and Cambodia, and salinity increases in the Vietnamese Delta. But, both these impacts are small compared with the impacts of sediment reduction.

- Main impacts on rice and maize production under three Scenarios relative to the 2007 baseline are due to sediment reduction, not inundation; and partially because of changes in salinity and gravity irrigation. Reduction in sediment inputs into communes of Viet Nam and Cambodia shows that the main change is from silt, and little from clay.

- Overall, total rice production in Viet Nam and Cambodia would decline by approximately 552,500 tonnes and 203,300 tonnes, respectively for 10 consecutive years of impacts. However, if sediment reduction lasts longer (up to 50 years), reductions in rice production could reach about 2,432,800 tonnes, and up to 430,100 tonnes in Cambodia.

- Maize production would decline by about 21,700 tonnes (approximately 10%) in Viet Nam and 41,000 tonnes (approximately 21%) in Cambodia.

Table 3.8-1: Agriculture impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7 ranked by level of impact

	Indicator	Scenario 1		Scenario 2		Scenario 3		Alternative 4		Alternative 5		Alternative 6		Alternative 7	
		CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN	CM	VN
Crop Production	Seasonal and annual rice production	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Annual maize crop production	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Crop Area	Rice crop area (ha) for the main crop seasons	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crop Calendar	Crop windows and period of rice cropping as limited by inundation and salinity, focus on Vietnamese Delta	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes:

1. 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact
2. CM = Cambodia; VN = Viet Nam

- Similar to Scenarios 1, 2 and 3, under Development Alternatives 4 through 7, the primary impacts on agriculture (rice and maize production) are also due to sediment reduction. The largest impact is seen under Alternative 6. Impacts associated with Alternatives 4, 5 and 7 are relatively minor. In Viet Nam, rice production under Alternative 6 could decline by approximately 2.3% and declines in maize production could be as much as 10%. In Cambodia, rice production under Alternative 6 could decline by approximately 4% and declines in maize production could be much higher (29%).
- Overall, agricultural impacts are projected as none to low for the four Development Alternatives (Table 3.8-1).

3.8.4 Indirect and secondary impacts

Indirect and secondary impacts could include impacts on livelihood and social well-being due to agricultural losses. The abuse of fertiliser application would also increase the cost of production, which in turn may reduce the farmer's earnings. The values of these indirect and secondary impacts on the economy of the Vietnamese and Cambodian Mekong Deltas are estimated in the economic analysis.

Additionally, the continued and anticipated increase in over application of fertilisers would be anticipated to have adverse long-term environmental impacts; although difficult to predict or quantify at this point in time.

3.8.5 Recommendations for future studies

A range of future studies could greatly increase the ability to anticipate and prepare for impacts to agricultural production. The following recommendations are identified by indicator(s).

Crop Yield:

- Refining the model with more details and grouping analysis to determine real diversity.
- Collect more data on soil profiles relative to crop varieties and yield.
- Collecting time series data and running the model for multiple years would strengthen future cumulative impacts analyses.

Crop Yield and Area:

- Collecting time series data for water conditions and running the model for multiple years to strengthen future analyses.
- Crop Yield and Calendar.
- Strengthening inventory data at commune and district levels.

Crop Yield, Calendar and Area:

- Consult additional expertise in each of these indicators to improve selection of information for use in modelling.

3.9 Economics

3.9.1 Input data

The input data used in this analysis includes the estimated changes in fishery and agriculture by product and several economic parameters that translate these physical measures of loss into monetary ones. Monetary measures of impacts for navigation services are developed from the potential loss in revenue from lower paddy production that would have likely traveled by vessel. The economic parameters include producer prices and costs, profit rates, labor productivity, and macroeconomic multipliers. Economic estimates of impact are accordingly developed in conjunction with each of the hydropower development Scenarios and sensitivity analyses on hydrological and operational conditions.

Economic parameters are developed from governmental sources where possible. These data are supplemented, as needed, with results from value chain surveys of fishers and farmer, which have been conducted in the region by local researchers. Data on economic multipliers, which account for economic impacts to members of value chains beyond producers, are taken from published economic analysis of the Cambodian economy and developed in this project for Viet Nam based on GSO data. Economic valuation of ecosystems services relies on published results of a meta-analysis of values of Asian wetlands. Altogether, these data provide a sound basis for estimating the total average conditions in Cambodia and Viet Nam. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.9.2 Methodology

Standard economic analysis methods are undertaken in this analysis to estimate gross revenue, income, labor demand, total economic impact and GDP. In accordance with the estimated physical changes in production from each sector (described above), the estimated economic value is based on the hypothetical condition as if dams were present in the year of evaluation. The value of impact is assumed to be realised once the full effect of dams on physical production would be expected to occur. For example, the reported agricultural production impacts are estimated after the sediment reductions have accumulated for 10 years. Fishery losses to migratory fish could take a similar length of time. The estimated losses are estimated for a single year's level of impact.

Efforts have not been made in the present study to forecast losses of value over time and then discount these losses to present value terms – an approach used in benefit-cost analysis. Accordingly, these results differ from those produced by the BDP2 and SEA studies. A benefit-cost analysis approach was not undertaken in the present analysis because the purpose was different. In particular, this study aimed to fill in gaps in understanding the economic impacts to production sectors and livelihoods Viet Nam and Cambodia from hydropower investments made upstream. Still, the annual losses in farm and fish income from the present study could be used for such purposes in future analyses. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.9.3 Direct impacts

Economic impacts under all three Scenarios were generally similar in magnitude and location. The only main difference arises with the dry year/drawdown conditions of Scenario 3, when reductions in water flows enable salinity intrusion to reach new farming areas further inland and cause a reduction in productivity.

Key impacts for Viet Nam include the following:

- Agricultural impacts are concentrated in districts and communes in An Giang and Dong Thap. The predicted declines are due primarily to the loss in natural nutrients transported by sediment. The estimated number of "Highly affected" communes, defined as losing over 10% of net income, amounts to more than 70 in An Giang and another 30 in Dong Thap. Among these sets of communes alone, the average decline in net income exceeds 20%, and the hardest hit communes could witness over a 50% decline in net income. The impacts to communities like these are discussed in more depth in the livelihood section.

- The economic impacts to the inland catch fishery sector are likely to be severe, especially due to the loss in white fish species. The loss in gross revenue in this sector could exceed 12,000 billion Vietnamese dong (VND), or approximately 575 million (United States dollars) USD. This loss represents a 48% level of decline from baseline fishery value. There would be a corresponding change in incomes of fishers. On the other hand, aquaculture production may be only marginally impacted by hydropower development.

- These impacts do not account for the corresponding mitigating actions that fishers and farmers in these areas would undertake measures to mitigate and adapt to these changing conditions.

- Impacts to navigation services are likely to be relatively minor because while a significant share of paddy is transported via water, most of the channels will remain passable for most of the year. Some vessel operators could however observe a decline in paddy products being shipped from An Giang and Dong Thap, where production is predicted to decline, unless farmers take mitigating actions.

- Overall, total potential losses across fishery and farming sectors amount to about 5,200 billions VND of GDP in the Vietnamese Mekong Delta region. These impacts on GDP capture direct impacts to producers, as well as indirect and induced impacts to processers, traders, transporters, and retailers of these farm and fish products. Also, it is possible that economic losses in fishery and farming sectors would have other indirect, knock-on impacts on the health and social well-being of the Delta residents.

- The value of losses in ecosystem services could potentially reach 380 billion VND per year.

Key impacts for Cambodia include the following:

- In Cambodia, inland fisheries contribute 8-12% to the national GDP. The estimated losses in production, especially white fish, could lead to a 50% decline in the value of the fishery sector. The impacts of this level of loss would be devastating to rural economies that are directly dependent on catching fish for income, employment, and nutrition. Impacts to aquaculture would be minor but its level of productivity would not be large enough to make up for the loss in wild catch.

- The farming sector in the impact assessment areas of Cambodia are also dominated by paddy, which depend on the natural floods and nutrient-laden sediments. Losses are concentrated in the provinces of Kandal and Kampong Cham and a number of communes within them. Losses in the hardest hit areas could lead to an over 30% decline in production and income.

- Overall, the combined losses to the fishery and farming sectors in Cambodia could lead to a 1,470 billion Cambodian Riel decline in national GDP.

3.9.4 Indirect and secondary Impacts

Changes in production, especially at the level predicted in highly impacted communes or fishing dependent communities, could lead to a variety of follow-on effects. For example, losses in wild caught fish could lead to corresponding increases in prices. Increased producer prices could in turn lower the direct income loss for fishers (as compared to a case when prices are fixed for the same level of production), but consumers would end up paying higher prices. This analysis has not attempted to trace such types of market effects but they are likely to occur in the most deeply affected areas.

At the same time, it is reasonable to expect that farmers and fishers alike will make investments and adjustments necessary to maintain their production and net incomes as much as possible. Farmers, for example, could increase costs by adding fertiliser to make up for the losses in natural nutrients in the soil. These farmers though would not likely be able to pass their costs on to consumers because the hardest hit areas only represent a relatively small fraction of total production in the region.

Another outcome from the loss in white fish could also affect the market. As discussed above, there is some chance that the biological population dynamics within the entire fishery could reduce the full effect of the lost value of a white fish could be mitigated by the natural increased availability of other fish at the same or lesser value. These types of analyses which would account for the likelihood and extent of these types of adjustments in production systems have not been fully implemented in the analysis.

3.9.5 Recommendations for future studies

The dataset of economic value and activity developed in this analysis is at an unprecedented geographical scale and depth, especially for faming systems and employment. Greater certainty is available from the data provided in Viet Nam but some questions remain in relation to fishery value and activity. In Cambodia, a number of uncertainties exist in data completeness and quality. These data may still be the best available from governmental sources.

This analysis has attempted to develop a highly quantitative foundation for understanding the impacts across the country. While this approach has led to successes in estimating likely impacts, the results depend on the quality of the data. Weaknesses in the data, such as inaccurate baseline conditions, could lead to erroneous results – either over- or under-estimated outcomes. Moreover, even if commune-level impacts are reasonably accurate, the consequences of these impacts could differ among the fishers and farmers, especially those with fewer means to adapt. Since producers differ in their abilities and conditions for generating revenue and income from their labor, the outcome predicted in this analysis may be insufficient in capturing the real effect to them.

For farmers, this depends highly on their cultivated area and for fishers, their use of equipment. The data available for this analysis did not attempt to distinguish the range of impacts to producers are different ends of the productivity spectrum. In addition, it may be noted as well that the level of detailed information on fishery production, by type of fish, location and value is particularly weak. The data were compiled from a variety of sources and expert judgment was required to determine how best to utilise these data.

As such, the following studies are recommended to strengthen future impacts analyses:

- Estimates of income as a percentage of earnings for paddy and fish production are lacking and this factor influences both per capita and total income. This factor is used to estimate income based on the overall measure of gross revenue. Studies to address this data gap would strengthen future analyses and follow on policy measures to assist adaptation efforts.

- Labor productivity for fishing and farming is unknown. This factor is used with changes in production to determine the impact on labor/employment demand. Studies to quantify this factor would strengthen future analyses.

- Analyses of farming systems in the hardest hit communes to better understand how dependent farmers are on natural nutrient loadings, especially in relation to their scales of production.

3.10 Livelihood

3.10.1 Input data

Historical data on population at the commune level were obtained from government agencies in Viet Nam (GSO), Cambodia, Lao PDR, MRCS, and international/regional organisations. Data on water level levels, salinity concentrations were provided by the MDS hydrological, and water quality modeling. Therefore, the available database and knowledge at the study meets the required sufficiency and quality for modelling and related analyses. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.10.2 Methodology

The assessment method was based on established principles previously used by the MRC to conduct a Social Impact Monitoring and Vulnerability Assessment within the LMB to provide data for preparing the BDP2 (MRC 2011). The Social Impact Monitoring and Vulnerability Assessment included a series of social impact indicators aimed at reflecting current socio-economic conditions and the extent of people's dependence on water resources. It was mainly focused on the link between people and water resources, particularly fish, OAAs, irrigation, and riverbank cultivation in the LMB.

The MDS assessment also included use of customised Excel spreadsheet-based modelling tools, which were used to estimate commune-level changes in daily/weekly water levels, and salinity concentrations. Input data for these spreadsheet tools were provided by MDS hydrological and water level quality model simulations. Livelihood indicators were then linked to conduct an analysis on the impact of changes in flows, flooding patterns, and salinity incursion at the province and commune levels. For additional information, refer to the MDS IAR, Volume 2, Chapter 3.

3.10.3 Direct impacts

The major direct impacts on livelihood of the three Scenarios are summarised below. They were ranked by indicator for all three Scenarios and the four Development Alternatives using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 3.10-1.

Overall, significant livelihood impacts are concentrated in specific sets of communes in Cambodia and Viet Nam, depending on the indicators (i.e., changes in salinity impacts on communes at the salinity intrusion fronts and water level drop in areas close to the main channels and near the Cambodian border). Fishery impacts could, however, occur throughout the region where inland fish are caught. The numbers of people affected and the degree of impact also depends on the indicator and can differ among Scenarios, as discussed below.

Salinity is an issue for 7.4 million people throughout the IAA in Viet Nam. In normal years, the hydropower dams could make additional 1.6 million people affected by an increase in 1 part per thousand of salinity for at least 7 days. Some of these people will experience higher salinity levels for the first time. The number of people affected by salinity increases for other Scenarios and in the dry year/drawdown conditions.

Table 3.10-1: Livelihood impacts under Scenarios 1 through 3 and Development Alternatives 4 through 7 ranked by level of impact

Key Indicators	Sub-Indicators/Parameters	Scenario 1		Scenario 2		Scenario 3		Alternative 4		Alternative 5		Alternative 6		Alternative 7	
		CM	VN	CM	VN	CM	VN	CM	CM	VN	CM	VN	CM	VN	VN
Flood Impact (0.5 m and in 10 continuous days)	Area affected	1	1	1	1	1	1	0	0	1	0	1	1	1	0
	Population affected	1	1	1	1	1	1	0	0	1	0	1	1	1	0
Water Reduction >15cm	Area affected	3	4	3	3	3	4	0	3	0	3	0	3	0	3
	Population affected	3	4	3	3	4	4	0	3	0	4	0	4	0	4
Salinity impact (1 ppt over 7+ days)	Area affected	0	4	0	4	0	4	0	1	0	1	0	4	0	4
	Population affected	0	4	0	4	0	4	0	1	0	4	0	4	0	4
Income / Capita of farmers	Impact in Highly Affected Areas	4	4	4	4	4	4	1	1	4	4	4	4	4	4
Income / Capita of Fishers	Impact on all Fishers	4	4	4	4	4	4	0	0	1	0	4	4	1	0
Food Security	Annual Average Consumption of fish per HH	4	4	4	4	4	4	0	0	1	0	4	4	1	0

Notes:

1. 0 = no impact; 1 = low impact; 2 = moderate impact; 3 = high impact; 4 = very high impact
2. CM = Cambodia; VN = Viet Nam:

Water levels in Viet Nam, defined as a change of 0.5 m over 10 days, pose slight impacts in normal years, accounted for approximately 100,000 to 300,000 people (around 1% of the impacted population in the baseline). On the other hand, under dry year/drawdown conditions, tens of thousands of people could face constraints in water supply because of possible water level drop at about 0.15 m. In flood season, the impacts are relatively modest.

Similarly, in Cambodia, changes in flood levels are insignificant. However, up to 1 million people could be affected by a 0.15 m drop in water levels during low flow periods in Scenario 3. Larger numbers of people would be affected in the dry year/drawdown conditions.

Impacts associated with food sources are likely to cause higher and longer effects on livelihoods. In Viet Nam, the nearly 360,000 tonnes of lost fish production, could translate to a decline of 28 kilograms (kg) per fisher – for about 1.2 million fishers, assuming that they would typically take home about 9% of their catch. This level of decline, if applied across all consumers in the region, would translate to a 10 kg decline in fish availability. These losses would require other fish (aquaculture) or other protein sources, which would in turn cause further land use and environmental impacts.

Reductions in food sources in Cambodia would be at a larger degree because their higher level of dependence on fish – at around 47 kg/person. The 42% loss of fish consumption leads the consumption rate down to 21 kg/person. Fishers themselves, who consume an even greater quantity of fish, stand to lose approximately 58 kg per fisher, annually. Other impacts are listed below:

- Income loss would occur for both farmers and fishers. In Viet Nam, farming income could decline by nearly 28% at the highly impacted communes of An Giang and Dong Thap.
- The income loss could affect poor farmers accounted for 7% and 14% in those communes in An Giang and Dong Thap, respectively. The loss of fisher income in Viet Nam could rise to 50% of normal earnings from the fishery.
- In Cambodia, impacts would also disproportionately affect poor rural households. The estimated loss in fishery income could be as high as 47% for an estimated 400,000 households of the country. Among the 2.7 million farmers, incomes could decline by approximately 4%, but impact the provinces of Kandal and Kampong Cham much worse.

3.10.4 Indirect and secondary impacts

As discussed in the fishery and agriculture impact assessment sections, direct losses in fishery and agricultural production indirectly affect livelihood of the resident populations. Fishery losses could affect hundreds of thousands of people in both Cambodia and Viet Nam with reduced income and food for consumption. In addition, losses in farming income could exceed 20% in many of the riparian areas of Dong Thap, An Giang (in Viet Nam) and Kandal and Kampong Cham (in Cambodia).

Potential capture fishery impacts would indirectly affect the food security, livelihood, social well-being, and economic status of a large segment of the population in the IAA, which relies, either part- or full-time, on fishing and associated occupations. After the fish are caught, they are passed on to collectors, transporters, wholesalers, processors, market sellers, and restaurant owners, and monetary value is added at each step. This monetary value directly increases the participant's purchasing power, allowing more to be spent on food, which in turn increases food security. Adverse impacts on capture fisheries would therefore translate into substantial economic hardships for large groups of individuals and families and at worst may lead to people migrating from rural to urban areas in search of new or different sources of employment.

Replacing the current contribution of wild-capture fish protein with other sources of protein is likely an expensive and challenging undertaking. In other words, the indirect impacts of capture fishery losses on food security simply cannot be easily and fully mitigated. For those families that are either already food insecure or on the brink of it, a reduction in the availability of fish and OAAs, which are their daily staples, could increase malnutrition. People's health could suffer and illness could become more common, and poverty may increase. Poorer families with low resilience capacity will probably bear the major brunt of the impact.

3.10.5 Recommendations for future studies

Flooding and salinity intrusion can affect households in a variety of ways depending on the severity and conditions of homes. Additional research should be conducted to assess vulnerability and coping mechanisms in the worst affected areas.

Health, and it's correlation with economy and livelihood, has been alluded to throughout this study. However, an in-depth health impact assessment was outside the scope of the MDS. Such a study is recommended in order to identify specific anticipated health-related challenges and position the government to proactively address them before they arise.

4 Impact Interrelationships

The single impact that is anticipated to have implications across the greatest number of resource areas in the IAA is the reduction of fisheries production. Predicted capture fishery impacts would directly impact biodiversity, and indirectly affect the food security, livelihood, social well-being, and economic status of a large segment of the population in the IAA, which relies, either part- or full-time, on fishing and associated occupations.

After the fish are caught, they are passed on to collectors, transporters, wholesalers, processors, market sellers, and restaurant owners, and monetary value is added at each step. This monetary value directly increases the participant's purchasing power, allowing more to be spent on food, which in turn increases food security. Adverse impacts on capture fisheries would therefore translate into substantial economic hardships for large groups of individuals and families and at worst may lead to people migrating from rural to urban areas in search of new or different sources of employment.

Replacing the current contribution of wild-capture fish protein with other sources of protein is likely an expensive and challenging undertaking. In other words, the indirect impacts of capture fishery losses on food security simply cannot be easily and fully mitigated. For those families that are either already food insecure or on the brink of it, a reduction in the availability of fish and OAAs, which are their daily source of animal protein, could increase malnutrition. As a result, the general health of the population could suffer, allowing illness to become more common and poverty to increase. Poorer families with low resilience capacity will probably bear the major brunt of the impact.

While aquaculture might provide some relief from the impacts of reduction in fisheries, aquaculture operations in the Vietnamese Delta could be indirectly affected due to loss of coastal fisheries as a result of the decline in sediment and nutrient loading and deposition. This is because the Delta aquaculture sector is dependent in part on protein from marine 'trash-fish' to feed the aquaculture fish for feedstock. This limits the potential for aquaculture to compensate for reductions in fisheries production.

It is possible that at the basin-level loss of fisheries in the IAA would be compensated for by an increase in reservoir fisheries. But it is likely that non-native invasive species and low-value fish would flourish in the reservoirs, and while this additional biomass would compensate for some lost fishery production, it is not likely to fully compensate for the loss of riverine stocks. Also, monetary and food security benefits from this type of compensation will mostly accrue in areas closer to the dams and reservoirs. Fishery communities in the IAA, which is a long way from even the lowest dam in the Cascade, will most likely see no benefit from any increase in reservoir fisheries.

Other interrelationships among resource areas include those of navigation and agriculture across economics and livelihood. The anticipated changes to navigation would result in increased navigation costs in certain river segments and sectors. This would directly and indirectly impact the economics and livelihood of not only those people reliant on small boat navigation, but the wider population dependent on goods moved via this riparian system. These impacts would be woven across the resource areas similar that described for the loss of fisheries production above.

On one hand, anticipated losses in agricultural production might be partially minimised because farmers are can modify agricultural practices to overcome adverse conditions. For example, loss of natural fertiliser loading could be almost immediately compensated for by external application of additional fertilisers. However, this would increase the cost of production, which in turn would reduce the farmer’s earnings. For farmers already at or near the poverty level, the requirement to fertilise to maintain even a reduced level of production could be an insurmountable challenge resulting in the loss of this livelihood, migration to urban areas, and associated stresses.

5 Uncertainty Assessment

The MDS was conducted using a series of science-based models and analyses. To implement these models and complete the analyses, the best available data describing past and current conditions were used and a series of assumptions about future conditions were developed. In other words, the projected impacts are based on a robust combination of quantitative and qualitative analyses of the best available data combined with advanced modeling systems and customised impact assessment tools.

However, the actual impacts may well be higher than projected because of varying levels of uncertainty associated with the data and method, the cumulative effects of other natural phenomenon (e.g., climate change, sea level rise), on-going changes in the LMB (land subsidence, and deforestation), and the uncertainty related to how the natural systems will respond to the major disruption in the LMB system. The major sources of uncertainty are briefly discussed below.

- **Data**: Modeling input has attempted to apply the best available information for estimating impacts. These impacts are intended to provide a perspective on the total average conditions; that is, the true impact to an individual fisher or farmer, say, could be higher or lower than the estimated impact. These data also include the currently available information on dam design and operations – information that continues to change. The data used in the analysis includes both single point and values that are averaged across several data sources. The data come from the MDS field studies, governmental statistics and other research. Uncertainty in data values arises because in most cases, a series of data points can only provide a snap shot of the actual variability of conditions across time and space.

- **Methods**: The methods for estimating impacts use widely accepted, science-based practices. At the same time, given the uncertainties and gaps in available data, alternate analytical approaches are used where necessary. For example, no scientifically validated standard methods are currently available to directly correlate loss of nutrients with changes in biological productivity. Accordingly, there is an inherent uncertainty in using alternate surrogate approaches.

- **Future Conditions**: The projected impacts are based on a comparison to recent and current baseline conditions. In reality, the dams will be constructed over several decades, and as such, the baseline will change over time. The LMB is undergoing rapid economic growth, and there are several anthropogenic factors such as increasing urbanization, deforestation, and sand mining could compound the projected impacts. In addition, projected impacts from climate change, sea level rise, and vertical land motion (subsidence) represent additional external threats to the region Accordingly, the interpretation of these results, while they represent the best available assessment of impacts for a specific hydrologic year of analysis, creates additional uncertainty related to developing appropriate mitigating actions.

- **Other Impacts**: The MDS IAA is located to the south of the lowermost dam in the proposed cascade. It is acknowledged that severe direct impacts are likely to occur within the footprint of each hydropower project but are not included in this analysis. As individual projects are built and operated, indirect impacts from individual projects will be compounded spatially and temporally and will influence direct impacts projected by the MDS for the

IAA. The trend and timing of such indirect influences cannot be projected with accuracy. It is also important that the results from these analyses are carefully and clearly communicated to articulate what aspects of the impacts are included and which ones are excluded from the project scope to avoid confusion.

- **Dynamic Feedback**: It is well established that biological resources are adaptive by nature and that over time, the LMB biotic communities will change in response to at least some of the projected impacts. However, the proposed cascade establishes a multiple, almost complete barriers across the river, which has no equivalent in the recent geological history of the basin. Therefore, while a certain degree of reduction in the projected impacts through natural change and adaptation can be assumed, the magnitude and direction of those changes are hard to project and they may not necessarily compensate for all projected impacts.

It is acknowledged that in a complex analyses such as that conducted by the MDS, uncertanity levels tend to propagate through the study. For example, uncertainity in modeling output will add on to the uncertainity associated with input data for directly impacted resource areas such as fisheries, navigation, and agriculture. This will in turn create an even wider range of uncertainity in projected indirect impacts such as livelihood and economics.

6 Avoidance, Mitigation, and Enhancements

6.1 Avoidance

In the ideal case, constructing no new dams along the Mekong River mainstream avoids impacts from hydropower development.

A potential option for mitigating or reducing the impact of hydropower development in the LMB is to undertake a full options analysis on the location of the proposed dams and consider the development from a wider ecosystem services delivery approach (Cowx and Portocarreo 2012).

It is possible that the dams could be constructed in different locations or using different scales of development to achieve power production with less environmental degradation and social impact. These alternative locations and/or scales are currently being investigated by the Natural Heritage Institute. The concept is to reduce ecological impact of the dams through alternative design and location solutions. Moving certain dams to alternative sites potentially provide the benefit of being able to generate hydropower while reducing the impacts on the Mekong River mainstream and the Delta.

However, no specific alternatives are identified at present that would allow for a detailed assessment of the reduction in impacts, or “relief” that such scenarios might provide.

6.2 Mitigation

6.2.1 Design

6.2.1.1 Sediment flushing and sluicing facilities

All the dams in the main stem of the Mekong River, except for the proposed Sambor Dam, are small compared to the annual flow of water in the river. It is therefore considered feasible to implement both sluicing and drawdown flushing at all these dams to maximise sediment passage. Previous studies on the Xayaburi Dam (Thorne et al. 2011) indicate that sediment sluicing and drawdown flushing can be implemented to significantly increase sediment passage.

Equipping these dams with well-designed sediment management facilities, particularly large low-level outlets will ensure that most of the sediment entering the reservoirs will be passed through to the Mekong Delta over the long term when implementing sluicing and drawdown flushing techniques.

Mitigation that will substantially reduce the trapping of sediment in the proposed Cascade by designing the dams to enable implementation of sluicing and drawdown flushing to pass most of the sediment towards the Mekong Delta is therefore considered feasible.

The effectiveness of sediment flushing and sluicing has been estimated using the Mainstream Sediment model for the various scenarios.

6.2.1.2 Fish passes

In the Mekong River, the migration of fish is characterised by a high biomass, high diversity and a wide size range of fish species, including small cyprinids from 15-30 centimeters (cm), large cyprinids and pangasiids that are 60-150 cm, and very large species up to 150-300 cm long. These species include fish that specifically use the surface, mid-water and bottom (benthic) zones, as well as those that specifically use the thalweg (deepest channel in the river). The smaller species often have weak swimming abilities and require lower water velocities in fish passes, while the larger fish have a greater swimming ability but require more space in fish passes.

These fundamental biological characteristics are critical to consider in developing effective fish passes. The designers of existing fish passes in large tropical rivers have generally 1) underestimated the upstream migratory biomass, and have undersized fish passes, including underestimating the required flow and space; 2) overestimated the swimming ability of smaller fishes, with high water velocities that these fish could not negotiate; and 3) underestimated the diverse behaviour of migratory fish, which swim to both sides of spillways and at various depths and locations along a powerhouse.

Effective fish passage can be defined as that which allows viable populations of the target species to be maintained. Some authors have suggested that in quantitative terms, effective fish passage is that which caters to at least 95% of each migratory fish species at all life stages (eggs, fry, juveniles, adults) over the range of flows in which migration occurs. The situation for each dam is unique in terms of hydrology, channel morphology, and the nature the of local and transient fish populations; therefore, 'off-the-shelf' passages are unlikely to be effective. Fish passages will only be effective if their design takes all local conditions into account (i.e., successful designs are likely to be site specific).

Broadly speaking, fish passes across dams <6 m high (low-level passages) are often more effective than those across higher dams (high-level passages). Indeed, passage around higher dams is rarely effective, especially if the passage facilities have to accommodate large numbers of fish in a short period of time, as is likely to be experienced in the Mekong. Low-level fish passages can be built into the structure of the dam as fish ladders or rock-ramp passes. Traversing the low-level passage is also easier because the gradient of the climb over the dam is generally low (less than 1:20), and consequently within the physical capability of the fish. So long as they are designed to account for species diversity and numbers, low-level fish passages can be effective.

By contrast, passage at high level dams (>10 m high) requires considerable engineering of the fish passageways, including the approaches and exits. The height of the dam generally means that fish have to be raised (through lifts or a system of locks), diverted (through fish ladders or artificial or modified bypass channels), or transported (trap and transport) around the barrier. These methods tend to be specific for certain fish species and can handle only limited numbers of fish. Passages for higher dams are mostly found in temperate rivers, where the numbers and types of fish migrating are relatively small. The most successful passages (fish ladders) have been built for fish that have innate jumping ability, such as salmon that 'leap' waterfalls as part of their normal migrations. Such passages would not be usable by many of the migratory fish species in the Mekong.

In summary, fish passage solutions for the large scale dams on the Mekong can at best be considered marginally effective. This is because:

- Facilities for upstream passage are not yet proven and there are several design features that need to be overcome, including attraction to the fish passage entrance, adequate flows through the pass at all time of the year, size of fish pass needs to be substantially larger than existing passes and need to be of a shallow gradient to allow all sizes and species to bypass the barrier (Schmutz and Mielach 2015).
- There are currently no options for facilitating the downstream drifting of larval and poor swimming juvenile stages over the extended distances (several km) experienced in most Mekong mainstream reservoirs. Consequently recruitment will likely be lost as the reservoir acts as a sump for downstream drifting life stages.
- Despite the name, 'fish-friendly' turbines are not available. All designs suffer for the same fish mortality problems associated with fish passage through the turbine, namely, blade strikes, pressure stress and shear stresses. To date no large-sized turbines have been developed, tried and tested globally that reduce fish mortality to levels deemed necessary to not compromise fish recruitment success (Halls and Kshatriya 2009) and where progress has been made it is mainly for salmonids. A possible candidate is the Aulden turbine but this has never been tested commercially (Neilsen et al. 2015).

6.2.1.3 Bypass channels

Possibly the best solution for allowing fish to migrate in the Mekong is to include bypass channels as part of the detailed design. Bypass channels should be explored as an option if the systems allow and there is water available to maintain flow through the channel at all times during the migration window – which appears to be throughout the year in the Mekong, but with periods of more intensive movements around the flooding cycle.

6.2.1.4 Turbine design

Improved turbine design has resulted in only marginal reductions in fish mortality. Therefore, improved turbine design does not offer any effective means to reduce fish mortality. However, Alden type turbines may be considered for installation, and subsequent monitoring of their effectiveness should then follow to potentially improve turbine design and functioning.

6.2.1.5 Screens and louvers

An effective way to improve survival of downstream migrating fish is to direct the fish away from the intakes using screens or louvers and then through systems which bypass the turbines. Directing more of the flow across spillways may also help reduce mortality. These measures may, however, reduce the efficiency of the turbines and the capacity of the generating plant, particularly in times of low flow.

6.2.1.6 Spillway fall/slope design

Minimising the fall of the spillway is one means to reduce mortality. Larinier and Travade (2002) reported that significant damage occurs to fish when the impact velocity of fish on the water surface below the spillway exceeds 16 m/s. This velocity is reached by water falling from a height of 13 m. Injury and mortality rates increase rapidly with higher fall heights and reach 100% for falls of 50–60 m. Ogive or 'ski-jump' shaped spillways are preferable since this shape tends to minimise abrasion to fish. Ensuring a sufficient depth of water at the base of the dam with no submerged baffles or rip-rap will help to reduce mortality rates.

6.2.1.7 River bank protection

The presence of upstream dams will cause bed scour downstream. Bed transport simulations of river bed erosion just downstream of Kratie indicates that up to 5 m deep scour could occur due to the reduction in sediment load in the Mekong River resulting from sediment deposition in upstream reservoirs. The simulations predict that river bed degradation will progressively move downstream at a rate of approximately 1.5 to 2 km/yr. Concurrent with such degradation, it is reasonable to expect river bank failure. River bank protection would be needed to prevent land loss due to river bank erosion as an integrated part of the dam design and construction. However, the introduction of river bank erosion protection may in itself have some adverse, local impacts that have to be considered in the design.

6.2.2 Dam operations

6.2.2.1 Flows

Impacts on water levels and water flows from the planned Cascade mainly originate from the considered operation, from hydropeaking during daily operation to the possibility of increased power production over shorter periods during the dry season, especially in dry years.

Options for mitigation include deferring from these types of operations, and adapting operations to best mimic the present, natural variations in the flow of water in the Mekong mainstream. Adaption of the operations could include the implementation of restrictions to the water fluctuations within certain limits. Besides, restrict the rate of down-ramping such that the downstream river stage does decrease only with a certain rate.

Besides, determine mandatory minimum environmental flows according to best available international practice.

6.2.2.2 Sediment

Sluicing and flushing operations

Sluicing operations intend to pass as much sediment through a reservoir as possible, without deposition. Flushing, on the other hand, is aimed at removing sediment previously deposited in a reservoir. Sluicing, as indicated below, can be implemented on an annual basis while flushing may only be used at longer intervals.

During the low flow season, the focus is on power generation and releases of environmental flows. The flows are therefore directed towards the powerhouse for power generation and appropriate amounts of environmental flows released. The sediment load of the Mekong River is normally very low during the low flow season and sediment passage by using sluicing is not a major concern. However, sediment contained in the environmental flows will be bypassed.

Implementation of sluicing occurs at commencement of the monsoon passing sediment downstream while concurrently generating power. The sediment transport capacity of the flows in the Mekong River is usually at its highest during the beginning of the monsoon season. If the gates in a dam are opened it will generally create high sediment transport capacity, thereby passing as much sediment through the reservoir as possible and reducing the amount of sediment that may deposit in the reservoir. By placing the intakes to the turbines at a low level, it will be possible to generate power during times when sluicing is implemented. Once the high sediment loads have passed through the reservoir, the gates at the dam are closed. Once the gates at the dam are closed energy generation continues.

Drawdown flushing may only be implemented when it becomes necessary to remove sediment that has deposited in the reservoir. When drawdown flushing is implemented it will not be possible to generate power. The reason for this that drawdown flushing requires the water surface elevation in the reservoir to be completely drawn down, matching downstream tailwater conditions. The intent with drawdown flushing is to create river-like flow conditions in the reservoir that have high enough sediment transport capacity to re-entrain previously deposited sediment and transport it downstream. Drawdown flushing is usually implemented during the non-monsoon season, and will have to be carefully crafted to generate enough sediment transport capacity to erode deposited sediment.

The application frequency of sluicing and drawdown flushing differ. Sluicing should be implemented on an annual basis. The reason for this is that this technique focuses on passing sediment through the reservoir without deposition. For it to be successful it is therefore necessary to implement it on an annual basis. Flushing, on the other hand, may only be implemented every 5, 10 or 15 years depending on the rate of sedimentation, acceptable sediment concentrations being passed downstream, and on economics of the project.

6.2.3 Resource-area specific mitigating measures

6.2.3.1 Fisheries and Biodiversity

- Operate mainstream dams to maintain passive downstream drift of fish larvae and other aquatic organisms, and the upstream and downstream passage of fish. The will probably require committing a substantial volume of water during the dry season to maintain appropriate flow rates through reservoirs and flow volumes through fish passages.
- Minimise daily or other rapid fluctuations in water levels downstream of the dams.
- Equip dams with well-designed sediment management facilities, such as large low-level outlets, and implement sluicing and drawdown flushing techniques to increase the transport of sediments and nutrients. Periodically flush or otherwise operate dams to maximise downstream transport of nutrients and organic matter. Sediment flushing must be implemented to minimise adverse impacts on downstream fish and other aquatic species.

6.2.3.2 Navigation

Projected impacts could be reduced through adoption of a safe operation regime across the Cascade that does not produce large fluctuations in discharge and water levels. At Kampong Cham, a weir could be constructed to re-regulate the flows and water levels downstream of Sambor dam as well as to minimise water level fluctuations. If hydropeaking operations are conducted at Sambor, then from Kampong Cham to Phnom Penh, a warning system should be installed to alert people when high flows are released downstream.

6.2.3.3 Agriculture

The following measures could be considered for avoiding and minimizing projected agricultural impacts:

Change of water level that causes additional pumping volume and cost

Changes in water levels that may cause additional pumping volumes and costs are most likely to occur in the Summer-Autumn (SA) crop under Scenario 2 in 2007 and in Winter-Spring (WS) and Autumn-Winter (AW) crops under Scenario 3 in 2007.

- Non-structural measures: adjustment of the crop calendar either earlier or later only helps at limited locations where the average water level is close to ground surface level during certain periods. Obviously adjustment of the crop area is a possible measure; for example, expand WS crops under Scenario 2, 2007, or SA crops under Scenario 3, 2007 to compensate for the losses due to this impact, or even expand the crop area of the same affected crops but at the non-affected locations.

- Structural measure: improvement of pumping capacity is needed to mitigate the water volume flowing into rice fields by gravity under the Baseline, 2007, mainly in Long An, Dong Thap and Kien Giang.

Change of salinity that causes yield reduction

Changes of salinity that may cause yield reduction are most likely to occur at some communes in SA crops under Scenario 3 in 2007 in Tra Vinh and Kien Giang provinces.

- Non-structural measures: Adjustment of the crop calendar to later can help to avoid the period when water has high salinity but become fresh later in Tra Vinh; but it cannot help in the case of long salinity periods as at some communes in Kien Giang. Application of salt-tolerant varieties is also an option, assuming that yield and quality of salt-tolerant varieties are not much different than non salt-tolerant varieties. Another option could be to expand the WS and AW crop area, or even SA area at non-affected locations to compensate for the production losses.

- Structural measures: Improvement of salinity control systems and irrigation systems to intake more fresh water to the affected area could be done, but only at communes close to fresh water sources.

Change of sediment that causes lower nutrients from sediment

The impacts of lower nutrients from sediment may not occur in reality because of the overuse of fertiliser currently applied by farmers. With the overuse of fertilisers, yield decline due to sediment reduction only occurs in some communes with poor soils while farmers are applying the same fertiliser rates as at other locations with more fertile soils. Regardless, increased fertiliser use can be considered as an option to mitigate the losses of nutrients due to sediment reduction. Other measures could include:

- **Non-structural measures**: In this case, adjustment of the crop calendar does not help much because it is assumed that the impact is from sediment is accumulated in rice fields; therefore, the effort to take more sediment during the crop season only contributes a minor amount. Adjustment of sluice operations to intake more sediment into rice fields without construction of new sluice and irrigation systems could be an option. Similar to the options to deal with water level and salinity, expansion of crop areas to compensate the losses in production, or change to higher yielding varieties (with similar quality) are possible options.
- **Structural measures**: Construction of new sluice and irrigation to intake more sediment from the river and canals into rice fields is a possibility. However, this option also requires the proper operation of sluice to intake water and trap sediment in rice fields; that may not fully compensate for the reducing sediment because the reduction rate is too high, approximately 56% in Scenarios 1, 2 and 3, 2007.

6.2.3.4 Economics

Avoidance and mitigation of economic impacts typically take the form of policy measures that support prices for producers or recommendations on technology adoption. Identification of specific measures should draw from a careful study of the preferred adaption actions pursued by farmers and fishers. As discussed above, hydropower development-induced impacts to production as analysed here could take 10 years to be realised by producers. Since many other drivers would affect farming and fishing systems over this time period, effective policy measures would build long-term monitoring of producers' needs.

6.2.4 Livelihood

Because livelihood is so closely tied to fisheries and agricultural production in the Mekong Delta, avoidance and mitigation measures applied for those resources would have corresponding impacts on livelihood. Measures to reduce the impacts on water quantity and quality also need to be considered. Those relating to other impacts not fully addressed in this MDS would be studied in later stages.

Further studies are also required to determine how additional avoidance and mitigation measures that could positively influence the livelihoods of residents in the Mekong Delta.

6.3 Enhancement

6.3.1 Dam related enhancements

In principle, there may be a potential for using the planned Mekong Mainstream dams for flood management to reduce the impacts of floods. However, in parallel with the MDS, a Masters' degree study has been conducted under the supervision of DHI to investigate the potential for using the mainstream dams for flood control. The study concluded that the proposed Lower Mekong mainstream reservoirs with the present design have very little capacity for flood control in the Mekong Delta with simulated reductions in the flood peak from 2 to 4% during high floods.

6.3.2 Enhancement measures for the Mekong Delta in Viet Nam

Structural measures

One option would be to adjust design and operation of infrastructure controlling water flows in floodplains to reconnect floodplains and restore degraded habitats, allowing for renewed fisheries production and increased biodiversity.

Further, improving and effectively operating flood protection, saline intrusion control, drainage, and irrigation infrastructure to increase agricultural production is an option.

Non-structural measures

Adoption of non-structural agricultural measures to increase agricultural production is an option. This could be done by expanding crop areas and introducing higher yield crop varieties, in addition to strategic adaptation of the cropping calendar to the annual changes in water availability.

The aquaculture production is still increasing and a further increase is an option to enhance the production.

6.3.3 Enhancement measures for the Mekong Delta in Cambodia

Essentially, potential enhancement measures for the Cambodian part of the Mekong Delta are similar to the measures described for the Vietnamese part of the Mekong Delta, except that salinity control measures are not relevant.

6.4 Monitoring, Performance Criteria and Adaptive Management

Predictions of the performance of the selected dam designs and operation plans are essential for designing the monitoring plans and interpreting the results. If the dams are well designed and operated as planned, and the monitoring results match the predictions, then the predictive models are adequately simulating the important processes. If the monitoring results differ from the predictions, then the models are not adequately simulating all the important processes and need to be modified.

River flow and reservoir storage monitoring should include the upstream and downstream river stage and discharge and reservoir water surface elevation and storage capacity. River bed aggradation or degradation can be monitored from the river stage and discharge measurements.

Reservoir sediment monitoring should include the upstream and downstream sediment loads and annual reservoir bathymetry. Reservoir water quality monitoring should include the upstream, in-reservoir and downstream water quality, including regular measurements of nutrient contents in water and sediments.

Besides monitoring the performance of the dams and the impacts on changes in drivers, it is important to monitor the impact on various sectors as discussed below to ensure that projected impacts are within the predicted ranges.

6.4.1 Fisheries and Biodiversity

- Monitor the upstream passage rates of adult fish and the downstream passage rate of adults and small fish at all mainstream and tributary dams. This monitoring should be designed to evaluate and improve the efficiency of all fish passage devices and to identify fish species that are being adversely affected by hydropower development.
- Monitor the abundance and population viability of migratory fish, the Irrawaddy dolphin, and other vulnerable species. Threshold levels of abundance and viability should be set, and when those thresholds are exceeded, additional conservation measures should be implemented to prevent the extirpation of species.
- Monitor fisheries throughout the IAA to identify changes in species composition, CPUE, and other factors that would indicate a reduction in freshwater and coastal fish yield.
- Measure changes in nutrient transport and deposition, and changes in primary and secondary productivity at selected biodiversity hotspots in the region. This monitoring should include annual measurements of waterborne nutrient concentrations, sediment and nutrient deposition in the floodplain, primary productivity in aquatic and wetland areas, and production of selected aquatic animals.
- Conduct additional aquatic and terrestrial biodiversity surveys throughout the IAA to improve characterization of the biodiversity resources that could potentially be impacted.

6.4.2 Agriculture

- In areas where sediment reduction is likely to occur, monitor the rates of sediment inputs into rice fields with and without diking in areas. This effort should also include measurements of changes in the rate of fertiliser application and rice yield (of different varieties) in those fields to monitor costs of nutrient and sediment losses.
- Conduct long-term monitoring of the effects of changes in sediment deposition on soil fertility. The Cuu Long Rice Research Institute conducted a similar experiment of intensive rice mono-culture from 1986-2003 to study the effects of nitrogen, phosphorus, and potassium from fertilisers to soil

elements, but did not consider the long-term effects of sediment deposition on soil fertility.

- Evaluate the effects of different methods of flood water management on sediment intake and dry and wet season yields of crops in fields with managing flood flows. This evaluation should be designed to better understand the relationships between water management, sediment intake, and crop yield and to identify methods for maximizing sediment deposition on affected fields.

6.4.3 Navigation

- Monitor daily water level fluctuations downstream of dams to identify areas where conditions are unsafe for the operation of vessels or for other uses of the river and the adjacent floodplain. This effort should also include an evaluation of the effectiveness of systems installed to warn vessels and residents of rapid changes in water levels or other unsafe conditions.

- Monitor the rates of erosion, and effects to navigation facilities, in and near areas where an increase in riverbank erosion is predicted to occur.

- Adaptive management would include installation of navigation aids along the river section downstream of the dam to guide vessels to avoid dangerous areas.

If monitoring results indicate that resource management objectives are not being achieved, then the reason should be determined and modified management actions should be implemented to achieve the objectives.

7 MDS Findings and Conclusions

Major findings and conclusions from the MDS impact assessment are presented below:

1. The proposed cascade would result in high variation on the flow regime (both discharge and water levels) with highest levels immediately below the last dam tapering off downstream to low impacts below Phnom Penh.

2. Though low to moderate changes are expected for normal hydrological years, high to very high short-term adverse impacts on river flow regimes would occur as a result of dam hydropeaking operations and dry-season drawdowns for maximum power production followed by filling (potential loss of 10-day water volume at Kratie is 60%, and at Tan Chau and Chau Doc the potential loss is 40%). The river course of Cambodia downstream of the cascade is projected to suffer the highest impacts from fluctuating flows and water level. Amongst the assessed Scenarios and Development Alternatives, impacts on flow regimes of Scenario 3 are the worst.

3. Sediment and nutrient deposition would decrease as much as 65% at Kratie and Tan Chau – Chau Doc and by smaller amounts off the mainstream, potentially causing a substantial decline in biological productivity, reduction in agricultural production, increase in erosion, and a decrease in the rate of buildup of riparian and coastal sites. Scenario 2 poses the most severe impacts on sedimentation and nutrients in comparison to the other Scenarios and Development Alternatives.

4. Salinity intrusion would increase in some coastal areas. Similar to flow impacts, Scenario 3 causes the largest impacts on salinity intrusion.

5. Overall, the proposed mainstream hydropower cascade may lead to an approximate 48 to 55% decline in capture fishery yields in both Viet Nam and Cambodia. The loss is due to the combined effects of decline in sediment and nutrient loading and dam barrier effects.

6. Reduction of fish migration by the dams, especially the most downstream dams in the mainstream cascade contributes to a major loss of fish yield under all scenarios and is potentially exacerbated under Scenario 2 where tributary dams also impede more localised movements of fish.

7. Dams acting as physical barriers will also interfere with the downstream drift of fish and OAA eggs and larvae. This blockage is an important trophic loss because it has the potential to impact secondary productivity within non-migratory fish guilds.

8. After the barrier effects of dams, the next largest impacts to fisheries, including coastal fish production and aquaculture, and to biodiversity including aquatic and terrestrial species composition and primary productivity, is due to reductions in sediment and associated nutrient transport and deposition.

9. From a dam operations perspective, hydropeaking operations are anticipated to cause large daily downstream water fluctuations. Such flow modifications are expected to have serious environmental impacts on the river immediately below Sambor and potentially as far downstream as

Phnom Penh. The regulated flows in this reach could result in losses in fish production, reduction in reproductive output, impedance of upstream migration by adult fishes, and increased difficulty of fishing. There could also be a loss or local extinction of rhithron fish species from the reach around Kratie – the most downstream reach supporting this fish guild. Hydropeaking would potentially severely degrade aquatic and riparian habitat from Sambor to south of Kratie.

10. Many freshwater fish species are confined to the Mekong and Chao Phraya basins in Thailand. Given the level of development in and around Thailand, the Mekong River mainstream has served as a refugium for several regionally endemic species. The proposed mainstream dams may therefore represent complete jeopardy for more than just the five species endemic to the Mekong basin which are projected to go globally extinct as a result of construction and operation of the Cascade.

11. The dams would block the movements of migratory fish and other aquatic species throughout the LMB, potentially causing:

a. The extirpation or extinction of up to 10% of the fish species that occur in the Mekong River of Viet Nam and southern Cambodia

b. Substantial reduction of any surviving species of migratory fish

c. Extirpation of the Irrawaddy dolphin from the Mekong River

d. Reduction in the distribution and abundance of freshwater mussels and reduction of drift of invertebrates.

12. The main impacts on navigation within the IAA would result from a reduction in river channel water depths and rapid water level fluctuations downstream of the lowermost dam. The river section from Kratie to Kampong Kor would be the most highly impacted, especially under dry year conditions. During such periods, larger vessels will face increased transit time, and smaller boats may not be able to operate at all. An increase in transit time would raise potential for delays and most likely result in higher transportation costs. Among the Scenarios evaluated, the greatest impacts are likely to occur under Scenario 3 which includes water diversions in Thailand.

13. While the scale of economic impacts, if measured across the economy of the entire Vietnamese Delta are relatively modest, when assessed for riparian communes the impacts are anticipated to be quite substantial.

14. For Cambodia, the predicted types and levels of impacts would have widespread and substantial impacts to the economy of the country with losses in fisheries affecting an entire national industry of high importance. Farming systems would also incur substantial losses. The scale of these combined losses could reach over 90% of production in some communes, resulting in a complete collapse of production for those communes.

15. Some agricultural areas along and near the mainstream branches of the Mekong River would experience large reductions in nutrients, and impacts to agriculture productivity and the livelihood of people in those areas would be high. Elsewhere, impacts to agriculture productivity and practices would be low to moderate.

16. Salinity impacts of at least one part per thousand over 7 days could be felt by an additional 1.6 million people in the Vietnamese Delta. Salinity worsens with tributary dams, water withdrawals, and during dry year drawdown operations.

17. The combined hydrologic impacts (salinity and water levels) and income and food availability impacts would affect livelihoods for millions of people. In the fishing and farming villages where livelihood impacts are concentrated, the impacts on local income generation from these activities would be dire. In some cases, producers' incomes could decline by 50%. As well, the hundreds of thousands of fishers who normally bring home part of their catch to feed their family could lose half of their total catch – forcing them to find other alternatives for nutrition.

18. Economic measures of the losses in resource production in Viet Nam amount to over 15.8 Trillion VND (760 million USD) in annual fishery and farming losses. In Cambodia, the estimated 1.8 trillion Cambodian Riel (450 million USD) is lost due to impacts to fisheries and farming. By comparison, the consequences to Cambodia's economy would be much larger in scale.

19. If dams were operated to meet daily peak power demands (hydropeaking), there would be large daily water fluctuations downstream of the southernmost dam (e.g., more than 2 m in daily fluctuations at Kratie), causing serious erosion, loss of aquatic habitat, disruption of movements and reductions in fish populations, and unsafe operating conditions for vessels in that section of the Mekong River.

20. A drawdown of water during a dry year to temporarily maximise power production would cause unsafe conditions for navigation downstream of the southernmost dam and temporary increases in salinity, with salinity intrusion extending 10 to 12 km farther into the Delta.

It is likely that the actual impacts may well be higher than projected because of varying levels of uncertainty associated with the data and method, the cumulative effects of other natural phenomenon (climate change, sea level rise), on-going changes in the LMB (land subsidence, deforestation, etc.), and the uncertainty related to how the natural systems will respond to the major disruption in the LMB system.

In conclusion, the planned hydropower cascade would cause high adverse impacts to Mekong River floodplains and Delta due to the combined interaction of dam barrier effects, highly reduced sediment and nutrient loading, and increase in salinity incursion. Yield of the critically important capture fishery could be reduced by up to 50%, and up to 10% of fish species in the region could be lost. The large amounts of sediment trapped behind the dams would greatly decrease the Delta's capacity to replenish itself, making it more vulnerable to sea level rise, saline intrusion, and may worsen coastal erosion. Loss of nutrients trapped along with the sediments will decimate the unmatched productivity of the entire Delta system.

In the Mekong Delta, the food, health, and economic security of the local populations are inseparably intertwined with the integrity of the natural environment. Mainstream hydropower development in the LMB would cause irreparable and long-lasting damage to the floodplains and aquatic environment, resulting in significant reduction in the socio-economic status of millions of residents and creating social and economic burdens on local and regional economies. With regard to the Mekong Delta as a unique system of national and international heritage, the planned hydropower cascade would substantially and permanently alter the productivity of the natural system leading to degradation of all the Delta's related values.

8 Recommendations for Future Studies

Recommendations for important studies that should be initiated during the next phase are listed below for individual disciplines.

8.1 Hydrology and Water Quantity

- Carry out a cross sectional survey from Stung Treng to Kratie to update the cross section information now derived from a 50 × 50-m Digital Elevation Model (DEM) to improve the accuracy of water flow and water level calculations for this stretch of the Mekong River.
- Prepare a more detailed DEM for Cambodia. Update DEMs for Cambodia and Vietnam regularly (e.g., every 5-10 years).
- Continued hydro-meteorological monitoring using the present monitoring network, supplemented with higher elevation hydrometeorological stations to capture rainfall at higher elevations. Continued hydrological and hydraulic monitoring using the present network for model updates.
- Monitor the LMB for developments of infrastructure and their operation for model updates.

8.2 Sediment and Nutrients

- Update the Additional Study 2014 information on sediments and nutrients by replicating the Additional Study (dry and wet season surveys and subsequent laboratory analyses) to confirm 2014 findings. Besides include the Thai border stretch not covered in 2014. At the same time carry out sub-bottom profiling between Vientiane and Kratie during the wet season.
- Study in detail the distribution of river bank erosion and accretion in the Mekong Delta and assess the factors affecting river morphology including sediment transport, river bed erosion, sand mining, and land subsidence.

8.3 Fisheries

Initiate long-term, basin-wide fishery data monitoring programs to collect the following types of information, which will further add to the understanding of the many complex and inter-linked ways in which mainstream and tributary hydropower development could affect fisheries in the IAA and LMB:

- Perform studies of the movement and seasonal habitat use of fish to identify migratory fish species and better understand their movement and habitat requirements.

- Continue to monitor catch yield and catch species composition throughout the basin.

- Perform genetic studies of vulnerable migratory fish species in the Mekong Delta, Tonle Sap, and central Mekong River to better understand population structure and vulnerability of those species.

- Monitoring of the effects of a decrease in sediment deposition, and associated changes in habitat structure, on benthic invertebrates and other aquatic species.

- Conduct aquaculture studies to better define the relationship between environmental drivers and aquaculture success; and then use that understanding and the data used to develop it to conduct a study with the aquaculture area extended over more provinces to further elucidate the potential impacts of hydropower development in the LMB on aquaculture in the Mekong Delta.

8.4 Biodiversity

- Conduct studies and monitoring to collect the following information needed to better understand how mainstream hydropower development could affect biodiversity in the IAA, including the following:

– Studies of the movement and seasonal habitat use of fish to identify migratory fish species and better understand their movement and habitat requirements.

– Genetic studies of vulnerable migratory fish species in the Mekong Delta, Tonle Sap, and central Mekong River to better understand population structure and vulnerability of those species.

– Research the effects of a decrease in sediment deposition, and associated changes in habitat structure, on benthic invertebrates and other aquatic species.

- Studies of the effects of a change in water-borne nutrient concentrations and deposition on primary productivity within aquatic and wetland habitat, and the secondary effects on the composition, structure, and reproductive output of plant and animal communities.

8.5 Agriculture

A range of future studies could greatly increase the ability to anticipate and prepare for impacts to agricultural production. The following recommendations are identified by indicator(s).

Crop Yield:

- Refine the model with more details and grouping analysis to determine real diversity.

- Collect more data on soil profiles relative to crop varieties and yield.

- Collect time series data and run the model for multiple years to strengthen future cumulative impacts analyses.

Crop Yield and Area:

- Collecting time series data for water conditions and running the model for multiple years to strengthen future analyses.
- Crop Yield and Calendar.
- Strengthening inventory data at commune and district levels.

Crop Yield, Calendar and Area:

- Consult additional expertise in each of these indicators to improve selection of information for use in modelling.

8.6 Economics

A variety of future studies should be developed to improve the breadth and depth of data to assess economic impacts. The primary gaps in knowledge to improve the economic analysis involve fisheries and include the following:

- Producer revenue and income data by scale of activity: formalised data collection on farmers and fishers to assess their net revenues by scale of production.
- Fishery labor production systems: additional information could be developed on the labor involved in producing each ton of fish.
- Fishery market survey: systematic market survey across a wide range of areas in the direct impact area could generate more reliable prices for fish types aligned with these categories in this study.
- Ecosystem services data analysis could also be improved through a localised study on the economic value of these services.

The agricultural database used for the economic analyses should also be updated with recent commune-level data for both Viet Nam and Cambodia.

8.7 Livelihood

- Flooding and salinity intrusion can affect households in a variety of ways depending on the severity and conditions of homes. Additional research could further assess the vulnerability and coping mechanisms in the worst affected areas. Such research could provide insights on building up capacity of the residents to cope with the changes.
- Health, and it's correlation with economy and livelihood, has been alluded to throughout this study. However, an in-depth health impact assessment was outside the scope of the MDS. Such a study is recommended in order to identify specific anticipated health-related challenges and position the government to proactively address them before they arise.

- Further studies are required to determine additional avoidance and mitigation measures that could positively influence the livelihoods of residents in the Mekong Delta.

8.8 Cumulative Impacts

- As previously discussed, the MDS study was not intended to comprehensively evaluate the cumulative effects of hydropower development and other changes in the region, or to be a comprehensive evaluation of future conditions in the region. As such, the assessment did not consider other factors that are known to contribute to important changes in the region, such as climate change, sea level rise, rapid urbanization, deforestation, and land subsidence. These factors are likely to have important effects on many of the same people and resources anticipated to be might be impacted by hydropower development. A comprehensive cumulative impacts analysis is recommended to improve understanding of the combined effects.