Study on the Impacts of Mainstream Hydropower on the Mekong River

Draft Impact Assessment Report

Impact Assessment Methods and Results – Summary Version

This summary of the MDS Impact Assessment Report should be used as a working document for the International Workshop on 4 December 2015 in Ho Chi Minh City, and subject to further improvements in the MDS Final Report

Ministry of Natural Resources and Environment

Draft Impact Assessment Report

Summary Version

December 2015

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The expert in WATER ENVIR

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Prepared for	Ministry of Natural Resources and Environment Government of Viet Nam

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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. There have been constant worries that 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 tremendous concern over the impacts of the planned hydropower cascade on the downstream floodplains of Cambodia and Viet Nam. That led to a strong need that conduction of additional studies and analyses, using the most updated data and best available scientific tools, were a must to improve understanding of how the planned hydropower 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 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 LMB mainstream hydropower cascade on the natural, social, and economic systems of Cambodian and Vietnamese floodplains** implemented in close cooperation with the Governments of Lao PDR and Cambodia. Accordingly, the primary objectives of the MDS were to evaluate changes projected to occur in the hydrological processes of the LMB resulting from the construction and operation of the planned 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, and 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: namely fisheries, biodiversity, navigation, agriculture, livelihood and economics. Inter- and intra-resource area impacts were identified and overall impacts of the various resources areas on the regional and national economy were forecasted. Two additional scenarios also were evaluated to examine the incremental effects of tributary dams and mainstream water withdrawals.

The impact assessment approach was based on internationally recognized 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 characterize 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 3 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.**

Notable adverse impacts on the individual resource areas include the following:

- Though low to moderate changes expected for 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 (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 wildly fluctuated flows and water level. **A mongst three assessed scenrios, impacts on flow regimes of Scenario 3 are worst, while those of Scenario 2 lesser.**

- Sediment and nutrient deposition would decrease as much as 65 percent 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. **The Scenario 2 poses most severe impacts on sedimentation and nutrients in comparison to the others two.**

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

- Travel routes of long-distance migratory fish (white fish), which account for 74% of the catch of the top ten 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 presence of the dams is expected to cause a very high decline in total capture fishery yields of about 50% for both Viet Nam and Cambodia**. Tributary dams and diversion may cause cause additional impacts on fisheries at a marginal increase.

- The substantial loss of capture fishery resources would adversely affect 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 percent 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, low to moderate adverse impacts are projected on agricultural productivity. But within the areas that are impacted, the impacts would be high.

- Key significant impacts to the livelihood of people in the region would occur due to water level reductions, and increase in salinity incursions in the Vietnamese Delta. Livelihood will also be indirectly impacted due to direct impacts on capture fisheries, agriculture, and navigation.

- Economic impacts within the riparian areas and the floodplains could be high.

Overall, in Cambodia a national industry of high importance (fisheries) would suffer very high decline in yields, 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 experience potential impacts 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 customized 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 recognizing that biological resources are adaptive by nature and over time to counter and overcome some of the projected impacts, but 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 diversity**. Therefore, it is uncertain what degree of relief fish passage technologies may 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 characterize the hundreds of fish species in the basin.

In conclusion, the planned hydropower cascade would cause very 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 over 50 percent, and up 10 percent 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 River 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 view of 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 Delta's related values.

1 Introduction

This document is a summary version of the Mekong Delta Study (MDS) Impact Assessment Report (IAR).

1.1 Study Goals and Objectives

The primary objective of the MDS is to define and evaluate changes in the hydrological processes that are anticipated to occur in the Lower Mekong Basin (LMB) resulting from the construction and operation of the proposed mainstream hydropower cascade and assess how these changes could impact the human and natural environment in the downstream floodplains of Cambodia and Viet Nam. This primary objective supports the overall goal, which is to safeguard the Mekong Delta and its resources, economies, and natural systems and to ensure the continued well-being of communities and their livelihoods in the Delta region through informed and scientifically justified decision-making on the use and exploitation of the river's resources.

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

1.2 Study Area

The study area considered in the MDS is broadly divided into an Evaluation Area, which includes most of the LMB, and an IAA, which covers the downstream floodplains of Cambodia and Viet Nam (Figure 1.2-1).

The IAA covers approximately 105,475 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 Sambor Dam and the southern boundary is the Mekong River coastal zone, which is formed by confluence of the Mekong River tributaries with the East Sea.

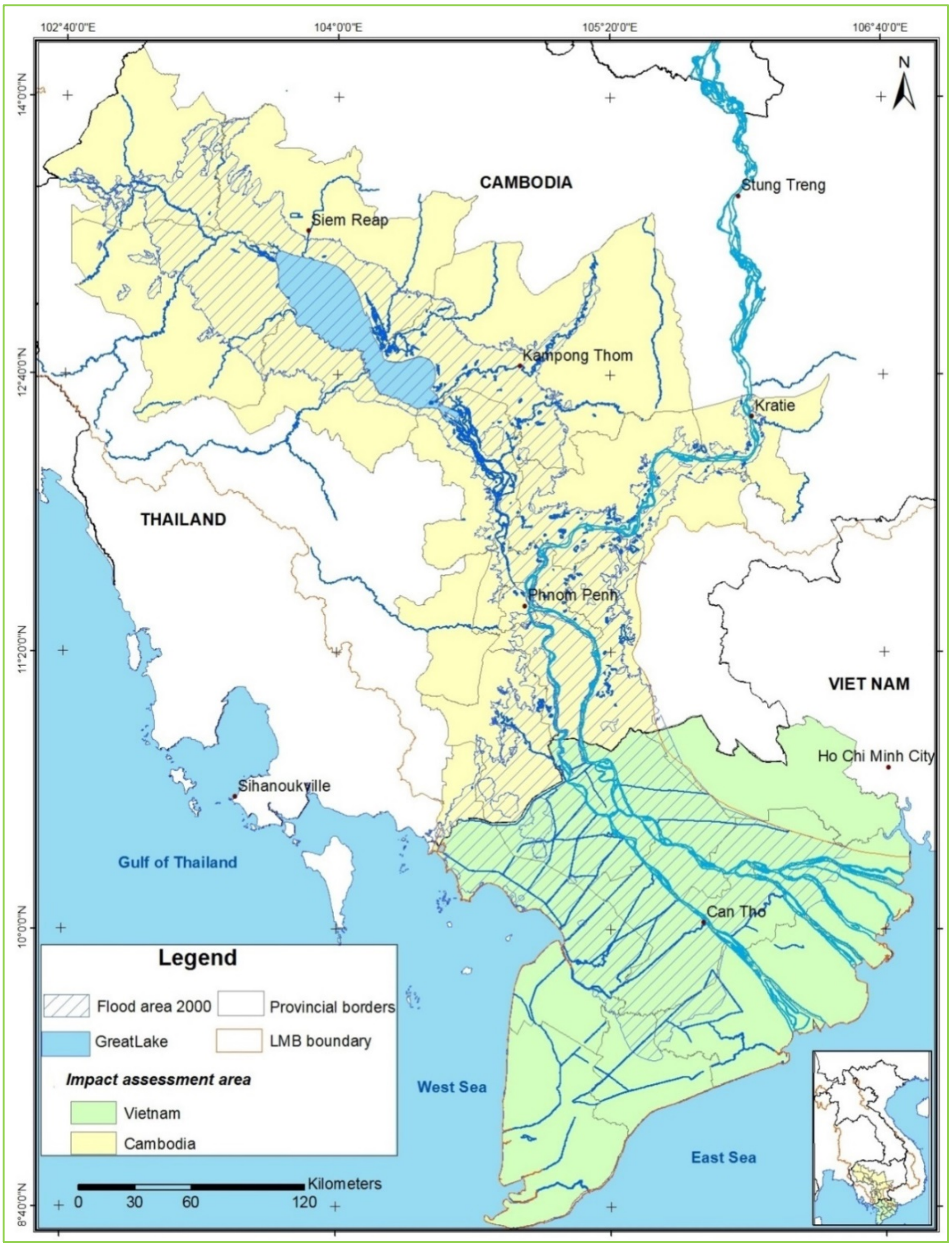


Figure 1.2-1: MDS impact assessment area

2 Impact Assessment Framework

2.1 Impact assessment scenario

For the MDS three main scenarios were evaluated as follows:

- **Scenario 1: Mainstream hydropower cascade** – This scenario was used to determine the overall effects of all 11 planned LMB mainstream hydropower projects operating simultaneously. Design specifications of each proposed dam, as reported in the Mekong River Commission's (MRC's) Basin Development Plan 2 (MRC 2011), were coded into appropriate physical models and simultaneous operations were simulated to provide data for the impact analyses. See Volume 1, Annex A for additional information on the design specifications of individual hydropower projects in the planned cascade.
- **Scenario 2: Mainstream hydropower cascade plus additional (tributary) dams** – This scenario was used to determine the cumulative effects of the planned cascade (Scenario 1) and selected LMB tributary dams. A total of 72 tributary dams mainly consisting of projects that were existing and 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 planned cascade (Scenario 1) and proposed water diversion projects in Thailand and Cambodia. Two main water diversion schemes were included in this assessment, namely 1) inter-basin transfer of about 290 to 350 cubic meters/second (m^3/s) of flow out of the LMB and 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.

For each scenario, potential impacts were identified by comparing model simulated conditions likely to occur under that scenario to normal (average) year hydrological conditions (as represented by year 2007). For this analysis, all mainstream dams were modelled as operating to meet peak daily power demand (i.e., hydropeaking). Impacts likely to occur during hydropeaking periods were separately identified.

In addition, for each scenario, potential impacts were identified by comparing model simulated conditions likely to occur under that scenario to dry year hydrological conditions (as represented by year 1998).

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).

2.2 Approach

The 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. For each scenario impacts expected to occur in the Cambodian floodplains south of Kratie (including Lake Tonle Sap's drainage basin), the Cambodian Mekong Delta, and the Vietnamese Mekong Delta (Figure 1.3-2) were evaluated. A broad qualitative assessment of impacts likely to occur in the riparian areas of Lao PDR under each scenario is also presented in this report.

The impact 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.

Major steps in the impact assessment process included the following:

1. Baseline conditions (upto 2012) were projected using model simulations for selected key indicators of river system flows and velocities, sediment loading and nutrient transport, and water quality. The baseline model simulations were based on historical data and on the results, observations, and findings of sediment and water quality characterization field surveys conducted in 2014.

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

3. Changes to occur in the key indicators of river flows and velocities, sediment loading and nutrient transport, and water quality caused by construction and operation of the mainstream hydropower cascade were projected through model simulations and compared to corresponding baseline conditions to characterize and quantify the change between the baseline and mainstream hydropower cascade conditions.

4. Changes likely to occur in key indicators of the six resource areas as a result of the projected changes in impact drivers were characterized and where possible quantified.

5. Impacts on individual resources were characterized as none, low, moderate, high or very high and ranked from 0 to 4 as shown in Table 2.2-1. As appropriate, for each resource area, these ranks were interpreted and more specifically defined based on the characteristics of the resource and the types of effects that could occur. 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.

6. The scenarios were also assessed the cumulative effects of planned 11 mainstream hydropower dams and two types of developments that could potentially influence hydrology in the LMB, namely tributary dams and large-scale water diversions.

7. These steps were then repeated for each of the other scenarios and the values of the key indicators were compared to the appropriate baseline conditions and to the results from other scenarios, where applicable.

Table 2.2-1: Scale for ranking of adverse effects associated with the hydropower cascade

Rank	Level of Impact	Impact Description
0	No	No noticeable or measureable adverse effects
1	Small	Low but detectable level of adverse effects to a resource
2	Moderate	Moderate localized 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

Development and implementation of the MDS impact assessment approach was influenced by the following key challenges:

- The complexity of the natural, social, and economic systems in the IAA.
- The area considered in the MDS is very large and diverse. The IAA is about 105,475 km^2 and includes a wide variety of human development and natural habitats. When possible, modeling and analyses were conducted at a small enough scale to address this diversity.
- Many aspects of the natural, social, and economic systems considered in this MDS have not been well studied or characterized. For example, biodiversity in much of the Mekong Delta has only been described in detail at a small number of sites. In addition, much of the available data was outdated, has been collected at disparate locations, at different times, using varying methodologies, and for different purposes. To obtain important information needed for impact assessment, field studies were conducted in 2014 to characterize sediment and water quality characterization in the IAA and to fill data gaps in information about fisheries, biodiversity, livelihoods, and navigation.

The Mekong River delta, especially in Viet Nam, is highly altered, rapidly changing, and has a complex series of canals, dikes, and other water control structures. To effectively model hydrological processes in that region, detailed information on topography and the water control systems in the delta was used in the MDS Delta Model. In addition, land use information was updated in 2014 and that revised map of land cover and terrestrial and aquatic habitat was used in the analyses of fisheries and biodiversity.

Indicators used in the impact assessment are listed in Tables 2.2-2 and 2.2-3.

Table 2.2-2: MDS Impact Assessment Indicators (Drivers)

Areas	Indicators	Units	Locations
Water quantity	Deviation of average flow and volume loss in dry season: - Dry season month - 10 day interval in dry season	billion m^3 and % billion m^3 and %	For control points : Luang Prabang, Vientiane, Pakse, Kratie, Phnom Penh Tan Chau and Chau Doc
	Deviation of water level in dry season - Dry season month - 10 day interval in dry season - Max fluctuation	m m m	
	Deviation of flood volumes - Seasonal change	billion m^3 and %	
Sediment	Yearly total sediment loss - Clay - Silt	million tonnes/y and %	For selected control points
	Increased length of bank erosion - River bank - Coastal bank	m m	Viet Nam
	Decreased growth rate of Ca Mau tip	m/y	Viet Nam
Water Quality	Max salinity intrusion	km	Selected branches
	Area of increased salinity intrusion	km^2	Mapping (All-over Delta)
	Yearly total N loss	1000 tonnes/y &%	For selected control points
	Yearly total P loss	1000 tonnes/y &%	For selected control points

Table 2.2-3: MDS Impact Assessment Indicators (Resources/Sectors)

Areas/Sectors	Indicators	Units	Remarks
Fisheries	Loss of fish catch yield	Tonnes & %	Quantitative
	Loss of OAAs yield	tonnes	Quantitative
	Loss of yield of economically important fish species	tonnes	Quantitative
	Species loss in catch composition	species	Quantitative
	Change in extent of aquaculture area per species group	hectares	Semi-quantitative
	Change in production per aquaculture species group	tonnes	Semi-quantitative
Biodiversity	Change in the extent of floodplain wetlands	hectares	Quantitative
	Species affected by loss of important floodplain habitat types	Relative risk of effects	Qualitative
	Change in wetlands composition within biodiversity hotspots	Hectares	Quantitative
	Risk of reduction in biodiversity	Relative risk of effects (on a scale of 1 to 5)	Qualitative
	Risk of extirpation	Relative risk of extirpation (on a scale of 1 to 5)	Qualitative
	Change in primary productivity caused by changes in nutrient deposition	Tonnes carbon	Quantitative
	Loss of riverine habitat caused by changes in sediment transport	Relative risk of loss of riverine habitat	Qualitative
	Loss of coastal wetlands (mangroves) caused by changes in sediment transport	Relative risk of loss of coastal wetlands	Qualitative

Areas/Sectors	Indicators	Units	Remarks
Navigation	Change in flow regime, water depth in the river changed.	m	Quantitative
	Transport capacity changed	Tonnes/year, TEUs/year	Quantitative
	Physical barriers – Longitudinal connectivity	hours	Quantitative
	Change river morphological condition due to sediment transport		Qualitative
Agriculture	Crop Production (P): Seasonal and annual rice production (t) Annual maize crop production (t)	 Tonnes Tonnes	Quantitative
	Crop Area (A): Rice crop area (ha) for the main crop	 Hectares	Quantitative
	Crop Calendar (CC): Crop windows and period of rice cropping as limited by inundation and salinity, focus on Vietnamese Delta		Qualitative

	Livelihood dimensions	Key Indicators	Sub-Indicators / Parameters	Units
Livelihood	Exposure	Population/area directly affected by flood (Affected standard is flooded 0.5 m and in 10 continuous days)	Area affected by flood	Hectares
			Population affected by flood	Millions
		Population/area directly affected by salinity intrusion (1 ppt over 7 days)	Population affected by salinity intrusion	Millions
			Area affected by salinity intrusion	Hectares
	Sensitivity	Farming population affected by changes in water level, sediment and salinity	Percentage of population in full or part-time farming	
		Capita income from farming	Total income from farming, as net benefit	(million VND) / Capita
		Level of dependency on water related resources	Annual Average Consumption of fish per HH	

	Sector/ Resource	Indicator	Units	Estimation method
Economics	Agriculture/ Fisheries/ Navigation	Change in gross revenue (measured in terms of VND) *Sub-indicator*: Direct estimate of value of production change for agriculture and fisheries *Sub-indicator*: Indirect estimate of navigation output change – based on change in production	VND	Quantitative
		Impact on the economies within the impact assessment areas and across the nations of both Viet Nam and Cambodia	VND/Riel	Quantitative
		Change in employment	No of people	
		Change in income per capita	VND	Quantitative
	Environmental Services	Economic change in economic value of a change in wetlands natural resources	VND	Quantitative

3 Impact Assessment Knowledge Base and Tools

3.1 *Introduction*

To evaluate the effects of mainstream hydropower development, the first step was to calculate baseline values for selected indicators for the key impact drivers (Table 2.2-2) during an average hydrological year (represented by year 2007). Values for these indicators were then calculated for conditions predicted to occur if the planned mainstream hydropower cascade was operating during an average year (Table 2.2-3). Indicator values were calculated using a series of customized hydrological, hydraulic, sediment transport, salinity, and nutrient models.

Differences in the indicators between baseline conditions and Scenario 1 were used to understand how mainstream hydropower development would affect hydrological conditions, sediment and nutrient transport, and salinity. These modeling results, and a consideration of how the presence of dams would create barriers to movements of fish and other aquatic animals (OAA), were then used to calculate Scenario indicator values (Table 2.2-3) for the resource areas listed below to describe likely effects of the mainstream hydropower cascade.

Drivers

- Hydrology
- Sediment
- Water quality
- Movement barriers

Resource Areas

- Fisheries
- Biodiversity
- Navigation
- Agriculture
- Livelihood
- Economic conditions

These steps were then repeated for the two additional scenarios to evaluate the cumulative effects of other developments in the LMB.

3.2 *Models and Modelling Approach Summary*

Input data - The MDS impact assessment relied upon output from hydrologic, hydraulic, sediment transport, salinity, and nutrient modelling to assess potential impacts of hydropower development scenarios. As appropriate and relevant, different sections of the MDS Evaluation Area (Figure 1.2-1) were modelled and simulation outputs were used to quantify changes relative to baseline conditions in patterns of flows, water levels, flow velocities, flooding patterns, sediment and nutrient transport, and salinity in the IAA associated with mainstream hydropower development and other development scenarios.

Methodology - 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 (SWAT and MIKEBasin for hydrology, MIKE11 for hydraulics, sediment transport and salinity intrusion for the Mekong Mainstream and Delta, and MIKE21 for the Great Lake and the Coastal for hydraulics and sediment transport) as present in Figure 3.2-1. 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, sediments nutrients and salinity 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 US.

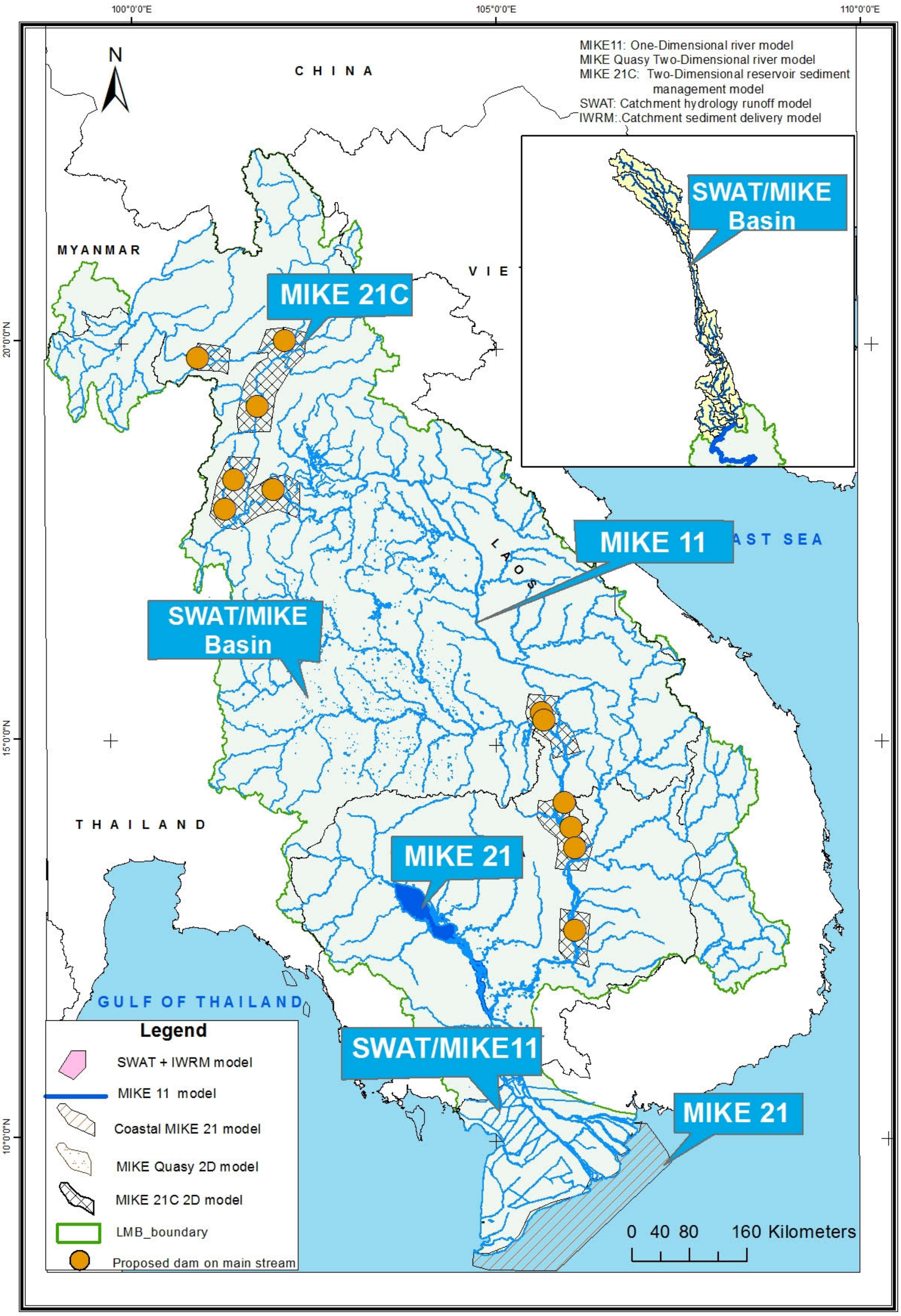


Figure 3.2-1: Application of various model types in the different parts of the LMB

The Study inherited the SWAT set-up used by MRC with an extended hydro-meteorological and hydrological dataset up to 2013. The setting up of the MIKEBasin has inherited the regional/national knowledge embedded in the IQQM model used by MRC. Similarly, the MIKE11 Mainstream model has inherited the river cross section information etc… from the ISIS model used by MRC. Finally, the MIKE11 Delta model constitutes a further development of models for the Cambodian part of the Delta under the JICA-WUP study and for the Vietnamese part of the Delta developed by SIWRP.

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 and nutrients for the entire Mekong Basin. This is also the first ever seen a comprehensive model package has been successfully applied to the Mekong Delta coastal area depending on receiving boundary data from East and West Sea regional models.

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.

The baseline has been created mainly using the hydrological baseline with respect to precipitation from 1985 to 2008 with an extension to 2013. With respect to sediment and nutrient baselines the most recent sediment data from the MRC DSMP study has been used, updated with the information and data obtained from the Additional Studies carried out in 2014 as part of the MDS. The scenario simulations have been carried out for a representative average and dry years with respect to the hydrology with corresponding conditions for the wet as well as for the dry season. The scenario simulations have been carried out based on the existing information on the design and operation of the 11 planned dams available at the MRC Secretariat and in the region.

3.3 Fisheries Impact Assessment Methodology Summary

Capture fisheries are an important source of livelihoods and contribute considerable to food security in the LMB. In tropical floodplains, fisheries are highly resilient to fisheries exploitation pressures but are extremely vulnerable to externalities such as human population growth and associated degradation (e.g. pollution and urbanisation), agricultural practices (e.g. isolation of floodplain habitats by levees to protect rice fields), abstraction and flow regulation, as well as the barrier effects of large dams to fish migration and distribution.

Thus, identifying impacts of hydropower development on fisheries required the teasing out of the impacts of other external pressures from those directly contributory to hydropower. In addition, there was a need to evaluate the switching from capture fisheries to aquaculture production, which is a trend that is occurring globally in freshwater ecosystems and is especially prevalent in the Vietnamese Mekong delta

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

Note that much of the available historical data are fragmented and of varying quality and completeness. The data has not been used extensively for focused impact assessment analyses. The data provided by the MDS fishery research study are specifically intended for use in impact assessment, but they were only collected for less than one year. It is well established that fish and fishery production varies substantial from one year to next in response to varying weather related and hydrological conditions.

Notwithstanding the constraints, the input dataset used for assessing fishery impacts represents the best recent and most comprehensive compilation of relevant fishery data. 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 OAA migration behaviour and improving understanding of the complex primary and secondary links between sediment and nutrient loading and biological productivity.

***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 impact of changes in water flow regime, water quality, and connectivity of the Mekong River on capture fisheries.
2. Assess 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 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.

3.4 Biodiversity Impact Assessment Methodology Summary

Input Data – The Study has an unprecedented database in the region, including all available data/information about the basin biodiversity characteristics from different sources such as: the MRCS, VN concerned Line agencies; from Laos and Cambodia; and from international/regional organizations such as WWF and IUCN.

Additionally, the Study also has additional survey conducted in 2014 to fill up the gaps in data and knowledge, and update wetland maps for the whole IAA.

The available database and knowledge built up at the Study have met the required sufficiency and quality for analyses at the highest possible level of quantification.

Methodology – Six related analyses were conducted to meet these objectives by assessing the magnitude of effects to biodiversity assets from the impact drivers described above and to identify the biological resources that would be affected by mainstream hydropower development.

1. **Landscape-Scale Habitat** – Predict changes in availability of riverine and floodplain habitat throughout the IAA
2. **Biodiversity Hotspots** – Quantify changes in hydrology at representative national parks, wetland reserves, or other key biodiversity areas and evaluate how those changes would affect biodiversity there.
3. **Sediment and Nutrient Transport** – Evaluate how decreases in sediment and nutrient transport would modify availability of riverine and coastal habitat and affect productivity of aquatic and floodplain areas.
4. **Daily Water Fluctuations** – An analysis of how daily fluctuations in water levels caused by the operation of the mainstream cascade to meet peak electricity demand would affect habitat and biodiversity downstream of that dam.
5. **Movement Barriers** – An analysis of the effects of movement barriers on the diversity of fish and other aquatic organisms in the IAA.
6. **Rare, Threatened, and Endangered Species** – Based on the results of the other analyses, identify the species or groups of species that are vulnerable to changes caused by mainstream hydropower development.

The biodiversity assessment focused primarily on permanent waters and portions of the floodplain within the IAA that are flooded seasonally by the mainstream Mekong River. Therefore, not all the geographical area of the Mekong Delta are included in the IAA for biodiversity assessment. For this analysis, the seasonally inundated floodplain was defined as all areas that were flooded to a depth of 10 cm during 2000 , a year with a very high volume flow.

The Study uses the best available and recognized methods for the region to do analyses with necessary adaptation.

- The relationship developed to predict the changes (in wetland habitats, or primary productivity) due to hydropower development are empirical ones adapted for the IAA with professional judge, which show justified results. However, uncertainties are also identified to pave the way to improve in the future.
- The methods enable the analyses from land scape to hotspot level, with a range of indicators related to landscape - level changes in habitat; changes to hydrology within biodiversity hotspots; changes in primary productivity due to change in sediment and nutrient transport; and effects on rare species.

3.5 Navigation Impact Assessment Methodology Summary

The following five analyses were conducted to assess the effects of mainstream hydropower development on navigation.

1. Assess impact of changes in water flow regime on water levels along important transportation routes.
2. Assess how daily fluctuations in water levels could affect navigation downstream of Sambor Dam.
3. Assess how changes in water level could affect transport capacity along important transportation routes.

4. Assess how the presence of dams could increase the time required to transport goods along the Mekong River.

5. Assess whether erosion and other changes in riverine and coastal morphology could affect transport facilities and navigation routes.

Input data – for navigation impact assessment was obtained from multiple official government sources including Viet Nam's Ministry of Transportation and the GSO, MRCS reports and publications, and a variety of external published sources. In addition, a navigation research study was conducted in 2014 to provide updated data on navigation capacity and facilities in the IAA. Accordingly, the dataset used for assessing navigation impacts represents the best and most comprehensive compilation of relevant data.

Methodology – A customized approach was developed for assessing and quantifying navigation impacts. This method incorporated general principles and scientific concepts adopted by similar assessments conducted in other parts of the world. 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 3 scenarios. Adverse impacts associated with dam locks, all of which are located outside the IAA, were also evaluated. The selected assessment method represents the most direct and validated approach for assessing navigation impacts in the LMB.

3.6 Agriculture Impact Assessment Methodology Summary

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 (N, P, and K) were provided by the MDS hydrological, sediment, and water quality modeling. Nutrient contents in the sediment are also provided by the MDS additional survey and compared with information from experimental results in the VMD provided in published references.

Methodology– A customized Excel spreadsheet-based modeling tool (MDS Agri Model) was developed and calibrated for the impact assessment. This model is based on a parametric method (Hoanh1996) 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. Relationships between water level, salinity and nutrients are from results from experiments by research institutes and universities in the VMD such as the Cuu Long Rice Research Institute and the Can Tho University provided in published references, and also information from publications of international research institutes such as the International Rice Research Institute (IRRI), Wageningen University in the Netherlands…

3.7 Livelihood Impact Assessment Methodology Summary

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 organization. Data on water level levels, salinity concentrations were provided by the MDS hydrological, and water quality modeling. Therefore, the available database and knowledge of the study meets the required sufficiency and quality for analyses

Methodology – The assessment method was based on established principles previously used by the MRC to conduct a Social Impact Monitoring and Vulnerability Assessment (SIMVA) within the LMB in supporting the preparation of the BDP2 (MRC 2011). SIMVA including a series of social impact indicators is 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 Study.

The MDS assessment also included use of customized Excel spreadsheet-based modeling 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.

3.8 Economic Impact Assessment Methodology Summary

The economic analysis of hydropower development impacts to Viet Nam and Cambodia has used sound methods and the best available data, at the finest geographical scale possible, to develop a solid understanding of the type and extent of impacts. This highly quantitative analysis is directly linked to the outputs from impacts to fisheries, agriculture, navigation and biodiversity. The additional contribution from the economic analysis entails the use of prices, costs, and productivities to assess these impacts in monetary terms. These monetized results enable the impacts to compared at the commune scale for agriculture and at the district scale for fisheries – a level of analysis that has not been possible or attempted to date. Accordingly, these methods and use of data has enabled communes which are likely to be highly impacted to be identified – a result that can help to target mitigation and adjustment support from local technical fishery and farming agencies.

While the scale of impacts is substantial, especially in some communities, this analysis recognizes that the estimated impacts only capture one year of impact that would not occur for many years in the future – a delay that is due to the time until (and if) all 11 hydropower dams are constructed and then impacts to fishing and farming begin to be observed approximately 10 years after this last dam is constructed. As such, the estimated impacts are decades away and these estimates depend on the dams being built as they are modelled. Differences in dam design and operation could increase or decrease impacts. In additional factor related to the timing of the impacts is that the economies and production systems in the Viet Nam delta and Cambodian flood plains are changing. Fishers and farmers will continue to adapt to changes caused by hydropower development and other external drivers such as public and private investments in infrastructure, as well as climate change. In this context, the results provide a snapshot of the impacts that could be caused by hydropower. The actual impacts over time entail a more complex assessment and continuous study.

Input data – The input data used in this analysis includes quantified measures of changes in yields of fisheries and farms and economic measures of producer prices, costs and labour productivity. These values are used to estimate the monetary value of the changes in yields for key fish and farm products. These changes also led to estimates of reduced revenue for vessel operators in the navigation section.

In some cases the data is obtained from governmental sources and industry-wide surveys and in other cases (fisheries, in particular) the data is drawn from a series of site specific surveys. For example, these data fully utilize agriculture production data from GSO at the commune levels for both Cambodia and Viet Nam. In addition, economic multipliers are taken from the literature for Cambodia and developed from GSO data for Viet Nam. Economic valuation of ecosystems services relies on 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.

Weaknesses in the data exist however, particularly in attempts to represent the diversity of impacts for fishers and farmers. These producers differ in their abilities and conditions for generating revenue and income from their labour. 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 was compiled from a variety of sources and expert judgment was required to determine how best to utilize these data.

Methods used – The methods undertaken in this analysis are well-founded in economics practice for estimating macroeconomic measures of gross revenue, labour demand, total economic impact and GDP, as well as microeconomic measures of changes in net income. Both of these measures contribute to the evaluation of impacts and identification of areas for implementing mitigation strategies. The scope of analysis has been focused on measures of impact with and without the dam for a single year of production. No efforts have been made to project impacts over time, as would be conducted in a benefit-cost analysis (BCA). In many project evaluations, a BCA is preferred because it represents a direct comparison with costs. However in this case, the purpose was to evaluate economic impacts since Viet Nam was not evaluating the trade offs in hydropower costs and benefits against losses in other sectors. Its focus, a reasonable one, was to determine the impacts to its areas of production from hydropower investments made by others upstream.

4 Mainstream Hydropower Cascade Impact Characterization

4.1 Impact Characterization on Drivers

4.1.1 Impacts on Water Levels and Flows

4.1.1.1 Daily Operations

The daily operation of the Mainstream Reservoirs for peak power production during the dry season generates high fluctuations in water flow and water levels downstream the dams that have further impacts on other sectors.

The fluctuations in discharges and water levels at Kratie, situated only 31 kilometres downstream of Sambor are around 16,000 m^3/s; and the fluctuation in water levels around 2m, see Figure 4.1-1 and Figure 4.1-2. However, the fluctuations in water levels and discharges dissipate downstream below Phnom Penh.

Figure 4.1-1: Discharges at Kratie for Baseline (average year 2007, green line) and Scenario 01 with mainstream hydropower dams (blue line).

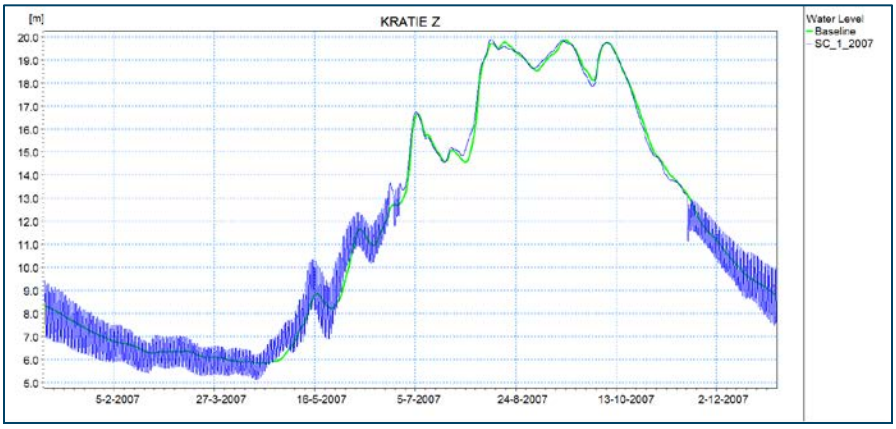


Figure 4.1-2: Water levels at Kratie for Baseline (average year 2007, green line) and Scenario 01 with mainstream hydropower dams (blue line).

4.1.1.2 Drawdowns for Increased Power Production during the Dry Season

Drawdowns and subsequent filling of the reservoirs for increased power production during the dry season have short term (weeks) high impact on water flows and water levels in the Mekong Delta, as illustrated in Figure 4.1-3 and Figure 4.1-4.

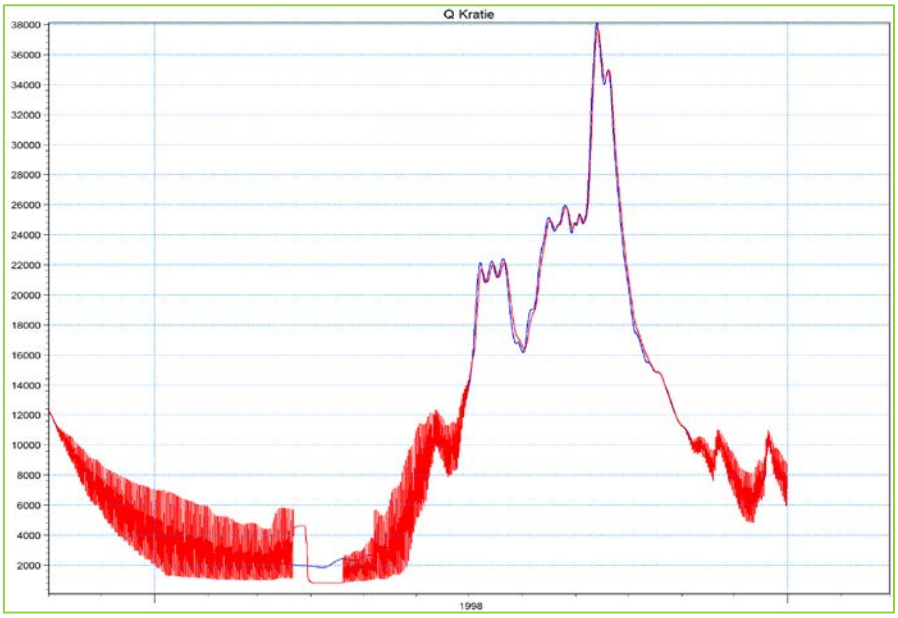


Figure 4.1-3: Water levels at Kratie for Baseline (dry year 1998, Blue line) and Scenario 01 with mainstream hydropower dams - Drawdowns (Red line).

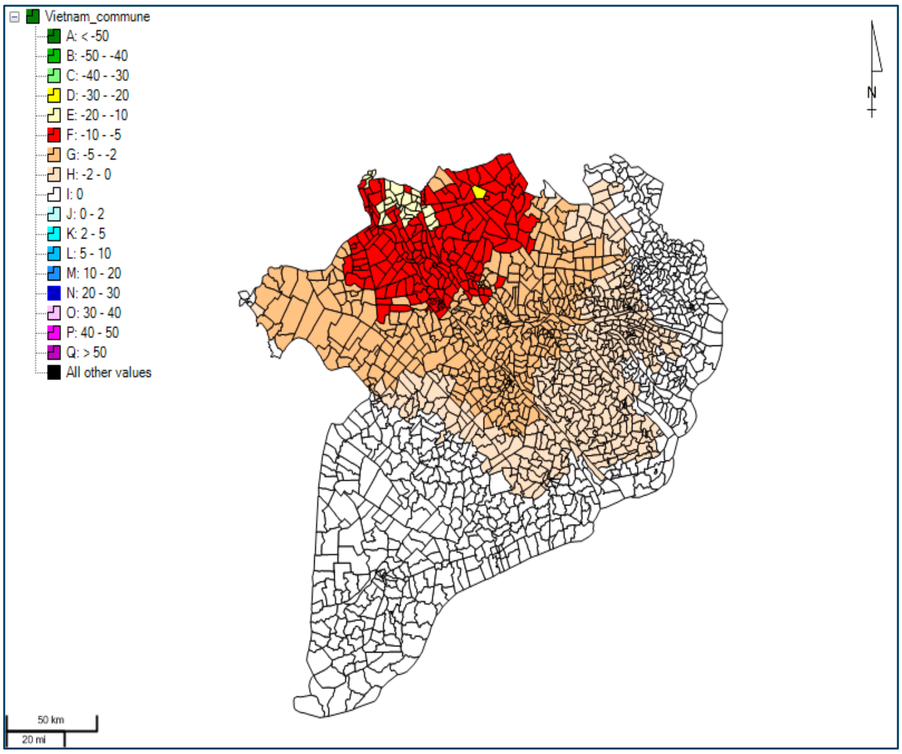


Figure 4.1-4: Changes in minimum water levels in the Delta during dry season filling subsequent to drawdowns for increased power production (Dry year 1998).

4.1.1.3 Impacts on Water Levels and Discharges of Scenario 2 and 3.

With the inclusion of Additional Dams in in combination with the planned Mainstream dams Scenario 2 the major impacts from daily operations on water flow and water levels remains at the same order of magnitude as for scenario 1.

Similarly, the drawdowns and subsequent filling of the reservoirs during the dry season (dry year 1998) scenario 3 has short term (weeks) high impacts on water levels and discharges similar to scenario 1. However, in scenario 3 these impacts on low flows and low water levels are aggravated by the diversion of water in Thailand, see Table 4.1-1, Table 4.1-2 and Table 4.1-3

Table 4.1-1: Indicators for Water Flows and Water Levels for Laos. Scenario 1, 2 and 3, representative dry year 1998.

Country	Position	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3
LAOS	LUANG PRABANG	Dry season	Drop down in Volume for 10day	Bill.m^3	-0,44	-0,34	-0,66
				%	-49,2	-38,18	-74,05
			Drop down in Volume for 1 month	Bill. m^3	-0,54	-0,62	-1,34
				%	-19,0	-21,92	-47,51
			Drop in Water Level for 10days	m	-2.70	-2,47	-2,92
			Drop in Water Level for 1 month	m	-2.26	-1,95	-2,61
			Magnitude of WL Fluctuation	m	1.71	1,73	1,77
		Flood season	Volume change in flood season	Bill. m^3	-0,03	-0,47	-0,95
				%	-0,3	-0,7	-0,52
	VIENTIANE	Dry season	Drop down in Volume for 10day	Bill.m^3	-0,60	-0,55	-0,82
				%	-62,0	-56,08	-84,59
			Drop down in Volume for 1 month	Bill. m^3	-1,32	-1,41	-2,03
				%	-42,8	-45,77	-65,81
			Drop in Water Level for 10days	m	-1,83	-1,59	-3
			Drop in Water Level for 1 month	m	-1,31	-1,34	-2,32
			Magnitude of WL Fluctuation	m	1,18	1,53	1,63
		Flood season	Volume change in flood season	Bill. m^3	-0,06	-0,51	-1,01
				%	-0,9	-1,75	-1,31
	PAKSE	Dry season	Drop down in Volume for 10day	Bill. m^3	-0,75	-0,39	-0,98
				%	-51,8	-32,27	-67,36
			Drop down in Volume for 1 month	Bill. m^3	-1,79	-1,13	-2,58
				%	-43,1	-27,25	-62,19
			Drop in Water Level for 10days	m	-0,69	-0,37	-1
			Drop in Water Level for 1 month	m	-0,54	-0,31	-0,87
			Magnitude of WL Fluctuation	m	1,40	1,39	1,32
		Flood season	Volume change in flood season	Bill. m^3	-0,15	-1,17	-1,06
				%	-1,3	-2,53	-1,89

Table 4.1-2: Indicators for Water Flows and Water Levels for Cambodia. Scenario 1, 2 and 3, representative dry year 1998.

Country	Position	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3
CAMPUCHIA	KRATIE	Dry season	Drop down in Volume for 10day	Bill. m^3	-1,15	-1,05	-1,33
				%	-59,5	-54,44	-68,77
			Drop down in Volume for 1 month	Bill. m^3	-2,60	-1,98	-3,39
				%	-46,5	-35,36	-60,72
			Drop in Water Level for 10days	m	-1,66	-1,12	-1,6
			Drop in Water Level for 1 month	m	-1,14	-0,54	-1,3
			Magnitude of WL Fluctuation	m	2,15	2,31	2,19
		Flood season	Volume change in flood season	Bill. m^3	-0,66	-1,76	-2,02
				%	-1,1	-2,17	-1,62
	PHNOM PENH	Dry season	Drop down in Volume for 10day	Bill. m^3	-1,11	-1,02	-1,2
				%	-47,0	-43,15	-50,79
			Drop down in Volume for 1 month	Bill. m^3	-2,28	-1,55	-3,22
				%	-32,4	-22,02	-45,78
			Drop in Water Level for 10days	m	-0,35	-0,32	-0,39
			Drop in Water Level for 1 month	m	-0,23	-0,15	-0,35
			Magnitude of WL Fluctuation	m	0,18	0,15	0,13
		Flood season	Volume change in flood season	Bill. m^3	-0,54	-1,47	-1,87
				%	-0,9	-1,86	-1,4

Table 4.1-3: Indicators for Water Flows and Water Levels for Viet Nam. Scenario 1, 2 and 3, representative dry year 1998.

Country	Position	Season	Indicator	Unit	Scenario 1	Scenario 2	Scenario 3
VIETNAM	Tan Chau - Chau Doc	Dry season	Drop down in Volume for 10day	Bill. m^3	-1,06	-0,97	-1,18
				%	-39,5	-36,07	-44,03
			Drop down in Volume for 1 month	Bill. m^3	-2,10	-1,31	-3,21
				%	-25,6	-16,03	-39,15
			Drop in Water Level for 10days	m	-0,13	-0,12	-0,15
			Drop in Water Level for 1 month	m	-0,08	-0,05	-0,13
			Magnitude of WL Fluctuation	m	0,03	0,02	0,03
		Flood season	Volume change in flood season	%	-0,24	-0,93	-1,24
				Bill. m^3	-0,5	-0,97	-0,73

4.1.2 Sediment Impacts

4.1.2.1 Bed Load Impacts

The mainstream reservoirs retain nearly all the bed material load. Therefore causing loss of bed material load downstream of the reservoirs in Lao PDR and Cambodia, in particular 18 Mt/year deposited at Pakbeng, 5 Mt/year deposited at Xayabury, 22 Mt/year at Bankum and 10 Mt/year at Sambor, and downstream of Sambor there is almost no upstream bed material load, see Figure 4.1-5.

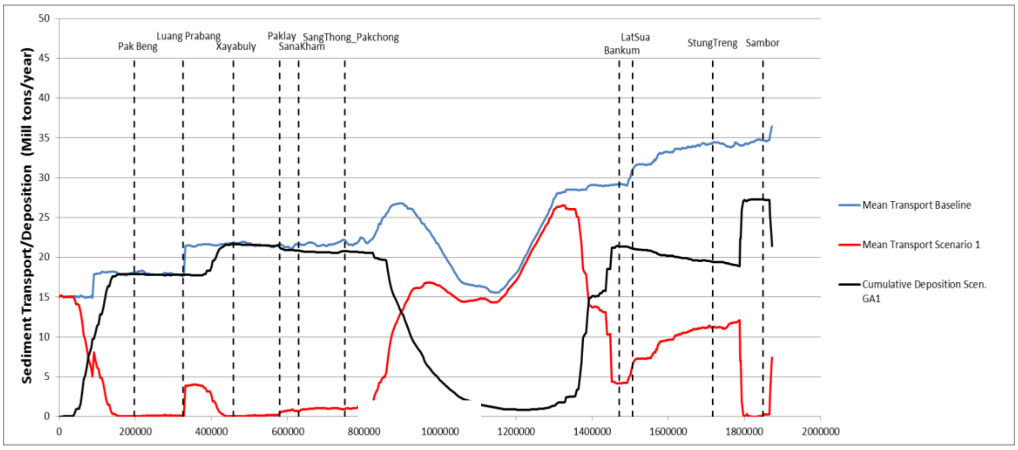


Figure 4.1-5: Cumulative transport and trapping of bed-load. Average for 1985-2008, Scenario 1

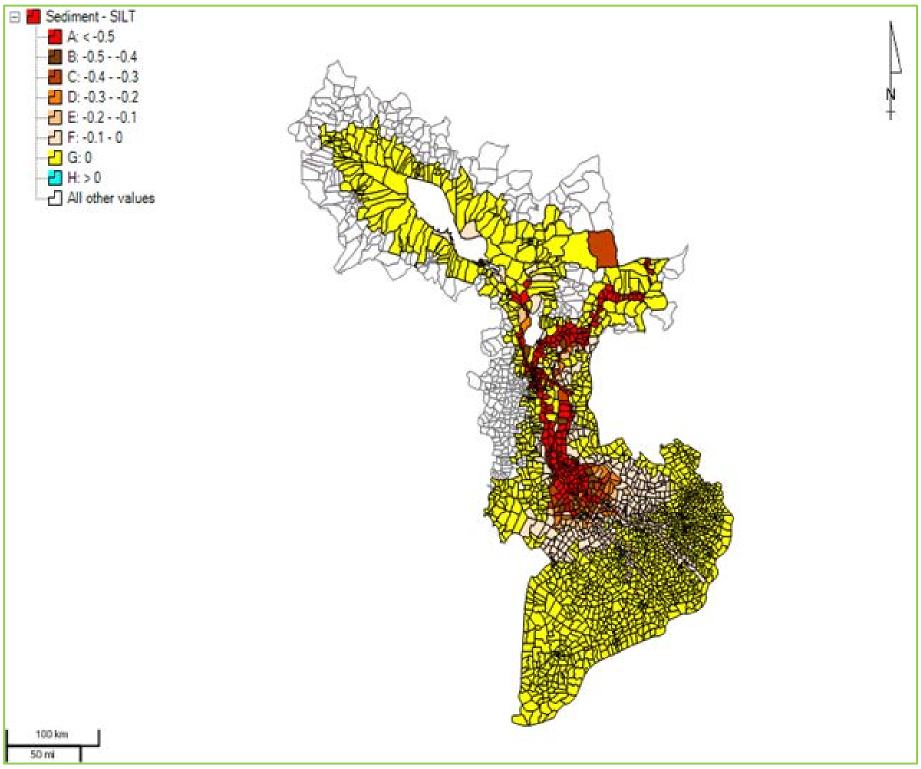
4.1.2.2 Washload Impacts

In a year with higher sediment transports (2008) the relative reductions in silt transport from the Baseline to the respective scenarios are similar to the relative reductions for 2007. The transport of clay is only marginally affected in the 3 scenarios compared to the Baseline both for 2007 and 2008. The transport of annual washload at Kratie and Tan Chau + Chau Doc is presented in Table 4.1-4.

Table 4.1-4: Transport of washload annually at Kratie and Tan Chau + Chau Doc for the Baseline and scenario 1, 2 and 3.

Scenario	Unit	Kratie	Tan Chau + Chau Doc
Baseline	*Mil tons/year*	52.6 ÷ 68.8	32.1 ÷ 42.3
Scenario 1	*Mil tons/year*	22.5 ÷ 25	13.9 ÷ 15.3
	% loss	57.2 ÷ 63.7	56.7 ÷ 63.8
Scenario 2	*Mil tons/year*	21.3 ÷ 23.3	13.7 ÷ 15.1
	% loss	59.5 ÷ 66.1	57.4 ÷ 64.4
Scenario 3	*Mil tons/year*	21.8 ÷ 24.4	13.7 ÷ 15.2
	% loss	58.6 ÷ 64.5	57.3 ÷ 64

Figure 4.1-6 shows the changes in washload transport in both the Cambodian and Vietnamese part of the Delta for 2007 (average year).The washload transport change and their distribution is similar for scenario 2 and 3 compared to Scenario 1.



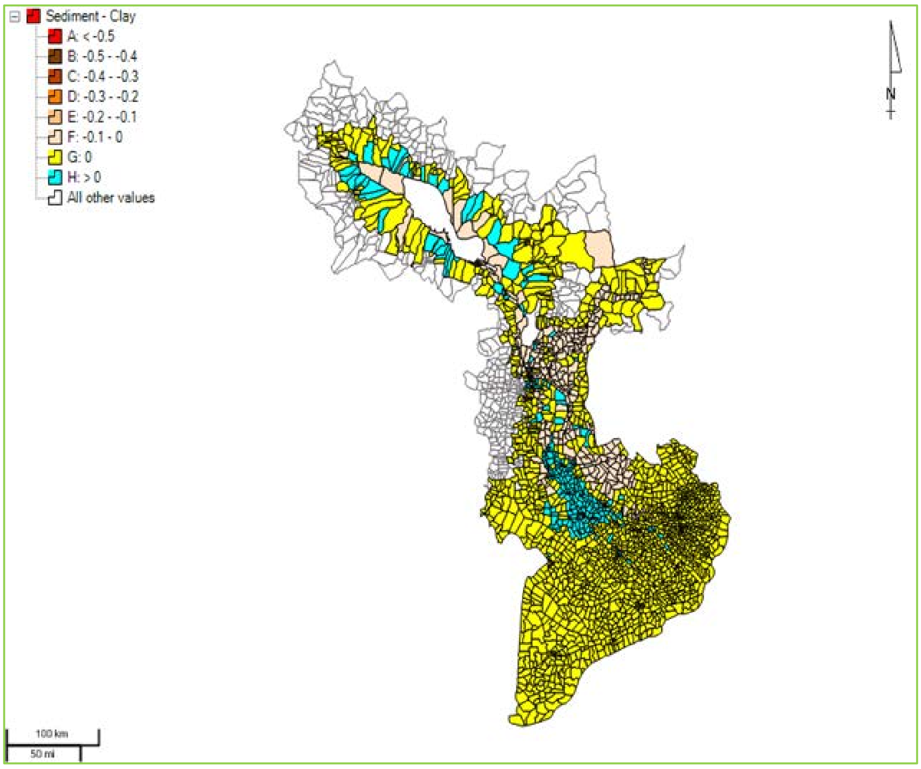


Figure 4.1-6: Impacts in washload transport in the Mekong Delta: Comparison between Scenario 1 and Baseline 2007: Silt (upper) and Clay (lower).

4.1.2.3 Impacts on Erosion

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 5m deep scour could occur due to the reduction in sediment load in the Mekong River resulting from sediment deposition in upstream reservoirs (Figure 4.1-7). 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.

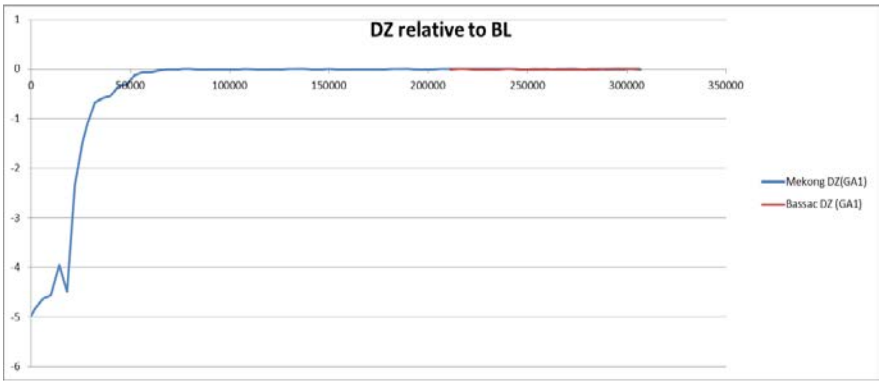


Figure 4.1-7 River bed erosion simulated for the period 1985 to 2008 for scenario 1 with Mainstream Dams.

4.1.3 Nutrient Impacts

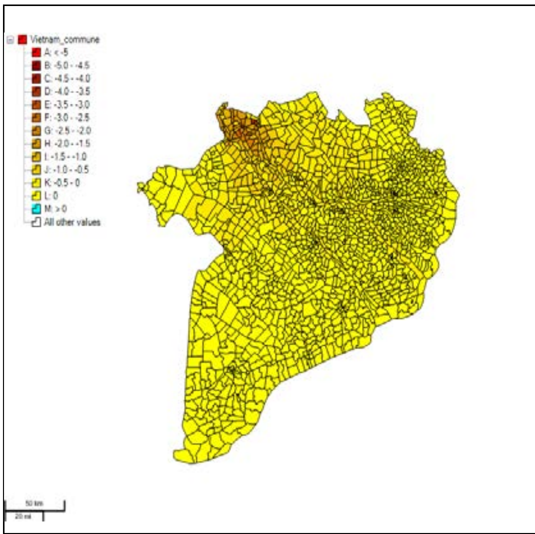
The transport of nutrients is affected through the reduction in sediment transport due to the amount of phosphorus and nitrogen adhered to the sediments. Table 4.1-5 shows the annual transports of nitrogen and phosphorus attached to silt and clay at Kratie and Tan Chau + Chau Doc for the Baseline and Scenario 1, 2 and 3.

Table 4.1-5: Transport of nutrients attached to silt and clay annually at Kratie and Tan Chau + Chau Doc for Baseline and scenario 1, 2 and 3.

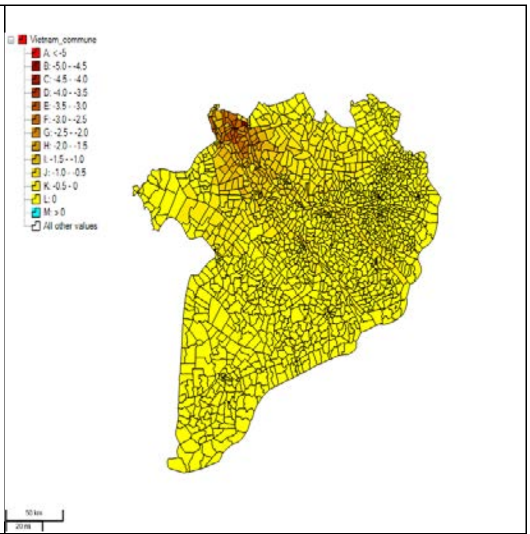
Nutrient	Scenario	Unit	Kratie	Tan Chau + Chau Doc
N	Baseline	1000 tons/year	48.7 ÷ 59.9	29.6 ÷ 36.8
	Scenario 1	1000 tons/year	21.2 ÷ 23.2	12.9 ÷ 16
		% loss	56.5 ÷ 61.3	56.4 ÷ 56.5
	Scenario 2	1000 tons/year	20.6 ÷ 22.7	12.7 ÷ 15.9
		% loss	57.7 ÷ 62.1	57.1 ÷ 56.8
	Scenario 3	1000 tons/year	20.6 ÷ 22.7	12.5 ÷ 15.9
		% loss	57.7 ÷ 62.1	57.8 ÷ 56.8
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

Similarly to the high impact on sediment transport, the effects of sediment trapping have a very high impact reducing the amount of nutrient transported to the Mekong Delta.

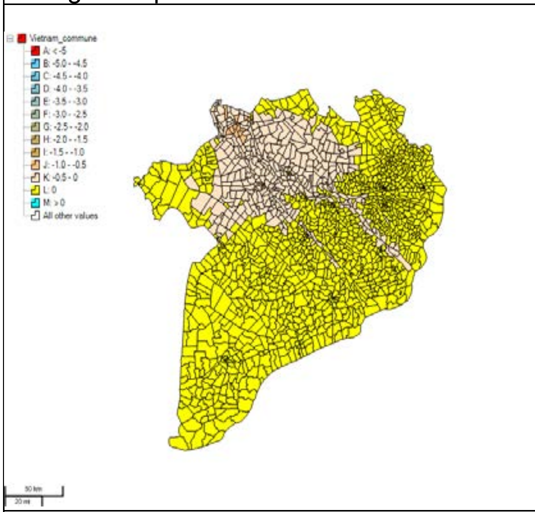
Figure 4.1-8 shows the distribution in changes in annual deposition of nitrogen and phosphorus in the Vietnamese part of the Delta for 2007 and 2008 in Scenario 1. Very high impacts in reductions of nutrient deposition rates are seen in the An Giang, Kien Giang, Dong Thap of the Vietnamese Delta. The size of reductions in nutrient deposition rates and their distribution are similar for scenario 2 and 3 compared to scenario 1.



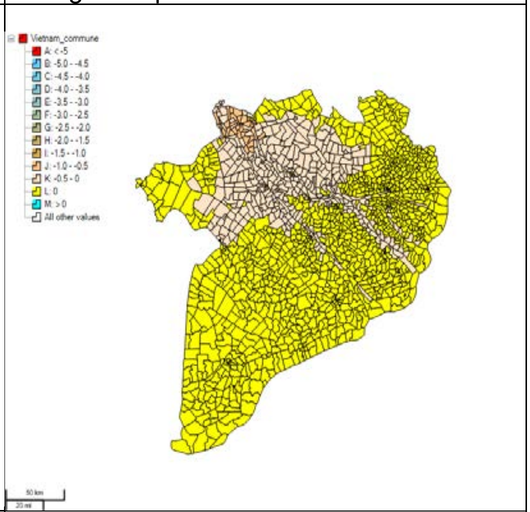
Nitrogen Deposition: Scenario 1 - 2007



Nitrogen Deposition: Scenario 1 - 2008



Phosphorus Deposition: Scenario 1 - 2007

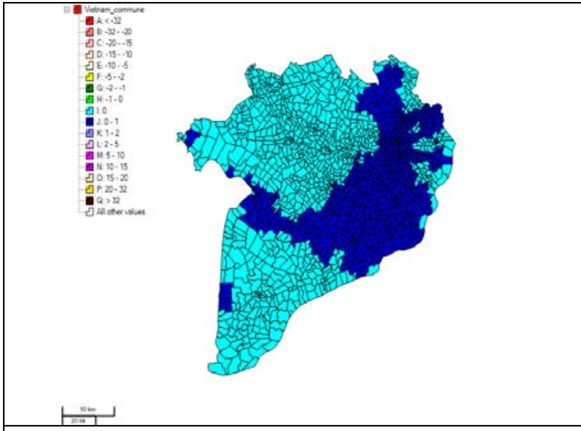


Phosphorus Deposition: Scenario 1 - 2008

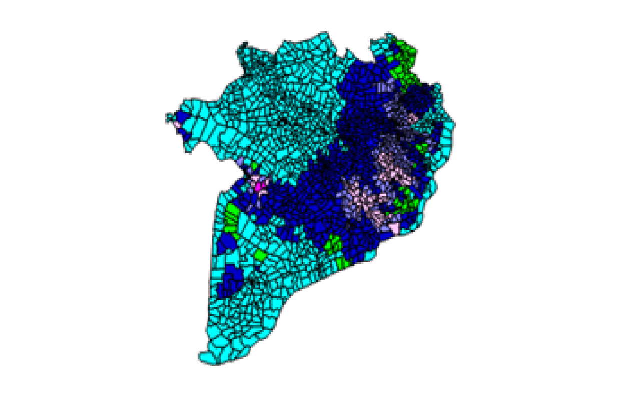
Figure 4.1-8: Changes in annual nitrogen and phosphorus deposition (g/m2/year) between Baseline and scenario 1 for 2007 and 2008.

4.1.4 Salinity Impacts

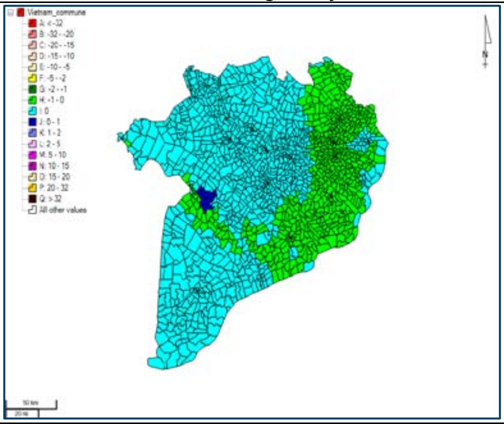
The introduction of the planned 11 mainstream dams result in a change in discharges as described above. These changes have a direct impact on changes in salinity intrusion in the Delta, especially during dry years, further affected by operation of the dams for increased power production, see Figure 4.1-9.



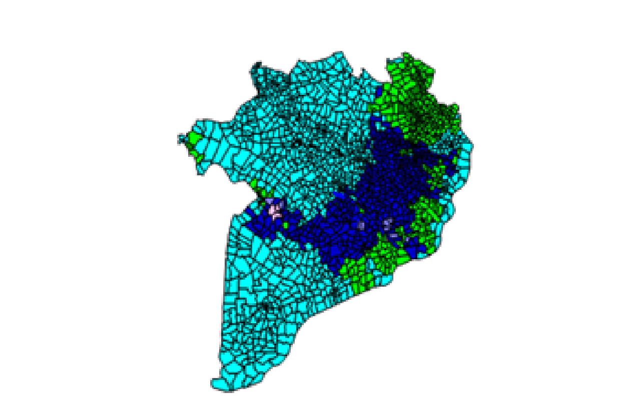
Scenario 1 – 1998 Average Dry season



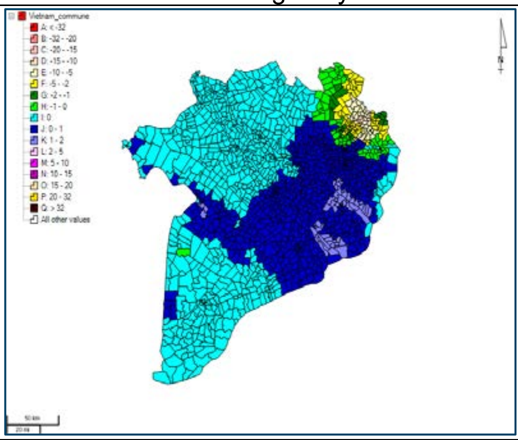
Scenario 1 – 1998 – Maximum Dry season



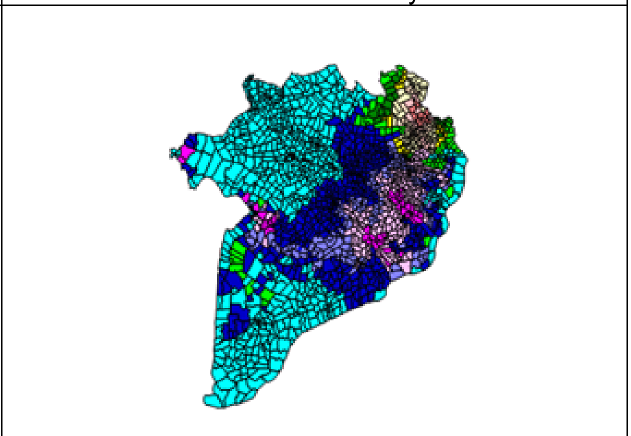
Scenario 2 – 1998 Average Dry season



Scenario 2 – 1998 – Maximum Dry season



Scenario 3 – 1998 Average Dry season



Scenario 3 – 1998 – Maximum Dry season

Figure 4.1-9: Difference in salinity levels (g/l) between Baseline and scenario 1, 2 and 3 for 1998 (Dry year). Average for Dry season (left) and maximum difference during the Dry season (right).

The changes in water discharges has medium to high impacts on the salinity distribution in the Vietnamese part of the Delta. There is an increase in salinity over the dry season in scenario 1 and Scenario 3 due to the implementation and operation of the Mainstream dams. Moreover, very high impacts on salinity in a short term (in the order of weeks) might be expected especially in middle of the dry season of the representative dry year with maximum salinity intrusion might go further into the Delta by 12.0 km and 10.0 km on the Mekong and Bassac branches, respectively.

4.1.5 Summary on impacts on drivers

Water levels and flows

Although the introduction of all 11 Mainstream dams (Scenario 1) together with additional tributary dams (Scenario 2) or water diversion (Scenario 3) may cause relatively modest reduction of water levels against the Baseline during normal or hydro-peaking operation of the dams (correspond to the representative average year of 2007) in the dry season, however, 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 level at Kratie is up to 1,66m, and 0.13m at Tan Chau in Scenario 1, up to 1,12m, and 0.12m in Scenario 2 and up to 1,60m, and 0.15m in Scenario 3, respectively.

Regarding water flows, similar to water levels, while water flow reductions between Baseline and Scenarios in the dry season during normal or hydro - peaking operation of the dams (correspond to the representative average year) seems to be relatively modest, however, short-term very high impacts might occur during the dry season of the representative dry year with the 10-day maximum loss of water volume at Kratie being approximately 60% in Scenario 1, 55% in Scenario 2, 68% in Scenario3 and at Tan Chau approximately 40%, 36 % and 44% for scenarios 1, 2 and 3, compared to the Baseline. Changes in flows are considered small in flood season

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 vary wildly (max 2.15m in Scenario 1, 2.13m in Scenario 2 and 2.19m in Scenario 3) against the Baseline. Further downstream the daily fluctuations would dissipate to small level at downstream Phnom Penh and continue declining to very small 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 probably cause wide fluctuation of water level immediately downstream and temporary, high reduction of river flow during the dry season of the representative dry year (e.g at Vientiane the magnitude of water level fluctuation is 1.18m in Scenario 1, 1.53m in Scenario 2,1.63m in Scenario 3 , and the 10-day maximum loss in water volume is about 62% in Scenario 1, 56% in Scenario 2, and 85% in Scenario 3). Changes during the flood season are considered small.

Sediment

Concerning sedimentation, all bed-load is considered to be trapped in the reservoirs at the present design. 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, from 59 % to 65% in Scenario 3, while at Tan Chau + Chau Doc the reductions are nearly the same for all 3 Scenarios, from 57 % to 64%, depending on hydrological years considered,

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 therefore impacts the accretion/erosion at and near the river mouths, with an estimated reduction of 4 to 12 meters per year, causing the loss of land in all 3 scenarios. Further away to the south-west, the impacts on erosion/ accretion rates are less than 0.5 meter per year, and the growth rate of the Ca Mau tip is expected to be reduced by approximately 1 meter per yearin all 3 scenarios. The changes add to a reduction in the present accretion and erosion rates. The recent accretion and erosion rates measured are considered to continuously being affected not only by changes in sediment transport to the Delta coastline, but also by sea level rise and subsidence caused by groundwater abstraction in the Delta. However, the rates of these future changes are not assessed as part of the present MDS study.

In the upper reach of the lower Mekong mainstream, it is considered that the mainstream reservoirs retain nearly all the bed material load and modest amount of washload. The retaining of bed material load coupled with the fluctuation of flows are likely to cause high rate of river bed and bank erosion downstream of the dam sites and along the mainstream. At the river courses in the Mekong Delta, due to the dams causing almost no upstream bed material load reaching the Delta, and in association with the increasing sand mining activities, the risk of erosion is high. The scope of this Study only initially 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.

Nutrients

The total transport of phosphorus in Scenario 1 at Kratie is reduced from 47% to 53% in Scenario 1, from 49% to 56% in Scenario 2 and 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% Scenario 3.

Similarly, the total transport of nitrogen at Kratie is reduced from 57% to 62% in Scenario 1, and from 58% to 62% in Scenario 2 and Scenario 3 compared to the baseline, while at Tan Chau + Chau Doc the reductions are approximately 57% for all Scenarios.

In the upper reach of the lower Mekong mainstream, it is expected that reduction of the total transport of nutrients are not high since the mainstream reservoirs only retain modest amount of washload that carries nutrients.

Salinity

Generally the changes in salinity are confined to the coastal areas in all 3 scenarios as expected. For the dry season in the average year with increase of salinity concentration covering a large area of approximately 7,550 km^2 in Scenario 1 and 11,200 km^2 in Scenario 3, while unchanged in Scenario 2. For the dry season in the dry year the area with increases in salinity is reduced in the southern part of the Delta while increased in the northern part, with a total area affected may be upto 14,000 km^2 in Scenario 1 and 14,700 km^2 in Scenario 3, and less in Scenario 2 (150 km^2). Moreover, very high impacts on salinity in a short term (several weeks) might be expected especially in middle of the dry season of the representative dry year with maximum salinity intrusion might go further into the Delta by more than 12.0 km and 10.0 km on the Mekong and Bassac branches, respectively.

The Table 4.1-6 below ranks the impacts on drivers:

Table 4.1-6: Summarized Table of Impact Assessment for drivers for all 3 scenarios

Country	Drivers	Hydrology	Duration	Scenario 1	Scenario 2	Scenario 3
VIET NAM	Water	Average year	Dry season	1	0	2
		Dry year	Dry season	1	0	2
			Short-term	4	4	4
	Sediment	Average year	Yearly	4	4	4
	Nutrients	Average year	Yearly	4	4	4
	Salinity	Average year	Dry season	1	0	3
		Dry year	Dry season	2	1	4
			Short-term	4	4	4
CAMBODIA	Water	Average year	Dry season	1	0	2
		Dry year	Dry season	1	0	2
			Short-term	4	4	4
	Sediment	Average year	Yearly	4	4	4
	Nutrients	Average year	Yearly	4	4	4

0	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

4.2 *Fisheries Impact Assessment*

Direct Impacts – Major direct impacts are summarized below in Tables 4.2-1. The projected impacts are ranked by indicator using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 4.2-2.

- Overall, there is an estimated about 50% reduction in fishery yield for both Viet Nam and Cambodia as a result of the mainstream hydropower cascade.. 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 ten commercial fish species.

- The major impacts on capture fisheries are due to migration of white fish species, the major commercially caught species, by the dams. 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 localized 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 3 scenarios. This reduction could potentially have substantial adverse impacts on fish productivity that may decline by as much as 50% throughout the IAA. This adverse impact will mostly affect the short distance migrating whitefish, grey fish, generalist and estuarine resident guilds.

- Sediment retention by the proposed Cascade could also have a major impact on coastal fish production, and subsequently on the Vietnamese fishing sector and fish trade.

- While flows and water levels are unlikely to change substantially in the Vietnamese Delta, there will be a disconnect caused by the reduced sediment loading, which will have a knock on 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.

- Changes in catch rate and harvest due to hydrological alterations under all 3 scenarios will be marginal and within the bounds of natural variability of the river's hydrology.

- Hydropeaking operations of the dams 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 refugee 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 and this will livelihood of the people dependent upon fishing in this region. Quantifying these effects is challenging of lack of fisheries data from the river reach around Kratie.

Table 4.2-1: Capture fisheries impacts summary by indicators

Indicators/Sub-indicators	**Viet Nam**			**Cambodia**		
	Sce.01	**Sce.02**	**Sce.03**	**Sce.01**	**Sce.02**	**Sce.03**
Total Yield loss of capture Fisheries (Tonnes, %)	335,675	336,799	337,840	238,377	241,075	241,511
	48.5%	48.7%	48.8%	49.5%	50.1%	50.2%
Yield loss of economically important species (tonnes)	196,739	197,397	198,008	116,805	118,127	118,340
Fish catch diversity (Species at risk)	33	33	33	37	37	37
	10.2%	10.2%	10.2%	14.0%	14.0%	14.0%

Table 4.2-2: Capture fishery impact summary ranked by level of impact

	Indicator	Scenario 1		Scenario 2		Scenario 2	
		Cambodia	Viet Nam	Cambodia	Viet Nam	Cambodia	Viet Nam
Capture fisheries	Loss of fish catch yield	4	4	4	4	4	4
	Loss of OAAs yield	4	4	4	4	4	4
	Loss of yield of economically important fish species	4	4	4	4	4	4
	Species loss in catch composition	4	4	4	4	4	4
Aquacult -ure	Change in extent of aquaculture area per species group	1	1	1	1	1	1
	Change in production per aquaculture species group	1	1	1	1	1	1

0	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

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

- The impacts of each individual dam are likely to be similar in terms of the types of impacts, although the spatial scale and intensity of the impact will vary depending of the dam design and operation, and success of proposed mitigation (especially fish passage) measures. The impact of the 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.

- Overall, however, the impact of dam development will be considerable and will affect food security and livelihoods in the Mekong delta and Cambodian floodplain. Alternative animal protein sources are likely to be required by rural communities to avoid nutritional deficits and societal disruption in the rural communities of the IAA.

- 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 projected to go globally extinct.

- The overall potential loss in fisheries yield represents a major loss in food provision for mainly the rural communities that are dependent on fisheries for over 60% of their protein intake, but also supply to markets in larger cities and towns.

- 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, nevertheless, are widely regarded as more complicated. The need for further study where the culture area extended over more provinces and when more data on relationship between environment 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 delta aquaculture sector is partly dependent on local protein source from marine 'trash-fish' to feed the aquaculture fish for feedstock.

Note that it is possible that at the basin-level, loss of fisheries in the IAA would be to some degree compensated for by increase in reservoir fisheries. But it is very likely that non-native, invasive species, and low value fish would flourish in the reservoirs and while this additional biomass would compensate to some extent for 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. Fishers in the IAA, which a long distance away even from the lowest dam in the cascade, will most likely see no benefit from any increase in reservoir fisheries.

Indirect and secondary impacts – could include the following:

- 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- of 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 probably going to a very 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.

- 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.

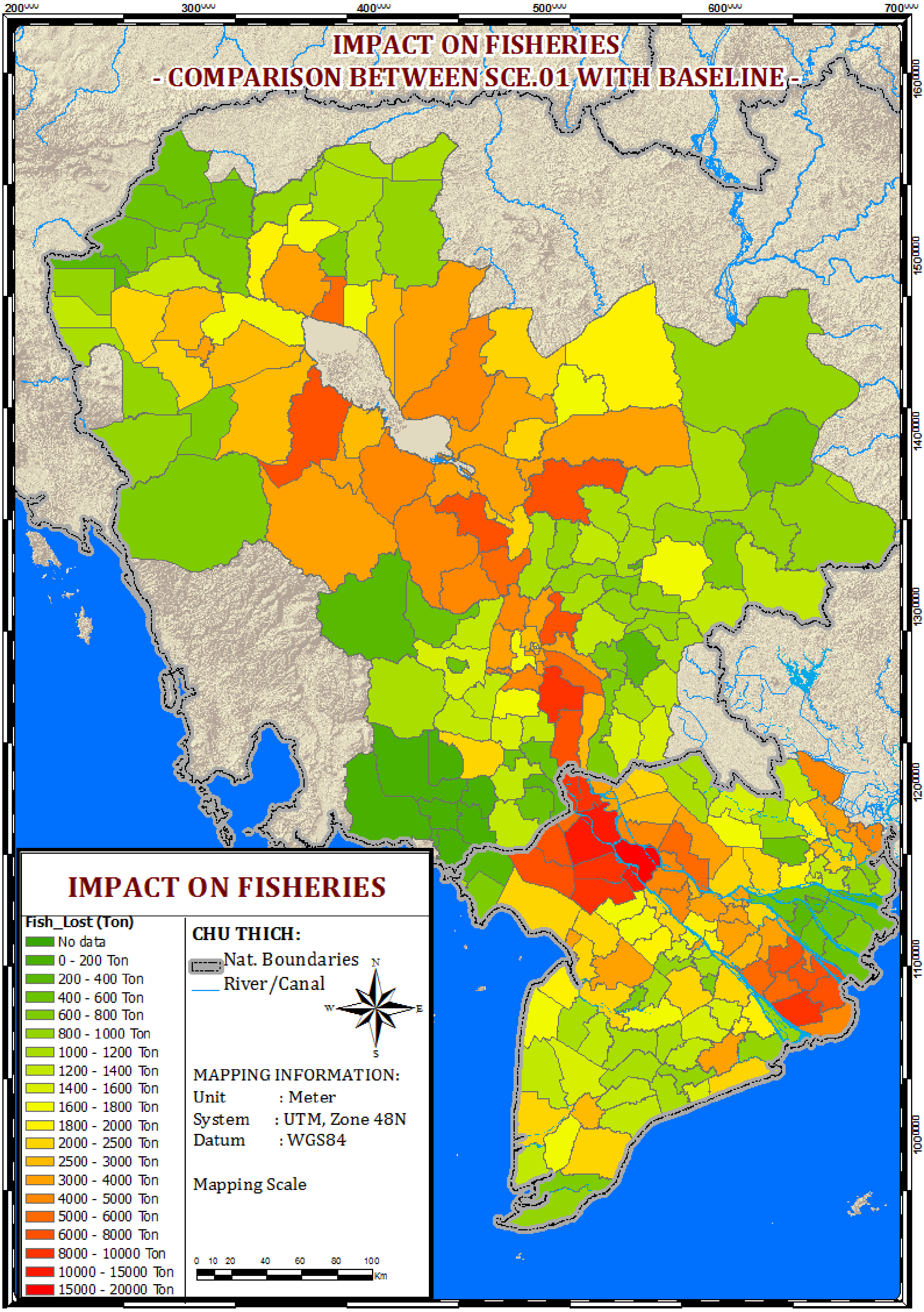


Figure 4.2-1: Total Fish Lost – Comparison between Sce01 and Baseline.

Recommendations for future data collection and studies – The robustness of the assessment results can be improved in the future 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 yiled and catch species composition throughout the basin.
  - Genetic studies of vulnerable migratory fish species in the Mekong River 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.

4.3 Biodiversity Impact Assessment

Direct Impacts – Major direct impacts are summarized below. They were ranked by indicator using a scale of 0 (no impact) to 4 (very high impact) as shown in Table 4.3 -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 percent 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, and
  - 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.
- Sediment and nutrient deposition would decrease by up to 60 percent 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 a reduction in productivity throughout the IAA.

- 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 and 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 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, there may unlikely be significant changes in the volume or timing of flows and thus not likely 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. 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 water withdrawals in Thailand and Cambodia, 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 are not likely to substantially affect movements of migratory fish or other aquatic organisms in the IAA.

Indirect and secondary impacts – could include the following:

- 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. About 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 conjecture that after the entire cascade is constructed and operated for some time; the LMB will most likely support fewer overall species of fish and OAAs, and therefore probably 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- of 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.

Table 4.3 -1: Biodiversity impact summary by indicators

Indicator	Scenario 1			Scenario 2			Scenario 3		
	Cambodian Floodplain	**Tonle Sap**	**Mekong Delta**	**Cambodian Floodplain**	**Tonle Sap**	**Mekong Delta**	**Cambodian Floodplain**	**Tonle Sap**	**Mekong Delta**
Change in the extent of open water and floodplain wetlands	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
Change in wetlands composition within biodiversity hotspots	0	0	0	0	0	0	0	0	0
Risk of reduction in biodiversity	2	0	1	2	0	1	2	0	1
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
Loss of riverine habitat caused by changes in sediment transport	2	1	1	2	1	1	2	1	1
Loss of coastal wetlands (mangroves) caused by changes in sediment transport			2			2			2
Risk of extirpation	4	4	4	4	4	4	4	4	4

0	**1**	**2**	**3**	**4**
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

- A decrease in nutrient availability and associated reduction in primary productivity will also cause changes in reproductive output and abundance of some terrestrial and aquatic animal species, and possibly a shift in the composition of animal communities. It is not possible to determine the magnitude of changes in abundance or reproductive output, or to identify the species most affected, as there have been very few studies of the effects of a change in water-borne nutrients on animal communities.

- A decrease in the transport of silt and organic matter, including large woody debris, could cause a change in the structure of aquatic areas and could cause a reduction in some benthic invertebrates and other aquatic species.

- Since overall the Mekong River ecosystem would be adversely affected under Scenario 1, due to direct impacts on water quality and biodiversity, it is reasonable to deduce that indirect impacts could also flow down to the intangible, biodiversity related benefits that the locals derive from the river. For example, the river dolphins are considered an item of national heritage. Blockage of the main river channel could adversely affect the range and distribution of this species and potentially lead to its extirpation from the region. This would be very high impact on a vital cultural resource.

- It is important to note that there is substantial uncertainty about the magnitude and direction of the secondary effects listed above, as there are no region-specific studies and few applicable analogous situations that can be applied to the LMB

4.4 Navigation Impact Assessment

Direct Impacts –Major direct impacts are summarized below. They were ranked by indicator using a scale of 0 to 4 as shown in Table 4.4-1.

- 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 3 scenarios evaluated, the greatest impacts are likely to occur under Scenario 3.

- The river section from Kampong Kor to Phnom Penh would be much less impacted and vessels as large as 2,000 DWT could continue to operate.

- No significant adverse impacts on navigation are projected down stream 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.

- Similarly, no detectable adverse impacts on navigation are projected for the Vietnamese Delta

- If hydropower cascades were to be operated for temporarily maximizing power production during dry seasons, there would be large fluctuations in discharge levels and water depths and sudden drops in water levels. This would be a serious safety hazard to vessels in the river, and could potentially cause an increase in 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 is estimated to be 45 minutes, which will add to transit time potentially leading to an increase in river transportation costs.

- Erosion of the riverbank near Kratie caused by large, rapid water fluctuations and a decrease in sediment transport, and it could cause damage to navigation facilities in that area.

Indirect or secondary impacts – are mostly related to 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.

Navigation impact avoidance and mitigation – Projected impacts could be reduced through adoption of a safe operation regime of hydropower cascades that does not produce large fluctuations in discharge and water levels. With view of hydropeaking operations at Sambor dam, a warning system should be installed from Kampong Cham to Phnom Penh to alert people when high flows are released downstream.

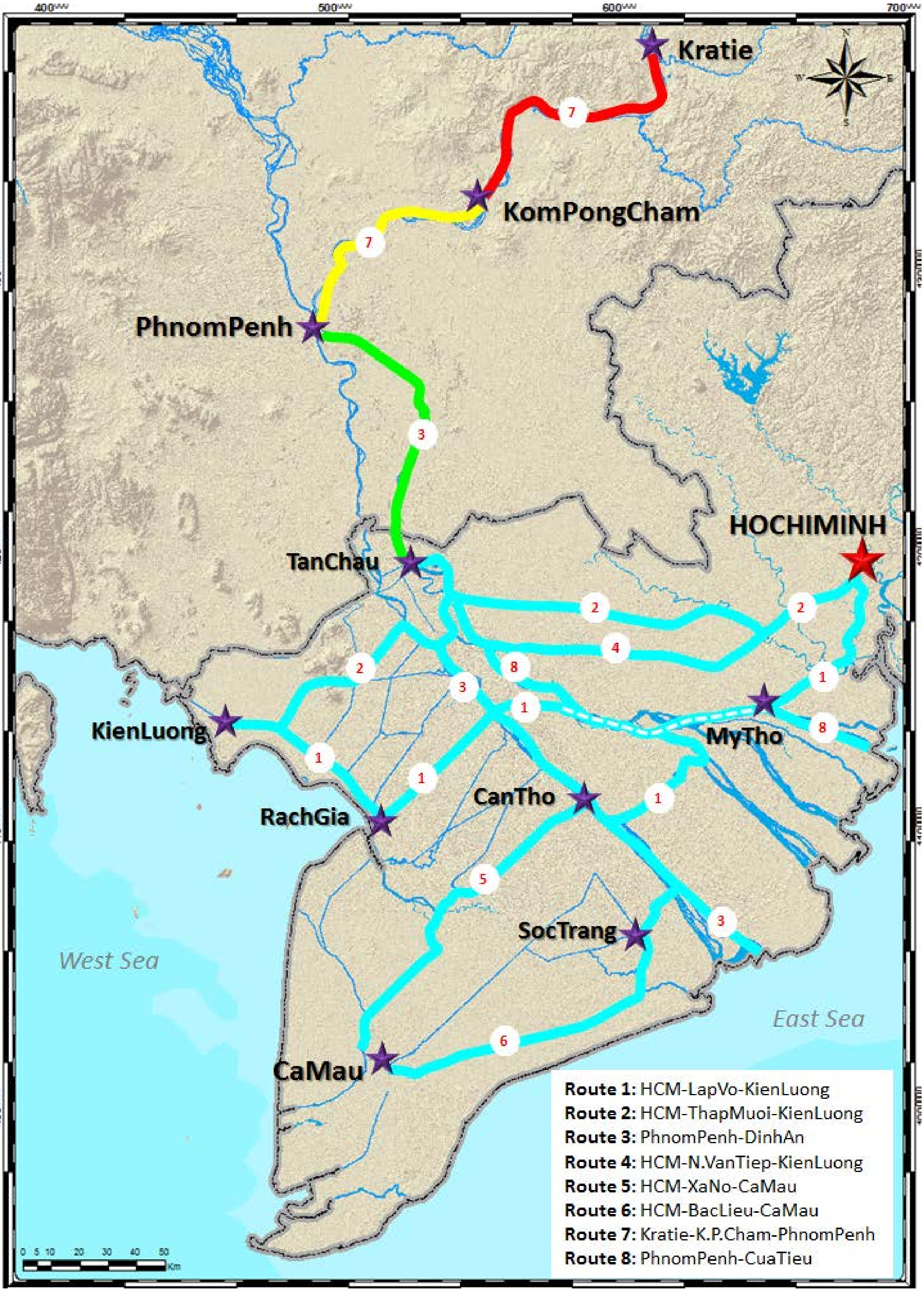


Figure 4.4-1: Summary of navigation impacts under Scenario 1.

0	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

Table 4.4-1: Navigation impact summary by indicators

Indicator	Scenario 1		Scenario 2		Scenario 3	
	Cambodia	**Viet Nam**	**Cambodia**	**Viet Nam**	**Cambodia**	**Viet Nam**
Change in flow regime, water depth in the river.	3	0	3	0	3	0
Change in transport capacity	1	0	1	0	1	0
Physical barriers – Longitudinal connectivity	1	0	1	0	1	0
Change river morphological condition due to sediment transport	1	0	1	0	1	0

0	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

Note: the moderate impacts in Cambodia are mostly due to dam operational modes such as hydropeaking and the impacts are localized in the area downstream of Kratie.

4.5 Agriculture Impact Assessment

Direct Impacts – Major direct impacts are summarized below. They were ranked by indicator using a scale of 0 (no impact) to 4 (very high adverve effect) as shown in Table 4.5-2.

- Under Scenario 1, comparable reductions in rice and maize yields have been estimated. Main impacts on rice and maize production (year 2007, if the hydropower dams release as normal operation and with hydro-peaking operation) are due to sediment reduction, not much due to salinity changes and not due to inundation. Reduction in sediment inputs into communes of Viet Nam and Cambodia shows that the main change is from silt, and only little from clay.
- Overall, the impacts due to sediment reduction are only about 2.3% of total rice production in Viet Nam if this reduction lasts for 10 years. However, if it last longer (up to 50 years), it could reach about 10%, with an average of 2% increase in reduction of rice production for every 10 years longer in Vietnam, and up to 8.1% in Cambodia.(see table 4.5-1)

Table 4.5-1: Projected decrease in annual rice production in Viet Nam associated with sediment reduction under Scenario 1

	Projected Rice Production Estimates under Scenario 1 (t/year)				
	10 years	**20 years**	**30 years**	**40 years**	**50 years**
Baseline 2007	24,009,228	24,009,228	24,009,228	24,009,228	24,009,228
Scenario 1	23,456,768	22,921,859	22,411,677	21,957,240	21,583,013
Scenario 1 – Baseline	-552,460	-1,091,552	-1,604,115	-2,056,230	-2,432,776
% difference	-2.3	-4.5	-6.7	-8.6	-10.1

- It should be noted that these percentage values are low because they are compared with the total rice production of the entire VMD or CMD, including the communes where impacts are very minor due to long distance or only having small channels linking with main rivers. For example, the reduction of 2.3 % in the VMD is a low value, but it is equivalent to a high reduction of over half of million tons, because the total annual rice production of the VMD is as high as over 24 million tons. If production in the provinces with significant impacts as An Giang and Dong Thap are considered, the reduction is higher, from 6% to 10%. Similarly in the CMD, the reduction in highly impacted provinces could be up to 17-23% of total rice production.
- Because the NPK nutrient balance for crops are not the same ratio of NPK provided by sediment, i.e. the crop may fully uses of certain nutrient (as N) but not all of the others (as P or K) provided by the sediment. The amount of fertilizers used by the farmers to compensate cannot be estimated by using the nutrients from sediment. Instead, the rate of each nutrient need to produce each tonne of crop product is used to estimate the required fertilizers. Therefore to compensate the reduction of 552,460 tonnes in Scenario 1, farmers in Vietnam (2007) would have to apply 22,098 tonnes of N, 3,315 tonnes of P and 11,049 tonnes of K. The cost of the compensation fertilizers is taken into account in the economic analysis.

- If local farmers who has not much technology experience feel that the sediment reduce will effect the supply of NKP to the crop, they will use more fertilizers to replace, and that reaction with cause more environmental problems in future.

Indirect and secondary impacts – could include impacts on livelihood and social well being due to agricultural losses. The abuse of fertilizer 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 in the economy of the VMD and CMD are estimated in the economic analysis.

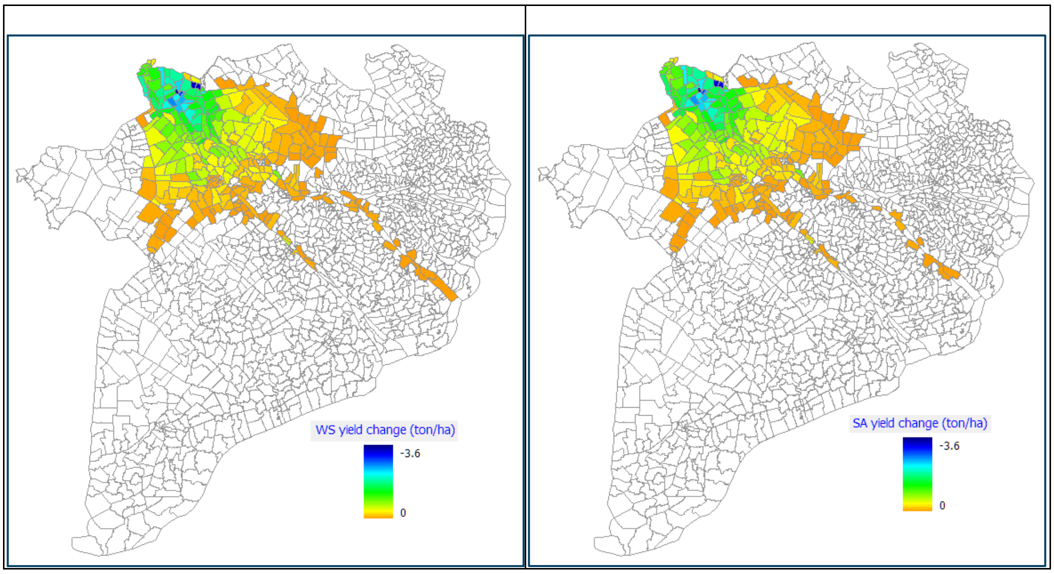


Figure 4.5-1: Change in WS, SA rice yield under Scenario 1

Table 4.5-2: Agriculture impact summary by indicators

	Indicator	Scenario 1		Scenario 2		Scenario 2	
		Cambodia	**Viet Nam**	**Cambodia**	**Viet Nam**	**Cambodia**	**Viet Nam**
Crop production	Seasonal and annual rice production	1	1	1	1	1	1
	Annual maize crop production	1	1	1	1	1	1
Crop Area	Rice crop area (ha) for the main crop seasons	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	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

4.6 Livelihood Impact Assessment

Direct Impacts – Major direct impacts of all Scenarios 1÷ 3 on livelihood are summarized below:

Key direct livelihood impacts in Cambodia and Viet Nam are due to changes in water level reductions (occurred when dam release is declined in dry season) and due to increase in salinity intrusion in Viet Nam part. Both these factors could potentially have **high to very high impacts on livelihood** in affected communes within the impact assessment area.

- There are about 32-36% local people within the impact assessment area in Viet Nam will be effected by flooding. And also about ~58% local people within the impact assessment area in Cambodia will be affected by flooding. The flood water will makes impact into around 33% and 87% total communes' area within the impact assessment area
- There are about 51-57% local people within the impact assessment area, corresponding with 50-61% total area in Viet Nam will be effected by saline water
- There are about 65-67% local Vietnamese farming people and about 83-85% local Cambodian farming people within the impact assessment area will be effected due to the water level reduction and salinity increasing
- Due to water level, sediment reduction and salinity increasing, direct losses in fishery and agricultural production indirectly affect livelihood of the resident populations, to be discussed in Economic sector. It was found that: In Cambodia, the local people will lose 23% their income from fishery and agricultural production and each HH will lose 15.3% of fish consumption per year. In Viet Nam, the local people will lose 16% income from fishery and agricultural production and each HH will lose 15.0% of fish consumption per year.

Indirect impacts – As discussed in the fishery and agriculture impact assessment sections, direct losses in fishery and agricultural production indirectly affect live hood of the resident populations. People with high vulnerability are most affected. Small, family-owned farms, in particular have high sensitivity to water level and salinity changes. Often this high sensitivity is coupled with low resilience and adverse impacts on such groups are proportionally higher. Even minor changes in flows or salinity can translate into large adverse effects. For such populations, even a small loss of income can translate into a disproportionally large change in living conditions, food security, employment, health, education, and overall well-being.

Water level reductions may adversely affect pumping of water for agriculture and domestic use. This could also lead to **high to very high direct and indirect impacts on livelihood**.

Due to the limitation of the project' resources and data availability, thus in this stage, during the assessment processing, not all the long-term indirect impact indicator of the livelihood sector which may cause some unexpected impact have been considered. So, a plan to further study the long-term indirect impact on the livelihood sector will be done in next stage

The major direct impacts on livelihood of the Scenarios are summarized below. They were ranked by indicator using a scale of 0 (no impact) to 4 (very high adverve effect) as shown in Table 4.6-1

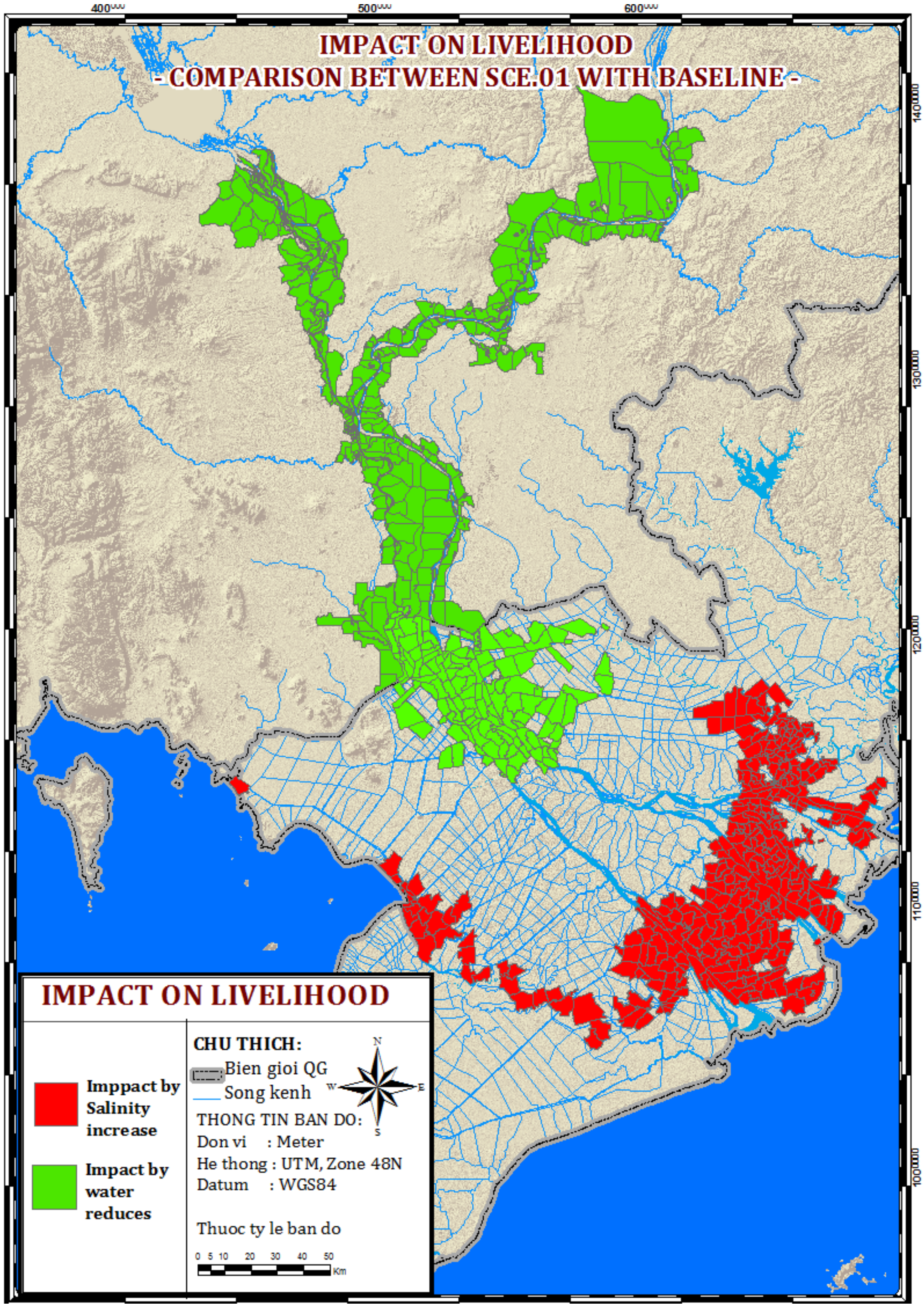


Figure 4.6-1: Impact of flooding and salinity to the livelihood of local people - Comparison between Scenario 1 and Baseline

Table 4.6-1 Livelihood impact summary by indicators

	No.	Key Indicators	Sub-Indicators/Parameters	Scenario 1		Scenario 2		Scenario 3	
				Cambodia	Viet Nam	Cambodia	Viet Nam	Cambodia	Viet Nam
Livelihood	Exposure	Population/area directly affected by flood (Affected standard is flooded 0.5 m and in 10 continuous days)	Area affected by flood	1	1	1	1	1	1
			Population affected by flood	1	1	1	1	1	1
		Population/area directly affected by salinity intrusion (1 ppt over 7 days)	Population affected by salinity intrusion	0	4	0	3	0	4
			Area affected by salinity intrusion	0	3	0	3	0	4
	Sensitivity	Farming population affected by changes in water level, sediment and salinity	Percentage of population in full or part-time farming	2	3	2	3	2	3
		Capita income from farming	Total income from farming, as net benefit	3	2	3	2	3	2
		Level of dependency on water related resources	Annual Average Consumption of fish per HH	2	1	2	1	2	1

0	1	2	3	4
No effect	Low adverse effect	Moderate adverse effect	High adverse effect	Very high adverse effect

4.7 Economic Impact Assessment

Direct impacts – Economic impacts under all 3 scenarios were generally comparable.

Key impacts for Viet Nam include the following:

- The scale of economic impacts, if measured across the entire Vietnamese Delta economy, is relatively modest.
- When the impacts are assessed from a more narrowly defined region – riparian communes – **the impacts are likely to be quite significant.** Among the over 110 communes that are highly impacted, i.e. they could lose more than 10% of net income, most are located in Dong Thap and An Giang. Among these set of communes alone, the average impact to net income exceeds 20%. The hardest hit communes could witness an over 50% decline in net income. The impacts to communities like these are discussed in more depth in the livelihood section.
- It is expected that fishers and farmers in these areas would undertake measures to mitigate and adapt to these changing conditions.

Key impacts for Cambodia include the following:

- The predicted levels and type of impact would widespread and substantial impacts to the country, not just to a single sector as in the case of fisheries in Viet Nam.
- These losses in fisheries will affect an entire national industry of high importance.
- Farming systems, especially in paddy growing regions near the Vietnamese border, will also incur substantial losses.
- The scale of these losses in over 40 communes could amount to over 90% of production and per capita income – which is a complete collapse of production there. Another 30 communes could include losses of per capita income of between 50 and 90%. These communes are located mostly Kandal and Kampong Cham.
- The impacts would also be incurred by farmers and fishers with the least amount of resources to adapt.

Indirect impacts – Changes in production systems, especially those that could be as widespread and deep as the agricultural impacts in some communes and the fishery sector in general, are not single events. The direct value of impact can be measured with current prices, but markets continue to adapt in a variety of ways. This analysis has not attempted, except in the analysis of agricultural impacts to assess farmer adaption strategies with supplemental fertilizer. Instead, this analysis has considered the quantified impacts as a potential indicator of change or a latent impact – before farmers respond.

It is reasonable for farmers and fishers alike to make the investments and adjustments necessary to maintain their production and net incomes as much as possible. In addition, it is also possible 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 note been fully implemented in the analysis.

5 Discussion and Conclusions

Key findings from the impact assessment are summarized below.

- Though modest changes expected for 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 (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 have the highest impacts from high fluctuated flows and water level. **Amongst three assessed scenrios, impacts on flow regimes of Scenario 3 are worst, while those of Scenario 2 lesser.**

- Sediment and nutrient deposition would decrease up to 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. **The Scenario 2 poses most severe impacts on sedimentation and nutrients in comparison to the others two.**

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

- Travel routes of long-distance migratory fish (white fish), which account for 74% of the catch of the top ten 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 presence of the dams is expected to cause a very high decline in total capture fishery yields of about 50% for both Viet Nam and Cambodia**. **Tributary dams and diversion may cause cause additional impacts on fisheries at a marginal increase.** The substantial loss of capture fishery resources would adversely affect 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 percent 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, low to moderate adverse impacts are projected on agricultural productivity. But within the areas that are impacted, the impacts would be high.

- Key significant impacts to the livelihood of people in the region would occur due to water level reductions, and increase in salinity incursions in the Vietnamese Delta. Livelihood will also be indirectly impacted due to direct impacts on capture fisheries, agriculture, and navigation.

- Economic impacts within the riparian areas and the floodplains could be high.

The nature, magnitude, and trends of impacts reported by the MDS should be interpreted with caution for the following reasons:

- The projected impacts are based on 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, sand mining, etc. that may compound the projected impacts.
- The projected impacts may be substantially altered due to natural phenomenon such as climate change, sea level rise, vertical land motion (subsidence). Due to schedule and resource constraints, the MDS was not able to include these factors into the analyses.
- The MDS impact assessment area is located to the south of the lowermost dam in the cascade. It is acknowledged that much more severe direct impacts, than projected by the MDS, are likely to occur within the actual footprint of each individual hydropower projects. As individual projects are built and operated over time, indirect impacts from individual projects will compound spatially and temporally and likely influence direct impacts projected by the MDS for the IAA. The trend and timing of such indirect influences need further studies.
- It is well established that biological resources are adaptive by nature and that over time, the LMB fauna and flora will adapt to counter and overcome at least some of the projected impacts. However, the proposed cascade represents establishment of 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 diminishing of the projected impacts through natural adaptation can be assumed, the magnitude and direction of the adaptions are hard to project and they can not fully compensate for all projected impacts.
- There is a range of uncertainty associated with the input data used of the impact assessment.
- Alternate analytical approaches were used where there was a lack of standardized protocols and modeling tools. There is therefore an inherent uncertainty in using an alternate surrogate approach.

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 3 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.**

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 diversity. Therefore, it is uncertain what degree of relief fish passage technologies may 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 characterize the hundreds of fish species in the basin.

The projected impacts are based on a robust combination of quantitative and qualitative analyses of the best available data with advanced modeling systems and customized 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 recognizing that biological resources are adaptive by nature and over time to counter and overcome some of the projected impacts, but such adaptations cannot fully compensate for the projected effects.

In conclusion, the planned hydropower cascade would cause very 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 over 50 percent, and up 10 percent 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.

Overall, in Cambodia a national industry of high importance (fisheries) would suffer very high decline in yields and widespread adverse impacts are anticipated in the riparian areas downstream of Kratie which would be most severely impacted. Viet Nam would also suffer great losses in fisheries and biodiversity, and experience potential impacts due to increase in salinity incursions.

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. **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 view of 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 Delta's related values.