MEKONG RIVER COMMISSION

THE COUNCIL STUDY

The Study on the Sustainable Management and Development of the Mekong River Basin, including Impacts of Mainstream Hydropower Projects

Modelling the Impacts of Climate Change and Development Infrastructure on Mekong Flow, Sediment Regimes and Water Quality

Modelling Volume 1: Summary Report

January 2018

Disclaimer:

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CONTENTS AMENDMENT RECORD

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Prepared By
1	1	Baseline and Main Scenarios	15 April 2017	MRC Modelling Team Sopheap Lim and Anthony Green with contributions by Nguyen Dinh Dat, Ornanong Vonnarat, Rattykone Sayasane, Rachel Blakers and Jorma Koponnen
1	2	Update for May 2017 including WUPFIN	19 May 2017	As above
1	3	Subscenarios formulation results	25 August 2017	As above
1	4	Additional Information for ISIS and Subscenarios results	19 September 2017	As above
1	5	Additional Sub Scenario results including WUPFIN and Coastal	31 October	As above
2	0	Draft Final Following Consultation comments	25 January	As above

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Executive Summary

This report contains a summary of the results from the application of a comprehensive set of water resource modelling tools to provide quantitative results for the MRC Council Study. The modelling builds on 15 years of development using the MRC Decision Support Tools (DSF) extended and utilised where needed with other detailed models developed under earlier 'WUP-FIN' project and incorporated eWater Source. The work significantly expands the knowledge base on hydrology, sediment and nutrient movement in the Mekong Basin that can be transferred into MRC Member Countries in line with the aims of the Council Study. The eWater Source model was used to extend the capability of the Water Resource model IQQM to sediment and Nutrient movement. WUPFIN tools were used to extend the parameters derived from the results of the DSF models for input to BioRA model 'DRIFT' (not included here) and the agricultural and aquaculture impact through crop simulation using the FAO 'Aquacrop' and a number of empirical formulations for impacts using a raster based approach coded into the 'IWRM' model. A preliminary coastal model was also developed.

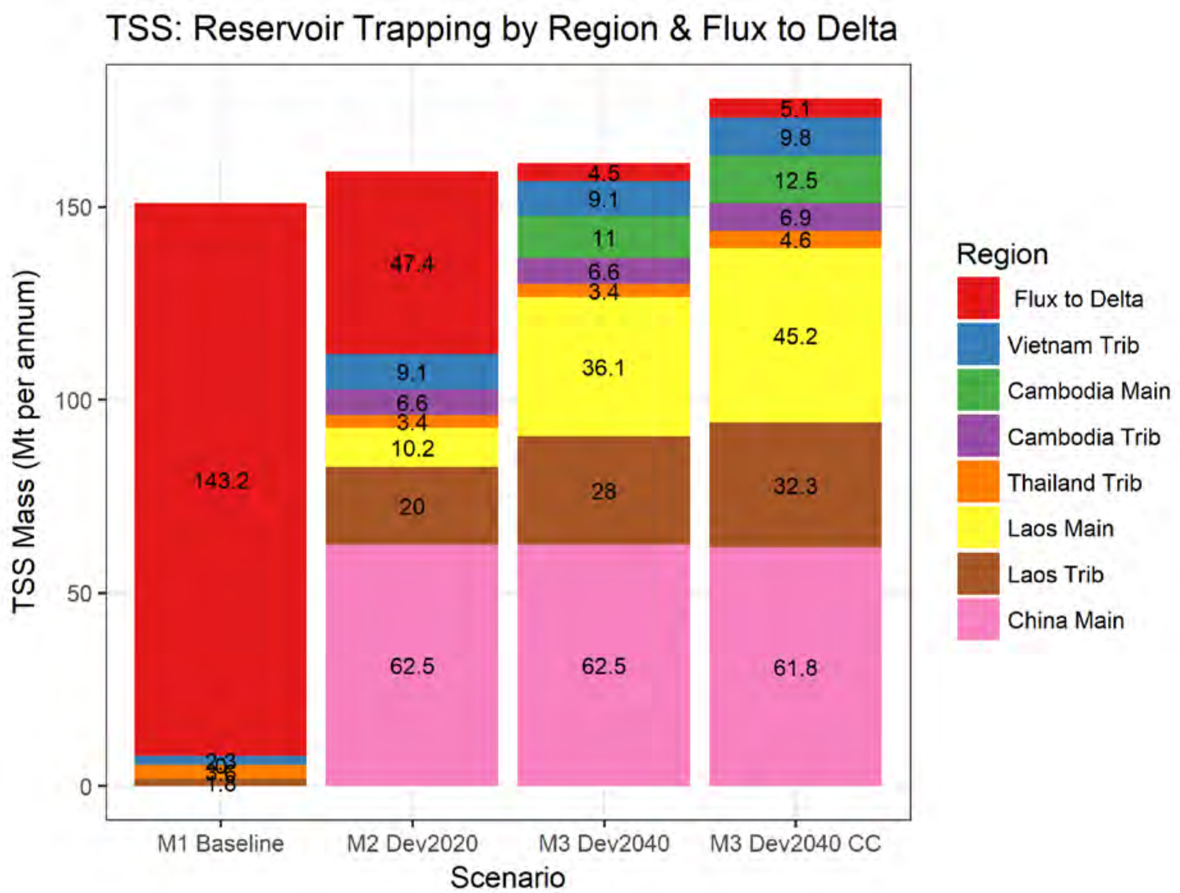
The Modelling supports other sector assessments (Land Use Change, Irrigation Development, Domestic and Industrial Water Use, Flood, Navigation and Hydropower) and provides information for Social, Economic and Environment components of the Council Study. A scenario based approach is being used to consider a range of future conditions in the near future (2020) and a longer term planning horizon (2040) compared with an early development condition (2007). Uniquely the future scenarios consider the whole range of likely water resource developments within the context of other exogenous change such as urbanisation and economic development. The 'Main Scenarios' are thus the best projected estimate of the future with all planned and expected change and a series of 'Sub Scenarios' are used to show the relative importance and consequence of different assumptions made in each of the main sectors related to water resources: flood and river bank protection, hydropower, irrigation, land use and agriculture, navigation, domestic and industrial water use and also climate change. This is a radical difference to studies that consider only narrow sectoral change.

The Key Results from the models and assessment tools show significant change can be expected in the Mekong River flow, sediment and nutrient regime due to the cumulative effect of all developments considered. There are, however, many facets and subtleties in the changes in flow regime of the Mekong system that may be positive and/or negative in different ways. Other reports of the Council Study provide biological, social and economic assessments of the changes based on the modelled outputs which are further elaborated for each of the 6 water sectors consdered. Within the modelling reports hydrological assessment (including sediment, nutrient and salinity) is also carried out in accordance with the MRC Procedures and Technical Guidelines and may be compared with the earlier findings of MRC such as for the Basin Development Plan.

Seasonal Flow Changes: With the development of storage dams for hydropower in both the Upper and Lower Basins there is a redistribution of flow between the wet season with lower flows and the dry season increased flows. The average changes are shown in Table 1. Whilst increased dry season flow may appear as a potential benefit, flood areas and the reversal of the Tonle Sap river to the Great Lake are reduced impacting the flood pulse dependent eco systems. The Lake also acts as a dry season storage benefitting the control of salinity at the coast. The reversal in flow on average (36km^3) will be 8% lower for M2 (2020), 5% M3 (No CC 2040) and 9%. Expressed another way a dry year would have a reversal of 58% (2020), 60% (M3) or 55% (M3 CC) of the baseline average. Much of the change occurs in Scenario M2 indicating the strong influence of the large dams in the Upper Basin.

Flooding: The peak annual flood flows in the Mainstream above Kratie show a decline in the average and high floods for M2 and M3 Scenarios. With climate change (M3 CC) the average flood changes little but extreme floods may increase significantly steepening the flood growth curve by up to 76% around Vientiane and increasing flood extents in the Lower Basin below Kratie though again average floods may be smaller.

Sediment Flux: The change in sediment flux is the most striking finding from the modelling so far. The blocking of sediment passage by the cumulative effect of dams in the Upper Basin, in tributaries and as proposed in the mainstream all but take out the sediment from the river when it reaches Kratie as only 3% continues to the delta as highlighted in red in the Figure below. The sensitivity of the overall trapping in LMB mainstream dams is found to depend greatly on the final dam in the cascade i.e. Sambor in Cambodia for M3 and most subscenarios.



Nutrient Fluxes: they are similarly affected though less than sediment as only a proportion is attached to sediment around one third pass through the LMB above Kratie.

Whilst the LMB mainstream dams are important it is found that they are not the only agent of change for hydrology, sediment and nutrient flux as shown in the Figure above.

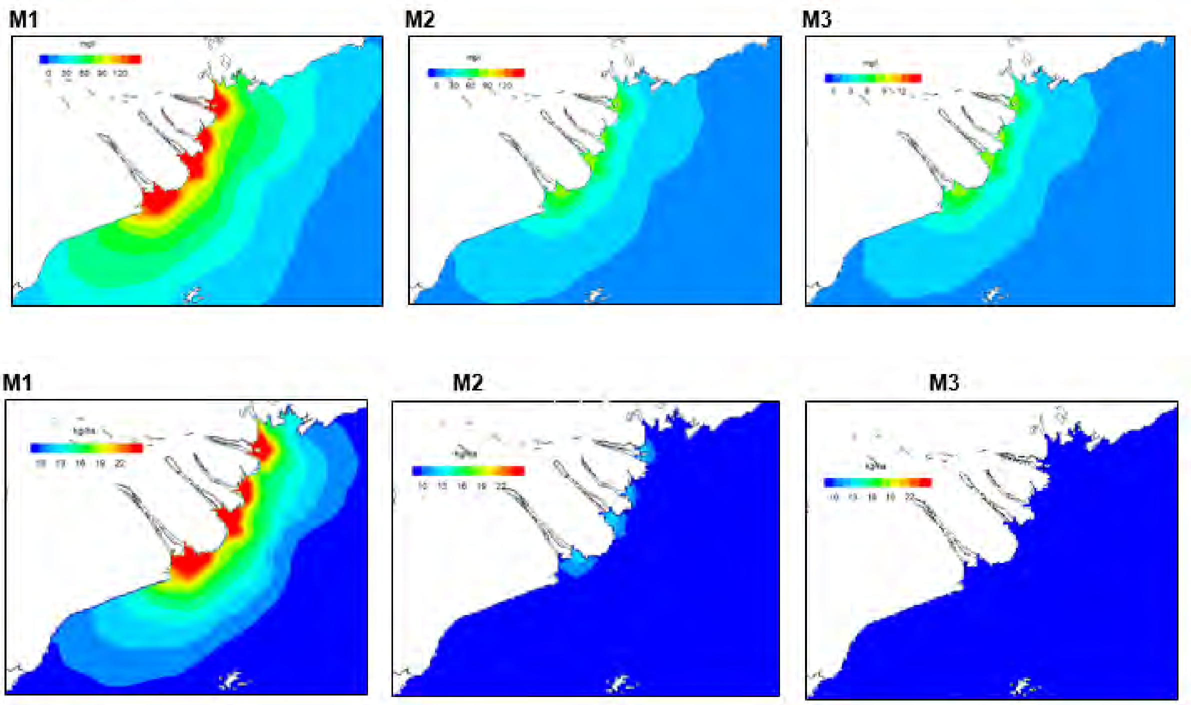


Figure 0-1 Changing conditions modelled at coast: sediment plume, coastal fishery based on upper basin sediment and nutrients

Sub Scenario results

Sub scenario modelling has been completed for each of the thematic water sectors plus climate change. The hydropower sub scenarios stand out as having the most difference. These help to quantify the significant mitigation that could be achieved if mainstream dams are built and operated to minimise the severe impacts of change expected with all planned development to 2040.

Abbreviations and acronyms

AIP	:	Agriculture and Irrigation Programme (of the MRC)
BDP	:	Basin Development Plan
BDP2	:	BDP Programme, phase 2 (2006 –10)
BDS	:	(IWRM-based) Basin Development Strategy
BioRA	:	Biological resource assessment team (under Council Study)
CIA	:	Cumulative Impact Assessment (under Council Study)
CCAI	:	Climate Change and Adaptation Initiative (of the MRC)
CNMC	:	Cambodian National Mekong Committee
DMP	:	Drought Management Programme (of the MRC)
EP	:	Environment Programme (of the MRC)
FMMP	:	Flood Mitigation and Management Programme (of the MRC)
FP	:	Fisheries Programme (of the MRC)
IKMP	:	Information and Knowledge Management Programme (of the MRC)
IQQM	:	Integrated Quantity and Quality Model by Murray Darling Basin Australia
IWRM	:	Integrated Water Resources Management
ISIS	:	Hydrodynamic Modelling Tool developed by Halcrow/CH2M Hill UK
ISH	:	Initiative for Sustainable Hydropower (of the MRC)
JC	:	Joint Committee (of the MRC)
LMB	:	Lower Mekong Basin
LNMC	:	Lao National Mekong Committee
M&E	:	Monitoring and evaluation
MIWRMP	:	Mekong Integrated Water Resources Management Project (of the MRC)
MRC	:	Mekong River Commission
MRCS	:	Mekong River Commission Secretariat
MRC-SP	:	MRC Strategic Plan
MWRAS	:	Mekong regional water resources assistance strategy (of the World Bank)
NIP	:	National Indicative Plan (C-NIP: Cambodia, L-NIP: Lao PDR, T-NIP: Thailand, V-NIP Viet Nam)
NMC	:	National Mekong Committee
NMCS	:	National Mekong Committee Secretariat
NAP	:	Navigation Programme (of the MRC)
PMFM	:	Procedures for Maintenance of Flow on the Mainstream
PWUM	:	Procedures for Water Use Monitoring
RDA	:	Regional distribution analysis
SOURCE	:	Water Resource Model by eWater Australia
SWAT	:	Soil and Water Assessment Tool
TCU	:	Technical Coordination Unit (of the MRCS)
TNMC	:	Thai National Mekong Committee
TRG	:	Technical Review Group (of the MRC)
UMB	:	Upper Mekong Basin
VNMC	:	Viet Nam National Mekong Committee
WUPFIN	:	Water Use Project of the MRC (2000-2006) Finnish Component

1 Introduction

1.1 Background

The MRC Council Study aims to assess past, ongoing and planned water resources development in the Mekong River Basin to further understanding of socio-economic and hydrological impacts (both positive and negative) across the basin. The Council Study Hydrologic Assessment Discipline Team led by the Technical Division which is responsible for carrying out the hydrologic, hydraulic, sediment transport, and water quality modelling required to support the assessment of environmental and socioeconomic impacts associated with water resources developments in six thematic areas. The six thematic areas include hydropower, irrigation, agriculture and land use change, domestic and industrial water use, navigation, and flood protection. The water resources development impacts are also to be studied in relation to climate change.

The core of the Basin Simulation Package for the Decision Support Framework (DSF) is the hydrological model (SWAT), the basin simulation model (IQQM) and the hydraulic model (ISIS). Regarding water quantity, only DSF has been used for the whole Mekong Basin. Pertaining to water quality, three selected models have been applied such as DSF, eWater and WUP-FIN. Because of limitations in the sediment and water quality modelling capabilities of IQQM, eWater Source has been identified to augment the functionality of IQQM and its application in the region upstream of Chiang Saen to Kratie. Due to complex of Tonle Sap Lake and Cambodian and Vietnam Delta, WUP-FIN has been employed.

This draft technical report focusses on the modelling work for three main scenarios of in the Council Study involving water, sediment and nutrient quality and quantity. The report is intended to demonstrate summary of modelling role in the Council Study, modelling process, source of data, approach of data for scenarios formulation, results and conclusion. It presents results of the three main scenarios by comparing from one to another to see how it may change/happen in the future 2020 and 2040 comparing with 2007. The final results of all main and sub scenario simulations will be described in the final report due in September 2017.

1.2 Objectives of the Council Study modelling

The main objective of using DSF, eWater and WUP-FIN modelling tools to support the Council Study is to provide the main inputs for the other sectors including social, environmental and economic for further assessment. Importantly, the scenarios have been set up to quantify the impact under different development conditions in 2020 and 2040 including climate change.

The following main points are the specific objectives of the modelling that support the Council Study:

1. Support sustainable development through close linkage and support to countries' dialogue and planning processes.
2. Fill-in of identified knowledge gaps with targeted field measurements and focused modelling
3. Provide more detailed Delta impact modelling that can consider water regulation better and has improved floodplain physical, chemical and biological description (necessitates coupled 1D/3D modelling).
4. Provide more quantitative estimates of morphological changes, their time scales and impacts such as lowering of water table and land subsidence
5. Provide more quantified, detailed and in-depth estimates on productivity changes for agriculture, aquaculture and capture fisheries
6. Provide more quantified coastal productivity and erosion impact estimates
7. Obtain improved understanding of historical changes and their impacts on the Mekong system. The modelling would cover pre-development and different land use, irrigation, hydropower and infrastructure (roads, dykes, channels) development phases.
8. Evaluate alternative development scenarios and their impacts.

1.3 The Mekong Basin (MB)

Mekong River is the 12th longest river in the world with a length of 4,800 km, a basin area of 795,000 km^2 and average annual runoff of 475,000 million m^3 (Dai and Trenberth, 2002). It rises in the Tibetan Plateau and flows southward through China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam where it discharges into the South China Sea (Figure 1.1).

The upper Mekong Basin makes up 24% of the total basin area and contributes 15-20% of the water that flows into the Mekong River (MRC, 2005). The flow regime is strongly monsoonal with a significant wet season 'flood pulse'.

Hydropower dams and reservoirs can have a significant impact on the sediment and nutrient balance in the Mekong river system, and this has flow-on impacts for the environment, agriculture and other activities. As of 2007, two smaller dams had been built on the on the mainstream of Lancang River of Upper Mekong Basin Manwan completed in 1993 and Dachaoshan in 2003. The total storage of the Manwan and Dachaoshan dams are 0.92 km^3 and 0.89 km^3 respectively. Although they had some impact on sediment regime from high initial sedimentation rates and induced additional sediment supplies due to landslides it was not until the construction of the large Xioawan and Nouzudhu dams in 2010 that major changes could be consistently measured in the Lower Mekong. For the Early Development Scenario Manwan and Dachaoshan are excluded which has the strong advantage of give a pre-development comparison for the upper basin. Since 2007, six other dams either have been completed or are under construction and data is already available showing some of the impact giving greater confidence in 2020 projections. An estimated 50 % of the Mekong's annual sediment load is derived from the Chinese section of the Mekong Basin; the construction of the Chinese cascade dams therefore poses a disproportionately large threat to the supply of nutrients downstream. The reduction in the wet season flood pulse caused by dams also limits the annual natural distribution of nutrients by floodwaters (Goh, 2004).

Thailand, Laos and Vietnam have also built several dams on the Mekong tributaries (MRC, 2003), for the purposes of hydropower production and irrigation, and plan to construct more. Irrigation structures in both the tributaries and the mainstream are also increasing (Hori, 2000). Irrigation may divert large volumes of water from the Mekong River and tributaries in both the wet and dry seasons. Flood and bank protection for communities and assets can impact on downstream flows, water levels and hard bank protection against erosion affects riparian ecosystems. Domestic and industrial water uses are small relative to the main river flows but returning effluent can affect downstream water quality increasingly with urbanization and agriculture and land use change which may alter runoff speed, sediment and nutrient fluxes. Aside from the impacts of the six-sector mentioned above, there are also two other external factors which may influence the water resources such as climate change and salinity intrusion. Climate Change will impact temperatures and rainfall affecting all water related sectors while sea level rise will affect flooding, drainage and salinity intrusion in the delta. All of this information has been added in the modelling scenarios formulation to determine the changes in terms of flow, sediment and other water quality.

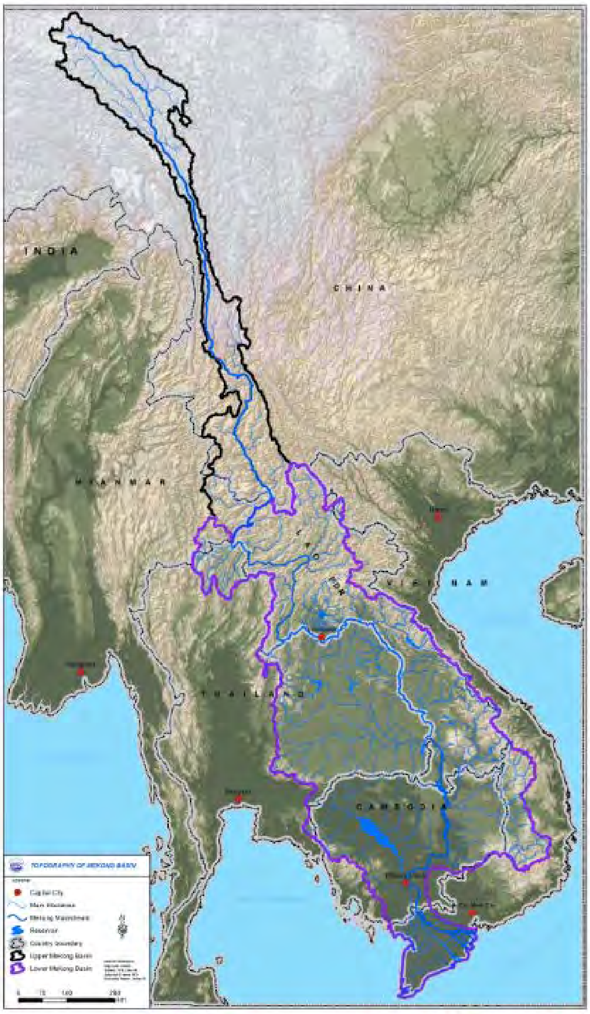


Figure 1-1 Mekong River Basin (Upper Mekong and Lower Mekong)

1.4 List of the modelling reports for all model packages

This interim technical report summarises the model preparation, development and use for baseline simulations for the Council Study by the Modelling Team of the MRC Technical Division. This Volume is accompanied by 8 Annexes giving more detail on each of the model components used.

Volume 1 : Main Modelling Report and Summary (This Volume)

Volume 2A : Analysis of Available Sediment and Nutrient Data

Volume 2B : Data and Gap Filling

Volume 2C : Timeseries Data

Volume 3 : SWAT Modelling (a. Quantity b. Sediment and Quality)

Volume 4 : IQQM Modelling

Volume 5 : eWater Source Modelling

Volume 6 : ISIS Upper Models Chiang Saen to Kratie

Volume 7 : ISIS LMB Model Kratie to the sea

Volume 8 : WUPFIN Tools

Volume 9 **:** Coastal Modelling

2 Modelling Approach and Tools use to simulate and assess the scenario

2.1 Overview of the modelling approach

The Lower Mekong Basin (LMB) can be divided into five zones as seen in Figure 2.1

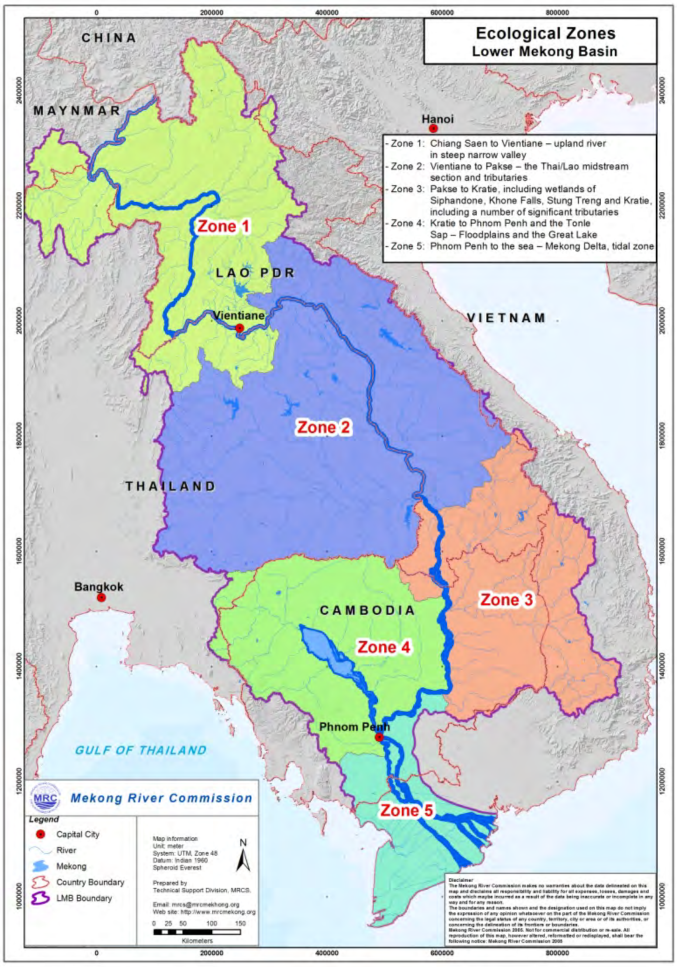


Figure 2-1 Ecological zones in the Lower Mekong Basin

MRC has agreed that the assessment of positive and negative impacts will put emphasis on:

- ☐ A corridor on both sides of the mainstream from Chinese border to Kratie (Zones 1 – 3)
- ☐ The Cambodian floodplains, especially Tonle Sap River and Lake (Zone 4)
- ☐ The Cambodian and Vietnamese Delta (Zone 5)
- ☐ The coastal areas directly influenced by the Mekong estuary.

As these areas are fundamentally unique in terms of their natural and socio-economic conditions the modelling approach needs to be different for these zones. The MRC TACT has selected balanced DSF/WUP-FIN option out of alternative approaches for the Council Study and the Countries have agreed for following approach for the different Zones as illustrated in Figure 2.2:

- **Zones 1-3**: Watershed hydrological (SWAT, IQQM with an additional supplement IQQM by Source Model). A new ISIS implementation on the upper part of the basin is for mainstream dam simulation including full hydrodynamics, flood and sediment impact modelling

- **Zone 4**: Tonle Sap hydrological (VMOD) and hydrodynamic (WUP-FIN 3D-EIA) modelling which is used for flooding, sediments, water quality (nutrients) and productivity impact modelling

- **Zone 5**: Delta hydraulic modelling (ISIS integrated with WUP-FIN VMOD Delta Impact Model) for floodplain sediment, water quality and productivity (agri- and aquaculture) modelling.

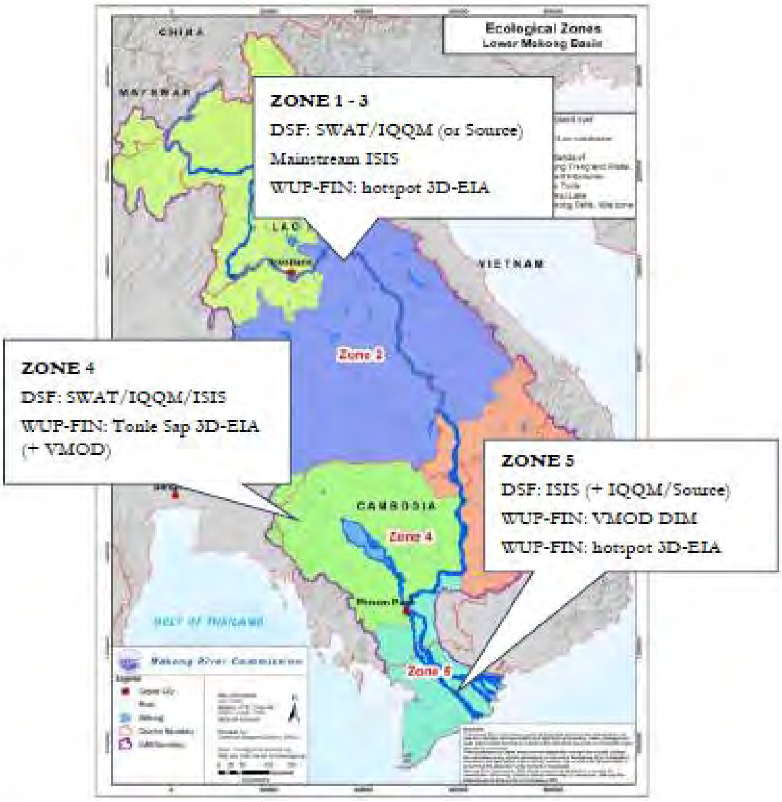


Figure 2-2 Models used in different Zones for the Council Study.

The DSF models provide discharges, water levels and sediment loads for the VMOD Delta Impact Model, Tonle Sap 3D-EIA model and the other hotspot 3D models (e.g. Nam Songkhram, Xe Bang Fai, Chaktomuk, Tan Chau, Tieu River Estuary) except the Tonle Sap VMOD will provide sediment and nutrient loads to the Tonle Sap Lake model. Delta IQQM provides water diversion data to the Delta ISIS model. In the Zones 1 – 3 the DSF will be supported by WUP-FIN for reservoir sedimentation, agricultural yields and water quality through integration of loads, parameters and impacts in the DSF.

2.2 Overview of the modelling process

Scope and definition of scenarios and assessment indicators have been discussed by MCs and line agencies. More importantly, improved input data through sectors consultation with line agencies, MCs and other partners and Results for Main Scenarios will be supplied to CS team for Triple Bottom Line Assessments as seen in Figure 2.3.

Tributary dam operation rule curves have been updated and operation of mainstream dams included in ISIS as well as IQQM and Source models.

Details for Sub Scenario Simulations and Indicator Outputs are currently being processed for reporting before August 2017.

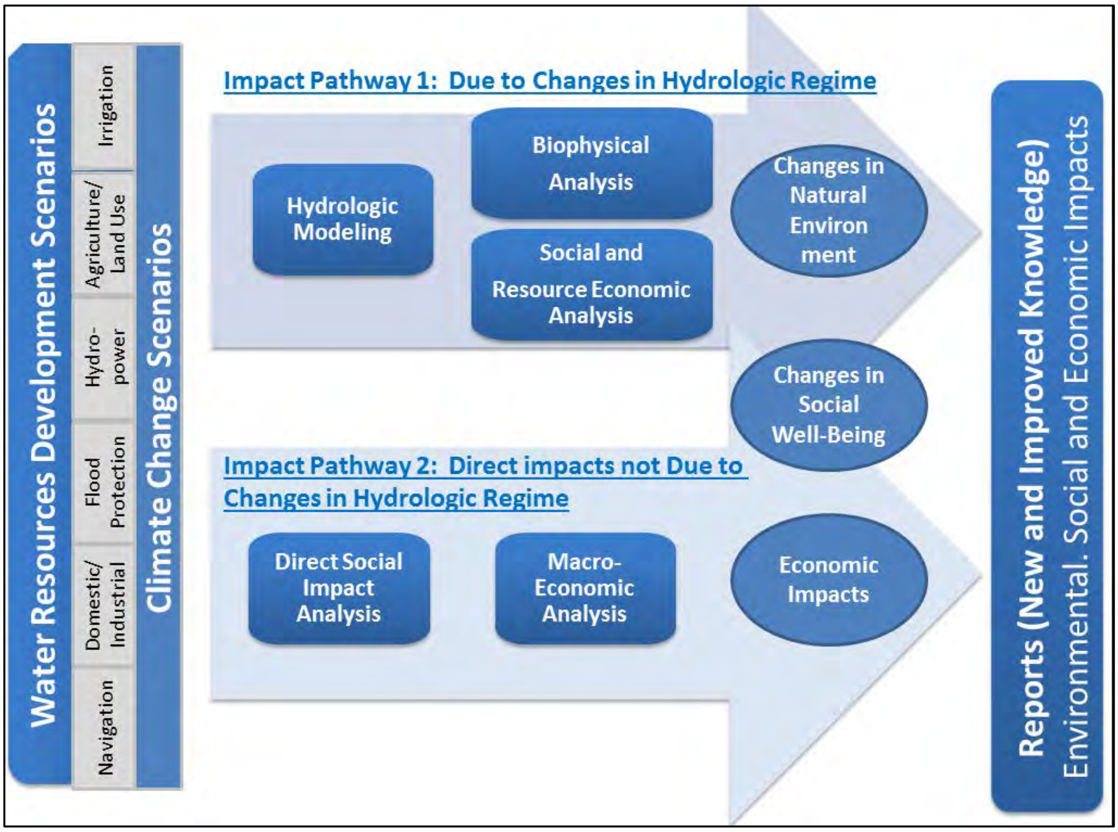


Figure 2-3 Modelling Outputs are central to providing quantitative analysis for the Council Study

3 Description of Simulation Models and Assessment Tools Used in the Council Study

To fulfil the Council Study objectives, three model packages have been applied namely: Decision Support Framework models (DSF), eWater Source and WUP-FIN tools.

3.1 Decision Support Framework (DSF)

The MRC Decision Support Framework (DSF) was developed through a process of consultation involving four member countries and relevant line agencies. The system comprises three main elements a suite of basin simulation model (SWAT, IQQM and ISIS), a Knowledge Base and a set of Impact Assessment Tools.

3.1.1 Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds. The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT has been set up for 10 separate models for the whole Mekong Basin (Figure 3.1).

(1) Area 1 : Chinese Border to Chiang Saen
(2) Area 2 : Chiang Saen to Luang Prabang
(3) Area 3 : Luang Prabang to Vientiane
(4) Area 4 : Vientiane to Mukdahan
(5) Area 5 : Mukdahan to Pakse
(6) Area 6 : Pakse to Kratie
(7) Area 7 : Chi up to Yasothon
(8) Area 8 : Mun up to Rasi Salai
(9) Area 9 : Great Lake

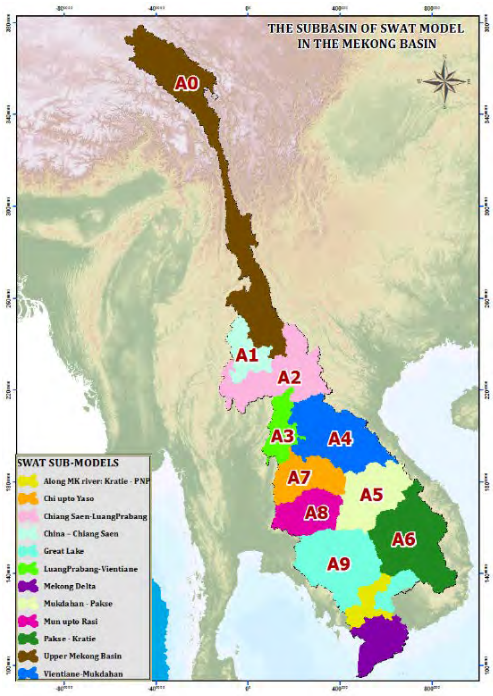


Figure 3-1 10 SWAT models in the Mekong Basin

For detail of each model schematization, it can be found in Annex A.

3.1.2 Integrated Quantity and Quality Model(IQQM)

The Integrated Quantity and Quality Model (IQQM), developed by the NSW Department of Infrastructure, Planning and Natural Resources, Australia was selected to use as part of Basin Simulation Model to simulate possible future water resource developments as to assess their effects on water availability geographically and for different sectors in the context of the Mekong Agreement. The IQQM can run for long periods of time, and model a time series of variables throughout the basin, river flows the most important, but also irrigation demand, reliability of supply and hydropower production.

The improvement (update baseline) of the river simulation model (IQQM) in the Mekong River basin is based on the updating separately existing models and combined into a single model (Figure 3.2). The existing models are used for this improvement are:

- ☐ China to Kratie in Cambodia which called as ChinKrt_9000 (Base on dam data till full development in MRB from BDP database)
- ☐ The water demand model for area around Great Lake and Tonle Sap which called as GL_1000 (Based on model that setup from baseline2000)
- ☐ The water demand model for Vietnam Mekong Delta which called as Delt_1000 (Based on model that was setup under BDP 2010 for BDP baseline2000)

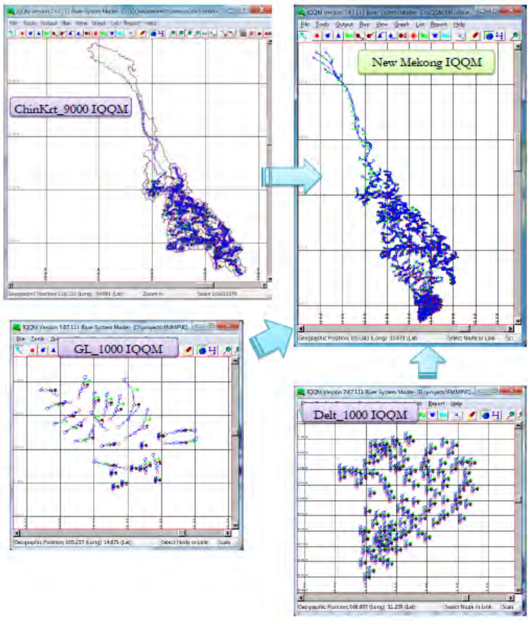


Figure 3-2 Schematization of IQQM model integrated 3 separate into one

The improvement of Mekong IQQM comprised 11 node types which had the 2,425 nodes in Total and it has been used to support the Council Study.

3.1.3 ISIS Model

The ISIS software developed by HR Wallingford and Halcrow is used to simulate the river system downstream of Kratie, including the Tonle Sap and the East Vaico in Vietnam where wet season flooding extends beyond the LMB boundary. The hydrodynamic model represents the complex interactions caused by tidal influences, flow reversal in the Tonle Sap River and over-bank flow in the flood season with the varying inflows from upstream. Typically it generates hourly data for water levels and discharges throughout the main channels and distributaries in the delta. A salinity intrusion model has also been set up with the ISIS software drawing on the results of the hydrodynamic model. ISIS also has capability to simulate other water quality parameters, including sedimentation. ISIS have been set up for three separate models such as (1) Chiang Sean -Stung Treng, (2) Stung Treng-Kratie and (3) Kratie-Cambodian and Vietnam Delta Figure 3.3.

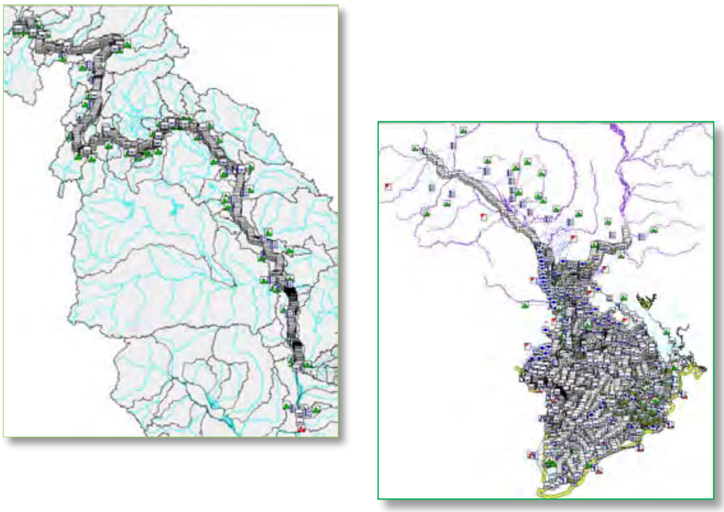


Figure 3-3 Schematization of ISIS models for LMB Upper Part and LMB Downstream of Kratie

The operating levels and basic data only on turbine capacity for mainstream dams are known but details such as width and likely levels of spillway gates are known only for the dams that have undergone the MRC PNPCA process. Thus for other dams the 'Xayaburi template' was used as agreed with ISH.

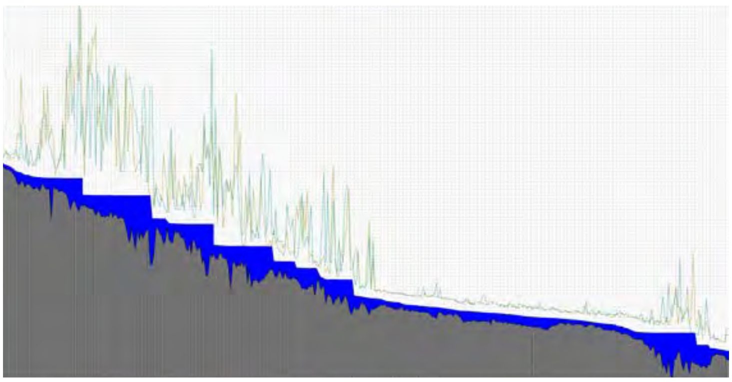


Figure 3-4 Mainstream Dams in ISIS models used for flood and sediment simulation (above Chiang Saen to Pakse Model)

3.2 eWater Source Model

eWater Source is an integrated water resources modelling tool developed and maintained by eWater Solutions. It is designed to provide a flexible, transparent, robust and repeatable approach to underpin water planning and management activities, including evaluating the trade-offs between social, economic and cultural use and re-use of water. Source was adopted for use in the Council Study for two main reasons. The first was to augment the water quality modelling capabilities of IQQM that do not meet the requirements of the Council Study. The second was that IQQM is no longer under active development and there is little support for bug fixes or technical advice. Source input was therefore converted from IQQM model input data for the Mekong Basin as seen in Figure 3.5. The Source model for the Council Study encompasses the Upper and Lower Mekong Basins, the downstream outlet being the gauge on the Mekong River at Kratie, Cambodia. It represents the Mekong River flow network, including major tributaries, and simulates reservoirs, dams, hydropower generation and water use for irrigation and other purposes.

The Source model of the physical river network and streamflow routing is a direct conversion from the MRC IQQM model. Both the Source and IQQM models are driven by inputs from the SWAT model, which produces estimates of:

- catchment rainfall-runoff
- sediment (TSS), total phosphorus (TOTP) and total nitrogen (TOTN) loads

Source models the transport of sediment and nutrient loads from upstream sources (SWAT land-phase) through tributaries to the Mekong mainstream, including trapping in reservoirs. The channel phase modelling in SWAT was found to be very dependent on the channel parameters in the SWAT models which could result in large losses or gains in sediment flux that were not physically realistic. Therefore, the sediment and nutrient outputs of land phase modelling of SWAT (which is based on the proven MUSLE) were transferred to Source calibrated with a catchment delivery ratio to match the observed annual flux at monitoring points. More information is given in the SOURCE Modelling Report (Modelling Volume 5).

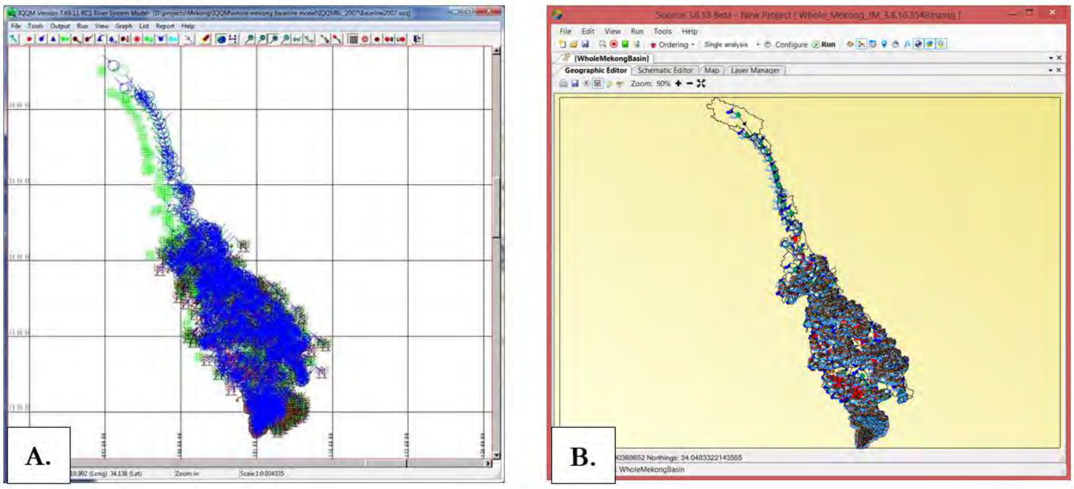


Figure 3-5 Schematization of eWater Source A) the whole Mekong Basin model as it appears in IQQM, and B) the converted model as it appears in eWater Source Geographic View

3.3 WUP-FIN 3D-EIA Model

The 3D Tonle Sap Hydraulic and water quality model is used for simulation of the Great Lake and Tonle Sap floodplain model (Figure 3.6).

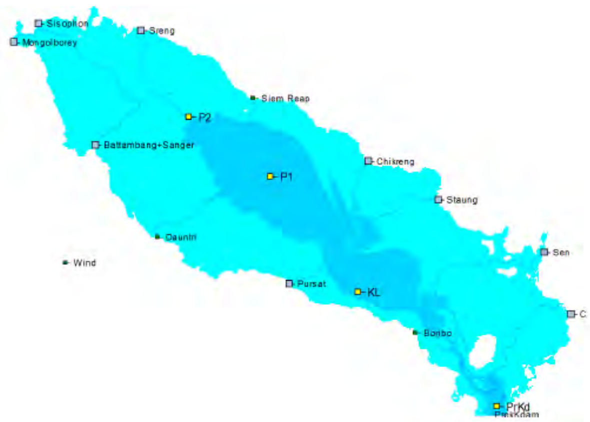


Figure 3-6 Schematization of WUP-FIN 3D EIA

3.4 WUP-FIN Tools and Impact Assessment Tool

The flood and crop modelling tools available in WUPFIN are used for the Delta Impact Modelling (Figure 3.7):

- Use of basic mapping instead of fully physical modelling to enable Cambodian Floodplains and Vietnam Delta floodplain sediment modelling with limited resources;
- Use of the existing model results (ISIS) as a basis for the flood and sedimentation mapping;
- Use of the Aquacrop model to simulate effects of climate and salinity on crop yields
- Next phase construct 1D/2D/3D hydrodynamic model for the channel and river network, floodplains, Delta and the coastal areas for fully physical approach. The approach is required for flooding but also for instance for more accurate sedimentation as it depends on flood flow, not only on flood mapping information.

The methodology is working well as demonstrated by the results later in this volume and described in more detailed in Modelling Volume 8. However, more ISIS data needs to be included especially in Ca Mau, along the Mekong mainstream and in areas with high salinity and flood depth gradients.

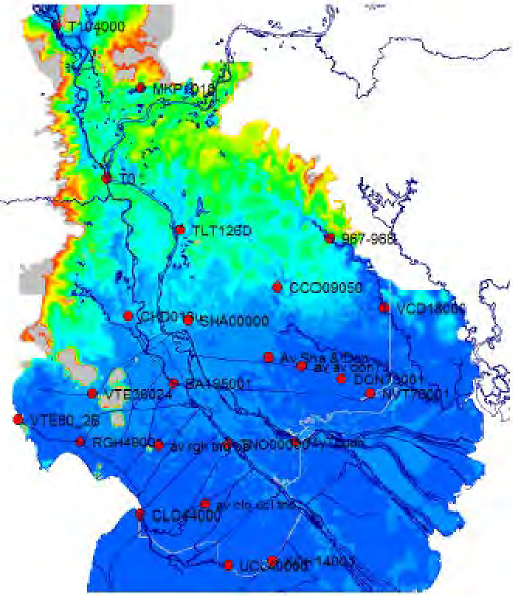


Figure 3-7 Schematization of WUP-FIN Impact Assessment Tool in the Mekong Delta

4 Modelling Scenarios Formulation

4.1 Background of the Scenarios Formulation

The Council Study uses a consistent set of agreed scenarios intended to enable the full assessment of water resource sectors, options and cumulative impacts. This is achieved through a set a main scenarios M1 for Early Development, M2 for Development 2020 and then M3 for Development 2040 with and without climate change impacts. Sub scenarios for each water sector then test changes in one particular aspect for the purpose of assessing the changes due to that sector.

For modelling of this process long term simulation is used for a 24 year record of climatic conditions to give the full range of flood and drought and the likelihood of occurrence using statistical analysis. The climatic record of 1985-2008 is used to simulate the reference climate. The same climate input is used in the 2020 scenarios whereas for 2040 climate change is incorporated using a perturbation (monthly change factors for temperature, precipitation humidity and solar radiation) used based on the analysis of the MRC CCAI/FMMP basin wide studies of 2013-2015 MRC (2015). This particular change is based on the results for the IPSL RCP4.5 GCM simulation for IPCC AR5 as this future climate scenario has the type of seasonal change being experienced in the basin. Other climate scenarios are studied under the Sub Scenarios for climate change. A key part of the climate change scenario is also the sea level rise in the delta relative to the land level.

4.1.1 Main Scenarios

The main scenarios incorporate the expected infrastructure condition and land use change for the particular reference year as shown in Table 4.1.

	Scenario	Level of Development for water-related sectors						Climate	Flood-plain development
		ALU	DIW	FPF	HPP	IRR	NAV	Hydrological Variability	
M1	Early Development Scenario 2007	2007	2007	2007	2007	2007	2007	historic	2007
M2	Definite Future Scenario 2020	2020	2020	2020	2020	2020	2020	historic	2020
M3	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Warmer & seasonal change projected to 2040	2040

Table 4-1 List of Main Scenarios Development

*ALU = Agric/Land use Change; DIW = Domestic and Industrial Water Use; FPF = flood protection infrastructure; HPP = hydropower; IRR = irrigation; and NAV = Navigation

4.1.2 *Sub Scenarios*

Under the Council Study, in total there were 13 sub scenarios for formulation under 4 selected thematic sectors (Hydropower, Irrigation, Flood Protection and Floodplain Infrastructure as well as Land use Change) and 1 discipline sector (Climate Change). All sub scenarios under each sector was illustrated as seen below:

- *Hydropower Sector*

N⁰	Description	Sub Scenarios Name	Detail information of sub-scenarios
1	Planned Development 2040 without HPP	**H1.a**	Dev2040_M3CC without HPP
2		**H1.b**	Dev2040_M3CC with Chinese dams and tributary dams but without ALL LMB mainstream dams
3	Planned Development 2040 with HPS1	**H2**	Dev2040_M3CC (with all dams in 2040)
4	Planned Development 2040 with HPS2	**H3**	Dev2040_M3CC (with all dams but mainstream dams and mitigation and operation)

- *Irrigation Sector*

N⁰	Description	Sub Scenarios Name	Detail information of sub-scenarios
1	Planned Development 2040 without iRR	**I1**	M3CC without iRR
2	Planned Development 2040 with High Level of iRR	**I2**	M3CC with High Level iRR

- *Flood Protection and Floodplain Infrastructure Sector*

N⁰	Description	Sub Scenarios Name	Detail information of sub-scenarios
1	Planned Development 2040 without FPF	**F1**	Dev2040_M3CC without Flood Protection
2	Planned Development 2040 with FPF2	**F2**	Dev2040_M3CC with urban protection at 1:100 ARP (100 year return period) + floodplain management 1:20 ARP
3	Planned Development 2040 with FPF3	**F3**	Dev2040_M3CC with floodplain development in Cambodia

- *Land use Change Sector*

N⁰	Description	Sub Scenarios Name	Detail information of sub-scenarios
1	Planned Development 2040 without ALU	**A1**	M3CC without ALU
2	Planned Development 2040 with High Level ALU	**A2**	M3CC with High Level ALU

- *Climate Change Sector*

N⁰	Description	Sub Scenarios Name	Detail information of sub-scenarios
1	Planned Development 2040 with CC Wetter	**C1**	M3 with climate change (GFLD)
2	Planned Development 2040 with CC Drier	**C2**	M3 with climate change (GISS)

4.2 Data Inputs and Gap Filling

The data used in models and where gaps existed and were filled in conjunction with discipline teams and consultation with MC. The details for irrigation, land use, flood control etc is given in more detail in Volume 2a and 2b and discussed further in the next chapter.

5 Data Input and Constraints

5.1 Requirements of the Council Study for MRC Modelling

The Council Study made extensive use of the MRC Modelling Capacity which was also extended beyond any previous work necessitating much new development and extension of what was modelled spatially, temporally, complexity and the number of physical processes included. Much data collection and analysis went into supporting the model development and output but it is recognised that gaps in data input, modelling experience in some processes and time constraints limited the information that could be supplied to some sectors and the confidence in some outputs has been questioned particularly by non specialists. The intention of this chapter is thus to clarify issues where possible.

Table 5-1 Models available prior to CS, data and uses

Type of Model		Model Used	Input Needed for Scenarios	Output to Sector	Calibrated
Hydrological	Basin except Cambodia and Delta	SWAT	Rainfall, Landuse, climate parameters and change	Output to other models	Yes recalibrated specifically for CS
Water Resource & Irrigation	Basin but irrigation only below Kratie	IQQM	Reservoir and Hydro details. Irrigation	Irrigation, hydropower, water use	Yes recalibrated specifically for CS
Hydrodynamic	Chiang Saen to Pakse	ISIS	Channel data, floodplain and flood protection, DEM	Flood and outputs for salinity and 3D	Calibrated previously. Chiang Saen Pakse model in bank only
	Below Kratie				
Salinity	Delta	ISIS	Tidal boundaries, salinity gates	Output to Agriculture	No new data available
3D Water Quality	Tonle Sap	3D EIA	Water quality input from Tonle Sap and Catchments	Output to fisheries	Calibrated for 2002-6 data

Similar modelling to that of Table 5-1 has been used for various MRC studies since 2004 including BDP2 in 2010 and thus both Modelling Team and experts in Member Countries have experience of these models through extensive capacity building since 2004. Whilst the data input in terms of, for example land use, to establish a '2007' reference condition was not directly available to use in SWAT, so both 2003 and 2010 datasets were analysed but 2003 adopted in the model build as had been used in the previous update to SWAT2015. As can be seen in the land use change scenario, the performance of the model on a basinwide basis is relatively insensitive to changes and with only a four year period a relatively high level of confidence may be placed in results from SWAT. There are other aspects of weaknesses in data and model detail as will be described later.

5.2 Requirements for additional modelling

For Council Study the modelling scope had to be greatly increased in response to the requirements of BioRA and Sector teams which necessitated use of much new data and new modelling techniques. Not all requirements could be met and not all the modelling could be tested and calibrated against data but modelling physical processes wherever possible. The new modelling and parameter outputs are summarised below as 16 new parameter requirements:

	Parameter Required	Model Used	Data Required ***** = Sufficient Data **** = Some data available **** = No data in MRCS
1	Water Level in the basin above Kratie	ISIS	Cross sections of the river, locations and spills and flood defences, tributary sections, ground elevations (DEM), control gates on tributaries. Data for calibration
2	Velocity and wetted perimeter in River Channel	ISIS	As Above
3	Sediment production/Soil Erosion and movement in tributaries	SWAT	Soil Erodibility, slope, calibration data, accurate rainfall. Tributary delivery ratio and grain size.
4	Nutrients Flux from each subcatchment (Agreed to be limited to TOTP and TOTN) but divided between dissolved and adsorbed components attached to sediments.	SWAT	Atmospheric deposition, Nutrient in eroded material, point source nutrient inputs, fertiliser applications and runoff to water bodies, bioavailable.
5	Other Nutrient and water quality components such as silicates, DO, Temperature	N/A	Agreed not simulated at this stage though DSF models and EIA tools have capacity
6	Sediment Trapping in Upper Lancang and Tribuataries	Source	Reservoir Capacity and Inflow and calibration data
7	Nutrient trapping and reaction within reservoirs in tributaries and Upper Lancang	Source	Nutrient fluxes and calibration
8	Fine and Coarse Sediment Movement and trapping in mainstream	Source and ISIS	. Grain Size and proportions of material in transport and in bed Average Depth of sediment across section to rock bed.
9	Nutrient Trapping and movement in mainstream	Source and ISIS	4+Nutrient concentrations and proportion adsorbed to sediment in transport broken down by grainsize and seasonal variation. Proportion released with time submerged. Wastewater nutrient flux when it

	Parameter Required	Model Used	Data Required ***** = Sufficient Data **** = Some data available **** = No data in MRCS
			reaches the main river after passing through wetlands.
10	Fine sediment deposition on floodplain	ISIS and WUPFIN	Calibration measurements and knowledge of bank levels/flood mechanisms
11	Nutrient Deposition on floodplain	ISIS and WUPFIN	As 8
12	Effect of flood, nutrient deposition and salinity on irrigated crop yields	WUPFIN Tool	Calibration data and agricultural trials
13	Effect of flood, sediment nutrient deposition on rainfed crop yields	WUPFIN Tool	Calibration data and agricultural trials
14	Fish Production changes on floodplain and Tonle Sap Lake	WUPFIN EIA	Calibration data and including years where sediment changed ie 2011-2015
15	Shrimp Production Changes	WUPFIN Tool	Calibration data and agricultural trials
16	Channel Erosion	ISIS	Calibration data on bank stability, grainsize and geotechnical information. Records of sand dredging.
17	Coastal Erosion	WUPFIN	Bathymetry, Calibration data on wind and ocean currents and plume from Mekong main mouths as well as observed erosion and protection measures taken.
18	Flood Depth duration for upper basin BioRA Nodes	WUPFIN	Water levels away from the river, flood defences, DEM

It can be seen that the amount of modelling new to the MRCS team was extensive though at the same time it had been decided to downsize the team to 2 specialists at the end of 2015. Previous team members and consultant contracts were thus used also for specific tasks. Much of the data necessary was not available at MRC and despite meetings very little additional data was available in member countries. In some cases better data was available for the period post 2008 – current day 2017 and thus some flows were generated from ratings to analyse data such as for sediment analysis (The landmark MRC DSMP project collected data 2011-2014).

5.3 Sediment and Nutrient Data Analysis and constraints

During the early phase of the Council Study, the Modelling Team concentrated its efforts on analysing the sediment and nutrient fluxes throughout the basin particularly to attain a reliable balance of the production spatially in the basin. More emphasis was put on the spatial coherence of the modelling and analysis rather than the seasonal variations for which the data was highly variable. Thus the analysis for sediment and nutrient fluxes should be seen as reproducing the mean annual and long term mean fluxes rather than details of monthly variation.

The amount of nutrient that will be adsorbed onto sediment particles is important for determining the likely change of river borne nutrient flux once reservoirs are introduced as it is expected that a proportion of the sediment will settle or 'be trapped' for which well established methods are available. This proportion is estimated by considering the chemical proportions of known soluble and non soluble components of the TOTN and TOTP that had been measured under the MRC Water Quality monitoring. The change in sediment concentrations at Chiang Saen following the closure of Nouzhudu and Xioawan dams in the Upper Mekong (lancing) part of the river and thus an estimate of the proportion of nutrient was estimated using the change in nutrient flux also recorded. The Delta Study for the Vietnamese Ministry of Water Resources initially had a stated aim to resolve this 'Knowledge Gap' and discussions were held to obtain the information collected which was supplied but the data turned out to be inconclusive. As described in the Source report thus fixed proportions are used using the findings available.

The sediment and nutrient flux balance was corrected for pre dam condition in the Upper Mekong as the early Chinese dams of Dachoushan, Manwan and Jing Hong are all relatively small and were filling rapidly with sediments whilst also triggering landslides such that no equilibrium was obtained before the construction and closure of the major dams in 2010/11. This also allow all comparisons to be given against a 'largely natural' state in the main scenario M1.

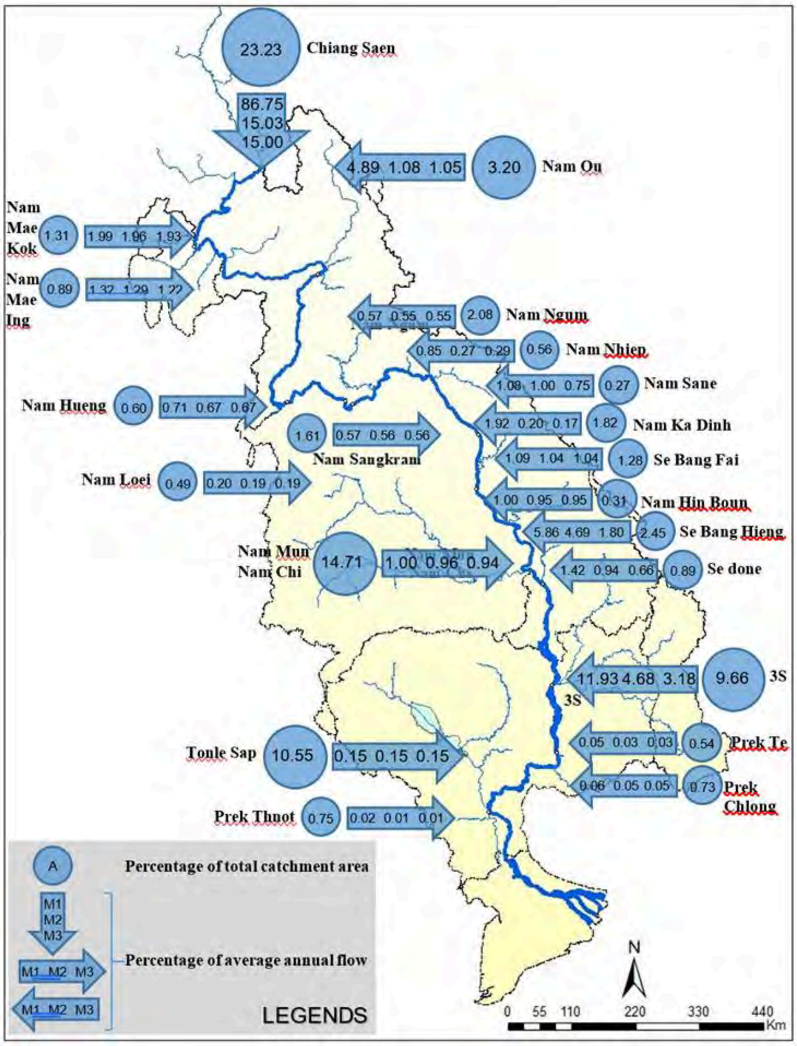


Figure 5-1 Sediment Contribution to mainstream from larger subcatchments

In preparing the data for use in the model as detailed in report 2b, all of the sediment data for the Mekong available at MRC was considered and the ratings derived for each tributary and mainstream monitoring location. This includes the Suspended Sediment Concentration data which has data back to the 1960s, the water quality monitoring of Total Susepnded Solid (TSS) and the DSMP data of the MRC Sediment Project. The USGS program 'Loadest' was used for fitting ratings and estimating loads. This has an advanced fitting routine more suited for the sediment data than simpler methodologies. Whilst there remain uncertainties in sediment fluxes and the changes during the period of record and variability of the measurement of flows and concentration the results, it is believed that a good result has been obtained that is fit for use in the Council Study and reference should be made to modelling report volume 2a for more details of the process followed and final resulting estimates against which models are calibrated.

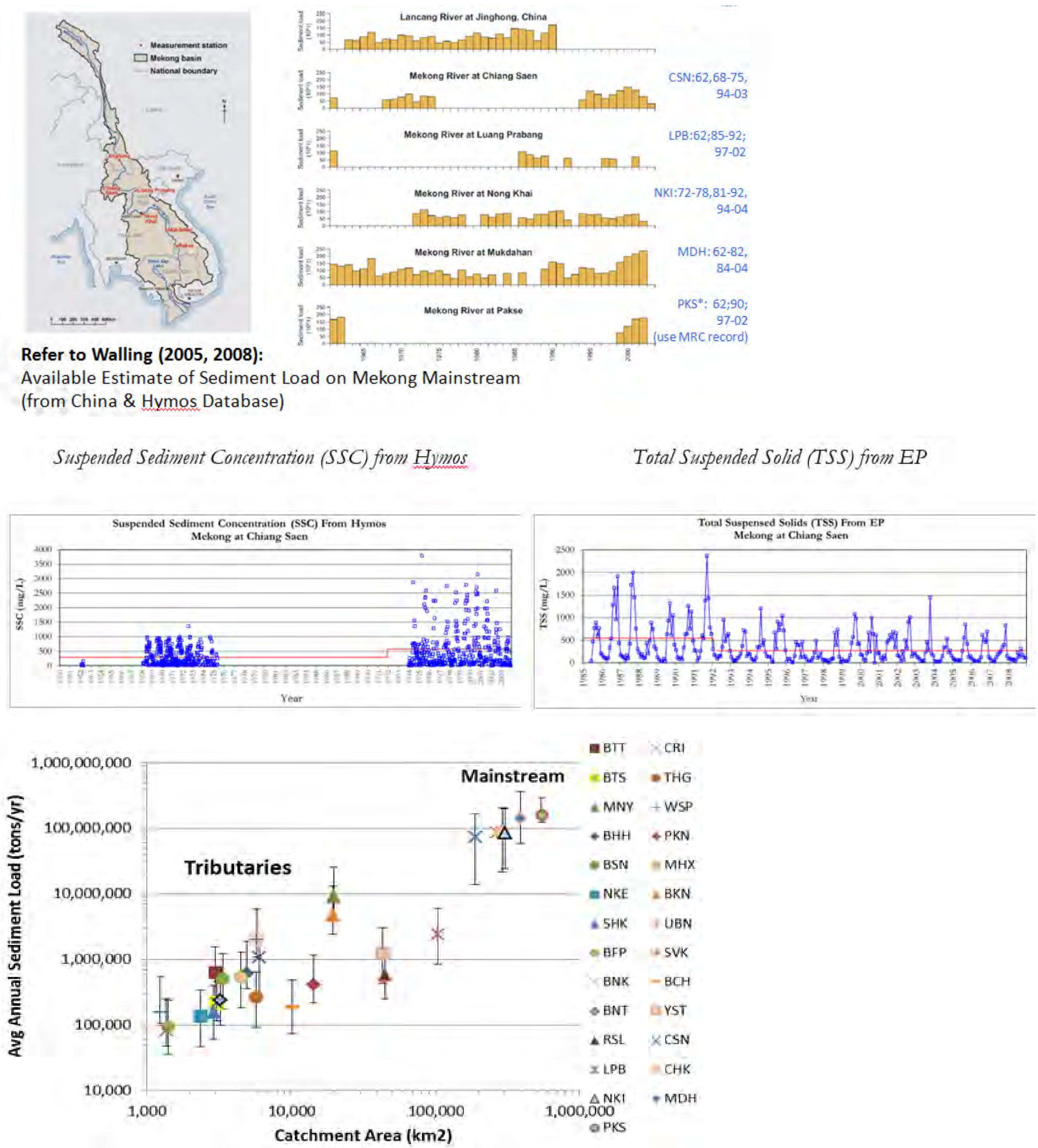


Figure 5-2 Examples of data and analysis of sediment data in Volume 2a

Figure 5-3 Summary of Analysis of Sediment Data to Annual Loads (Million Tonnes/yr) for Key Gauge Stations in the LMB

The variations in nutrient and flux that are apparent within the available data for the LMB present a challenge for any basinwide analysis. Both tributary and mainstream stations were analysed systematically and a cohesive set of data assembled for use in model calibration. It is inevitable that there will be some uncertainty over the actual values predicted and further analysis and targeted measurements and checks on the sampling and laboratory analyses need to be carried out to understand the differences between stations and periods of record. Nevertheless for the purpose of the Council Study it is believed that the data and analysis presents the correct picture of likely change and further refinements can be made in future. Comprehensive discussion and analysis is given in Modelling Report 2a.

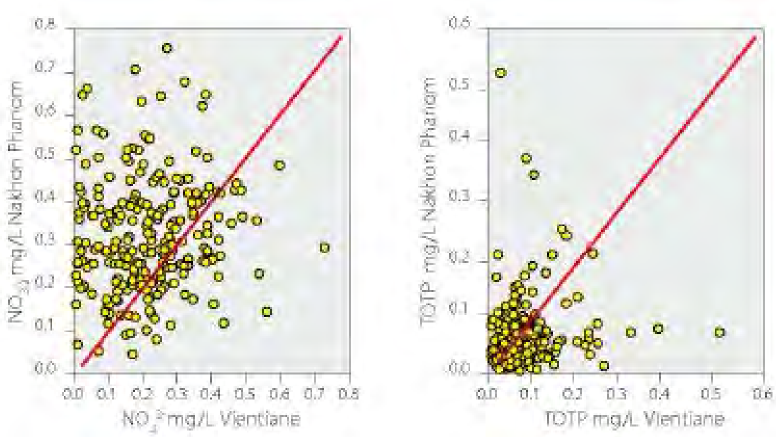


Figure 5-4 Example of correlation of measured NO3 and TOTP at Neighbouring stations (Red line is 1:1 relationship)

Another issue occurs where different parameters are measured in different countries, for example TOTN was not available for Lao stations only NO2 (+NO3) and NH4. The available sum of nitrogen data was thus correlated against the stations with the TOTN measurement and thus a TOTN time series could be created.

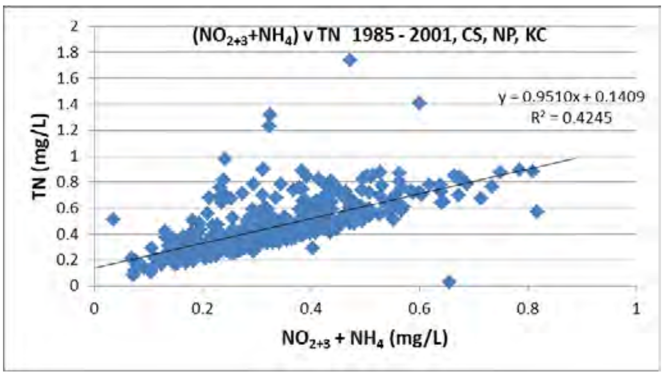


Figure 5-5 Estimation of relationship between TOTN and the sum of nitrate/nitrite and ammonia

The phosphorus measurements were assessed for consistency and it was found that 7 out of 8 mainstream stations were suitable for calibration and 13 tributary stations could be used. The period of data used was 1985-2001 as this dataset is more consistent than some of the more recent data which also has less stations.

5.4 Channel Data Pakse to Kratie

To build a new hydraulic model for the missing reach from Pakse to Kratie, cross section data is essential. The other parts of the modelling of the Mekong have been based on the hydrographic atlas prepared for navigation. Unfortunately this reach is complex as the channel divides into many different branches including where it passes over the Khone Falls near the border of Lao and Cambodia. The hydrographic atlas typically focusses on the main channel used for navigation though in this case there is very little traffic due to the difficulty to pass the Khone falls. An example sheet is shown below illustrating the problem that depths are available at very few points to define cross sections.

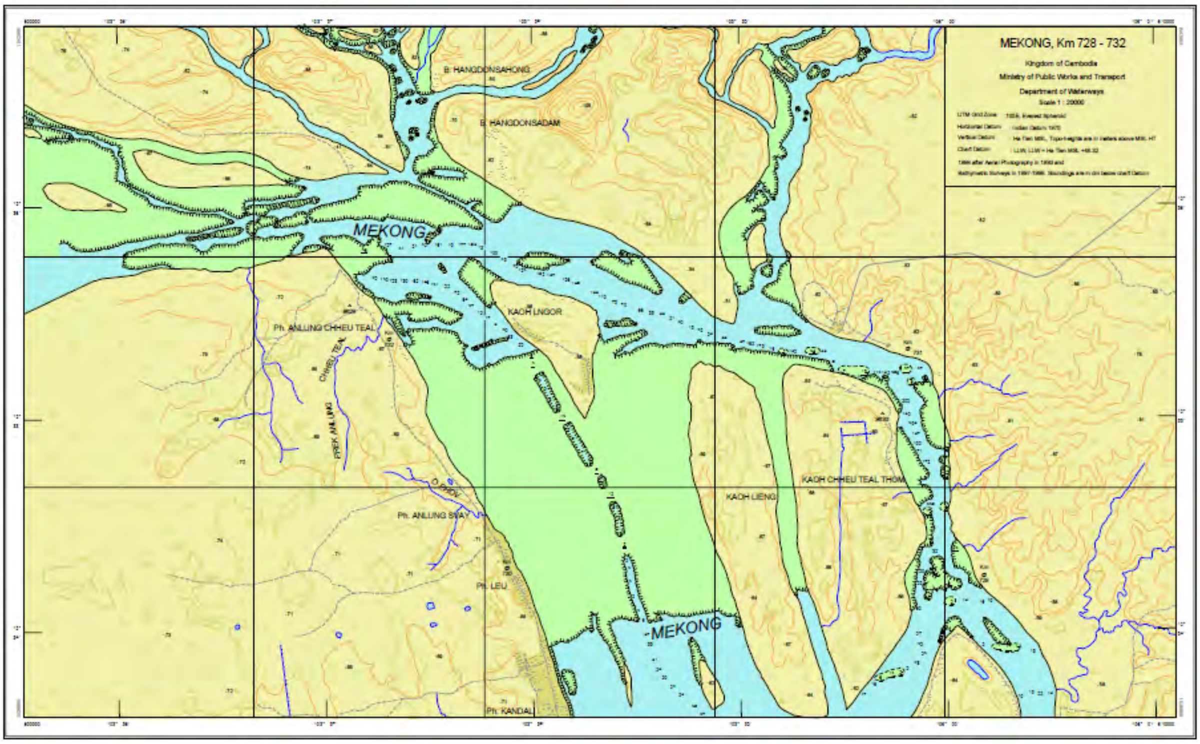


Figure 5-6 Example of hydrographic Atlas data available (single point line measurement of bed level in main channels) for building the Pakse to Kratie hydrodynamic and sediment model

There is a further issue in terms of referencing the depth soundings to a fixed MSL datum where water gradients may be high and some post model build corrections were needed upon inspection of the gradients.

The quality of the model is dependent on the data available and thus the Pakse to Kratie model is of a lesser quality than the other reaches. It is however fortunate that the reach being relatively steep and with a rocky bed does not significantly modify flow or sediment transport rates which generally pass through with only a time lag and thus the limts of this model have little impact on the CS results. For Scenarios with dams in the reach then the sections derived give a first approximation and more data that goes with the feasibility of specific dams such as Don Sahong and Stung Treng/ Sambor should be sought for use in the model.

5.5 Ground Elevations DEM

The data available on ground elevations is key for any flood mapping or flood assessment. The data used at MRC is based on historic surveys generally as this is more accurate than the satellite based ground observations which have accuracy only of the order of +/- 5m.

Newer ground level information is becoming available in member countries and specifically Lao and Vietnam have more datsets than available to the MRC. This lack of more modern ground data is a serious constraint to more detailed analyses of flood extents, damages, flood defences etc and thus the basin analysis is constrained. An example of the sample DEM available for the Mekong floodplain near Chau Doc is compared with the best DEM available for MRC (upper part) in the Figure below. It can be seen that the resolution and detail is much better in the newer remotely sensed data.

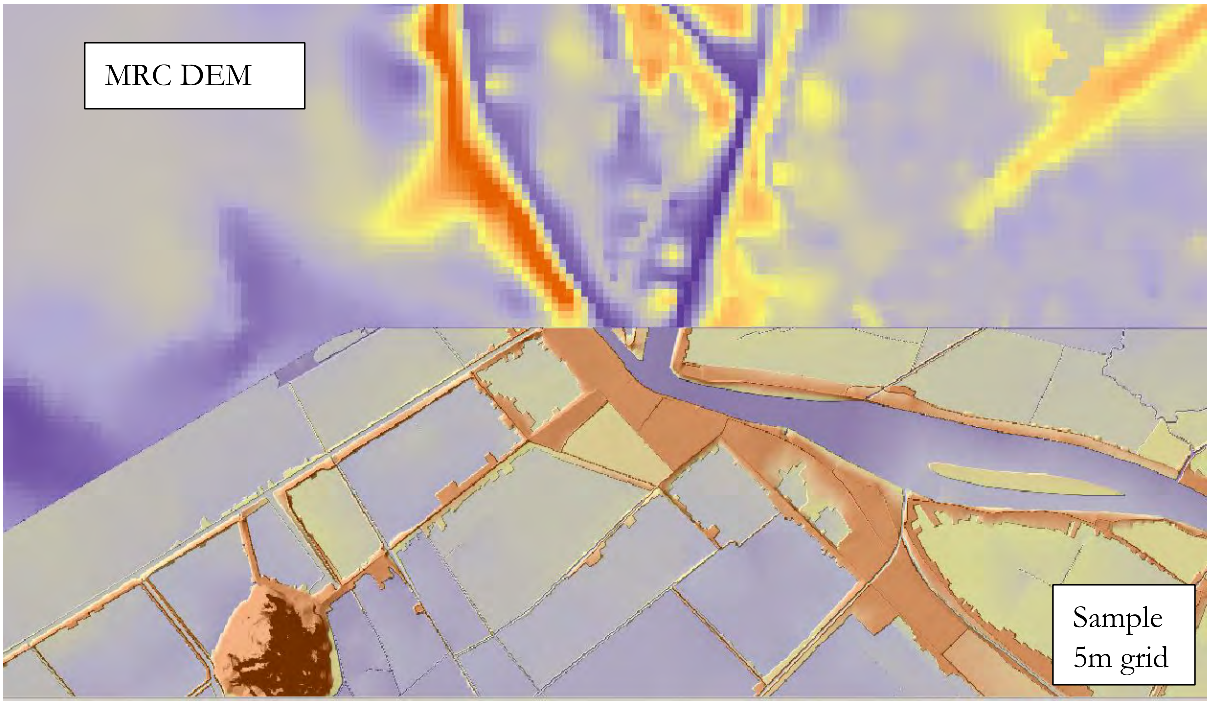


Figure 5-7 Comparison of Ground Model Data (DEM) available at MRC (above) and newer Lidar survey (below – only a sample is available 5*5m pixel).

5.6 Agricultural Modelling

As described in the WUPFIN Tools modelling report volume 9, the agricultural modelling of yield and production was done in a raster based implementation of the Aquacrop model. The model outputs depend on relatively detailed information regarding the location of the crops, planting calendar, agricultural practises such as seed variety, fertiliser and weedkiller application, irrigation. The response to flooding obviously depends on the state of the crop when the flood occurs. The farmer is likely to adapt his cropping accordingly. The use of a fixed crop calendar in the modelling would seem to be a significant restriction in the results obtained in some flood prone areas, in others the constraint is more that MRC have very scant information on the location of irrigation areas as only a point is available for irrigation schemes in the MRC database.

5.7 Fisheries and Aquaculture Modelling

There are various types of aquaculture practised in the LMB including fish ponds, fish cages, paddy field fisheries, reservoir fisheries and brackish shrimp production near the coast. The modelling only considered shrimp production. Within the BioRA there is also limited consideration of aquaculture so more effort is needed to collect information on the location and response of aquaculture and the likely future developments.

The main modelling regarding fisheries is that relating to the Tonle Sap and the Cambodian Floodplain for which data is available for estimated catch as well as hydrological condition. The modelling thus estimates the primary productivity and links it to the average fish catch. The methodology follows research on the flood pulse rivers openly published and reviewed in the literature. The limited availability of hydrological data limits the extent to which the model can be calibrated as already the lower sediment yields post 2010 could be tested against the observed change in fish catch. The technique also depends on knowledge of the amount of floodplain that is protected against floods for which much improved data could be collated.

5.8 Sedimentation in Floodplains

Within the WUPFIN tools a simplified flood sediment spreading and sedimentation equation has been implemented primarily for input to the BioRA. Within ISIS the sediment deposition within flood cells is also simulated. Both methods seem to be giving reasonable values and the WUPFIN tool has the advantage of being closely linked with the agricultural modelling. However the data to calibrate and test the method for Mekong conditions needs to be collected and collated to move beyond a preliminary analysis. Significant studies and modelling have already taken place in Vietnam and this data could be built upon to include the Cambodia part (Manh et al 2014)[1]. The delivery and availability of nutrients is also similar, more data is available in the published literature and working with the right national experts, the Council Study modelling could be improved.

5.9 Coastal Modelling

The model setup for Coastal assessment as described in *Modelling Reports Volume 9 Coastal Modelling* is very much preliminary and more detailed quantification of the development impacts would require much more involved study utilizing past research and monitoring. However, the model produces useful indication of expected impacts including increased erosion due to increased net erosion and very significant coastal fisheries production reduction.

[1] Manh et al Large-scale suspended sediment transport and sediment deposition in the Mekong Delta. Hydrol. Earth Syst. Sci., 18, 3033–3053, 2014

5.10 Scenario Data

The Scenarios used for the Council Study are for a used in models and where gaps existed and were filled in conjunction with discipline teams and consultation with MC. The details for irrigation, land use, flood control etc is given in more detail in Annex/Volume 2. Every effort was made to use data supplied from member countries but it seems that due to the length of time of the study some areas such as expected irrigation may differ from that now expected by Member Countries and further updating is desirable.

.Following review of the MRC Hydropower database and discussion with ISH, who in turn have consulted member countries a list of projects for 2020 and 2040 scenarios has been derived. A large number proposed projects are included in the scenarios and these are put into the IQQM and Source Models. All Mainstream Dams are modelled in ISIS as well as IQQM and Source. There is however uncertainty as regards the lower Lao dam at Latsua which is expected to be sited at an alternative location but revised information could not be provided. Also Sambor was under intense study by the Cambodia Ministry and the design expected now differs to the information available for the Council Study assessment.

One aspect common to all the dams in tributaries and mainstream is the lack of information on Operating Rule Curves. Information is not available even for those dams in operation. The method used in BDP2 has thus been applied again as described in the gap filling report. This method has also been discussed with counterparts in China in 2010 and it was agreed that the approach gave a reasonable outcome expected for releases from the Upper basin reservoirs. Of equal importance is the likely mitigation measures to be tested for mainstream dams. Neither the facilities (ie low level gates) nor the likely operating procedures could be supplied by member countries. This is clearly an area that need future coordination and study.

It is believed that the results of the study are relatively robust to variations in the choice of reservoir development and a way to do this would be to compare the active storage of revised scenario of development with that used in the study (76,000 MCM for 130 projects), a small proportional change is unlikely to change results significantly.

Table 5-2 Hydropower Energy and Storages planned in UMB and LMB 2020 and 2040

No	Countries	EDS 2007			Development 2020			Development 2040		
		No Projects	Annual Energy (Gwh)	Active Storage (MCM)	No Projects	Annual Energy (Gwh)	Active Storage (MCM)	No Projects	Annual Energy (Gwh)	Active Storage (MCM)
1	Lao PDR	7	3,561.9	1,818.3	60	40,592.3	33,023.7	82	85,045.6	43,937.3
2	Cambodia	1	3.0	0.1	10	5,497.5	12,777.3	14	22,918.1	14,074.1
3	Thai Land	6	902.0	3,580.9	6	902.0	3,580.9	8	9,498.0	4,918.6
4	Viet Nam	5	5,867.0	789.8	14	12851	2751.8	14	12851	2751.8
5	China	2	29,760.0	12,575.0	11	87,165.0	23,803.0	12	88,845.0	23,818.0
6	Whole Basin	21	40093.9	18764.1	101	147007.8	75936.7	130	219157.7	89499.8

5.11 1960s Data

The data needed for a 1960s assessment could not be assembled in time for the Council Study. It is believed that this would be possible in the future given a lower level of accuracy for land use mapping such as available on contemporary paper copy and statistics of the time though this will take time to compile in a suitable digital form.

Figure 5-8 Example of historic Atlas showing land cover vegetation in Cambodia, Lao and Vietnam before satellite data became available.

5.12 Sand Mining

Although there have been studies of sand mining in the Mekong including that by WWF in conjunction with the MRC Sediment Project in 2012, the data are not accepted by Member countries as being representative of the historic or current rates of mining. Further work is thus needed to establish a correct picture and this can then be included in the detailed modelling.

5.13 Conclusions on Data Constraints

The extension of scope of modelling for the Council Study compared to that carried out by the MRC previously is very significant and further data was needed. Only some of the data required was available from Member Countries so gap filing was necessary and is described in the reports Volume 2a and 2b and Thematic Reports. The modelling carried out is based on fundamental physical principles and it is expected that the process can be seen as transparent and repeatable. Special efforts have been made in particular to analyse available sediment and nutrient data.

The resulting outputs help illustrate where additional information gathering and effort should be focussed. From a modelling perspective they would be:

1. Extending the hydrological, sediment and water quality baseline allowing analysis of the extremes of 2011 (flood) and 2016 (drought) and including the impact of major Lancang dams and testing of the assumed operation rules.
2. Improving the survey base of the upper (Chiang Saen to Pakse) and middle (Pakse to Kratie) hydraulic models specifically cross sections and flood plains
3. Calibration data of floodplain sedimentation and
4. Calibration data of agricultural modelling including cropping calendars
5. Collection and collection of flood defence information for current and planned developments
6. Mapping of irrigation and freshwater aquaculture areas
7. Salinity Data including sea boundaries for recent conditions such as 2016 drought
8. Improvement of data for sediment particularly grainsize in transport including all bed material loads
9. Improvement of nutrient and water quality data analysis and bioavailable component
10. Ground Elevation (DEM) improvement for mapping of floods
11. Collection and collation of data on sand mining

6 Main and Sub Scenario Results

6.1 Land Phase and Irrigation Modelling (SWAT & IQQM)

The SWAT model has been calibrated to provide the flux of water, sediment, Total Nitrogen and Total Phosphorus. The results are shown spatially in Figures 5.1 to Figure 5.4.

Inputting flows to IQQM together with detailing the irrigation demands, dam infrastructure and control, flows and hydropower generation are output.

Table 6-1 Example of monthly average flow changes for main scenarios at key stations

The long term change in flows generally follows a pattern of the redistribution of flow from the wet season to the dry as would be expected with increased regulation. It is notable though that the changes are greater in the upper part of the basin and that in May at the end of the dry season, the wet season flows at Kratie decline significantly both with the current climate and with the projected base climate change. 2020 has less change than 2040 as would be expected though most of the change at Chiang Saen and Luang Prabang has occurred by 2020.

In SWAT only Sub Scenarios for Climate Change and Land Use Change are simulated as other Sub Scenarios have no catchment changes relative to main scenarios. The same catchment inflows from SWAT are used in the sub scenarios for hydropower, navigation, irrigation development, flood protection and changes are made to represent the sub scenarios in

IQQM/SOURCE/ISIS/WUPFIN tools. Thus only the changes in SWAT for Climate and Land Use are presented.

(1) Sub Scenario - Impact of Climate change modelled in SWAT

The result at 10 key stations is presented in Table 5.3

- The flow, sediment, Nitrogen and Phosphorus load result from SCN C2 (GFDL-wetter climate) are higher than M3 (no climate change) because of increasing of rainfall in Basin. Average flow increase about 3-7% at key station, 14-23% increase of annual sediment, 7-12% increase of Total Nitrogen and 6-12% increase of Total Phosphorus comparing with no climate change.
- The flow, sediment, Nitrogen and Phosphorus load result from SCN C3 (GISS – drier climate) are lower than M3 (no climate change) because of decreasing of rainfall in Basin. Average flow decrease is about 12-21% at key stations, increase of annual sediment of 24-38%, 14-23% increase of Total Nitrogen and 10-24% increase of Total Phosphorus compared to the no climate change case.

(2) **Sub Scenario Impact of Landuse change in SWAT**

The results at 10 key stations is presented in Table 5.4

- The flow result from SCN A1 (LU 2007) are not significant change (less impact from Landuse change) when compare with M3CC (LU2040).
- The sediment, Nitrogen and Phosphorus load result from SCN A1 (LU2007) are not significant changed at stations from Chiang Saen untill Pakse, but decrease more at Stung treng and Kratie (-3.6% for sediment, -5.2% for Nitrogen and -6% for Phosphorus) when compared with SCN M3CC (LU2040). This is because of quite high changes from forest to agriculture in the Vietnam Highland between Landuse 2007 and Landuse 2040.
- The flow, sediment, Nitrogen and Phosphorus load result from SCN A2 (LU High) do not change greatly (less impact from Landuse change) when compared with M3cc (LU2040) because there not much change in the basin landuse according to the criteria supplied for Council Study.

Table 6-2 Change in Monthly Average Flow in Main Scenarios from IQQM

UNIT : cms

Station	Scenario name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wet (May -Oct)	Dry (Nov - Apr)	Average	Compare with M1		
Chiang Saen	M1 - EDS 2007	1,240	994	863	826	1,240	2,177	4,450	5,845	5,397	4,018	2,686	1,635	3,854	1,374	2,614			
	M2 -Dev 2020	1,534	1,244	1,145	1,074	1,355	1,942	3,556	5,376	5,270	4,077	2,827	2,029	3,596	1,642	2,619	-7%	20%	0%
	M3 -Dev 2040	1,533	1,242	1,143	1,073	1,354	1,941	3,554	5,376	5,268	4,076	2,825	2,028	3,595	1,641	2,618	-7%	19%	0%
	M3cc - Dev 2040	1,602	1,292	1,172	1,093	1,316	1,699	2,797	4,618	5,264	4,915	3,190	2,143	3,435	1,749	2,592	-11%	27%	-1%
Luang Prabang	M1 - EDS 2007	1,505	1,166	1,020	1,046	1,825	3,210	6,746	9,605	8,432	5,394	3,469	2,053	5,869	1,710	3,789			
	M2 -Dev 2020	1,904	1,516	1,385	1,346	1,903	2,880	5,660	8,991	8,288	5,462	3,656	2,526	5,531	2,056	3,793	-6%	20%	0%
	M3 -Dev 2040	1,964	1,586	1,469	1,426	1,919	2,807	5,436	8,827	8,253	5,456	3,678	2,601	5,450	2,121	3,785	-7%	24%	0%
	M3cc - Dev 2040	2,135	1,684	1,534	1,469	1,803	2,284	4,309	7,666	8,588	7,458	4,494	2,844	5,351	2,360	3,856	-9%	38%	2%
Chiang Khan	M1 - EDS 2007	1,558	1,183	1,057	1,142	2,300	3,913	7,439	10,823	10,074	6,320	3,817	2,170	6,811	1,821	4,316			
	M2 -Dev 2020	1,984	1,536	1,422	1,446	2,353	3,593	6,335	10,220	9,928	6,386	4,004	2,662	6,469	2,176	4,322	-5%	19%	0%
	M3 -Dev 2040	2,081	1,613	1,502	1,523	2,325	3,521	6,092	10,071	9,902	6,387	4,028	2,761	6,383	2,251	4,317	-6%	24%	0%
	M3cc - Dev 2040	2,310	1,715	1,552	1,515	2,108	2,835	4,858	8,800	10,534	9,216	5,137	3,044	6,392	2,546	4,469	-6%	40%	4%
Vientiane	M1 - EDS 2007	1,569	1,186	1,053	1,134	2,314	4,037	7,481	11,098	10,535	6,523	3,906	2,201	6,998	1,841	4,420			
	M2 -Dev 2020	1,998	1,538	1,417	1,440	2,384	3,735	6,372	10,483	10,376	6,581	4,079	2,679	6,655	2,192	4,424	-5%	19%	0%
	M3 -Dev 2040	2,110	1,601	1,480	1,504	2,307	3,655	6,089	10,348	10,368	6,577	4,131	2,795	6,557	2,270	4,414	-6%	23%	0%
	M3cc - Dev 2040	2,382	1,705	1,532	1,492	2,103	2,957	4,830	9,044	11,044	9,502	5,318	3,073	6,580	2,584	4,582	-6%	40%	4%
Nong Khai	M1 - EDS 2007	1,573	1,187	1,056	1,140	2,341	4,092	7,548	11,204	10,674	6,581	3,920	2,209	7,073	1,848	4,460			
	M2 -Dev 2020	2,003	1,540	1,421	1,447	2,410	3,792	6,439	10,588	10,514	6,641	4,098	2,690	6,731	2,200	4,465	-5%	19%	0%
	M3 -Dev 2040	2,114	1,600	1,483	1,510	2,334	3,711	6,154	10,453	10,505	6,636	4,148	2,804	6,632	2,276	4,454	-6%	23%	0%
	M3cc - Dev 2040	2,387	1,706	1,534	1,497	2,124	3,001	4,896	9,145	11,220	9,614	5,346	3,086	6,667	2,593	4,630	-6%	40%	4%
Nakhon Phanom	M1 - EDS 2007	2,117	1,593	1,416	1,637	3,667	8,292	13,619	19,393	18,463	10,184	5,482	3,083	12,270	2,555	7,412			
	M2 -Dev 2020	2,910	2,252	1,999	2,037	3,373	6,941	11,717	18,191	17,939	10,272	5,987	3,862	11,405	3,174	7,290	-7%	24%	-2%
	M3 -Dev 2040	2,731	2,006	1,853	1,932	3,025	6,544	11,151	17,780	17,715	10,023	5,699	3,645	11,040	2,978	7,009	-10%	17%	-5%
	M3cc - Dev 2040	3,061	2,158	1,947	1,917	2,716	5,519	10,195	16,647	19,017	13,852	7,574	4,006	11,325	3,444	7,384	-8%	35%	0%
Mukdahan	M1 - EDS 2007	2,121	1,602	1,445	1,723	3,842	8,844	15,263	21,814	20,336	10,756	5,588	3,106	13,476	2,598	8,037			
	M2 -Dev 2020	3,069	2,375	2,137	2,215	3,632	7,589	13,516	20,865	20,073	11,127	6,336	4,095	12,800	3,371	8,086	-5%	30%	1%
	M3 -Dev 2040	2,859	2,100	1,974	2,102	3,286	7,174	12,945	20,457	19,848	10,846	5,996	3,837	12,426	3,145	7,785	-8%	21%	-3%
	M3cc - Dev 2040	3,189	2,252	2,061	2,054	2,905	6,053	12,070	19,373	21,379	14,907	7,906	4,202	12,781	3,611	8,196	-5%	39%	2%
Pakse	M1 - EDS 2007	2,398	1,733	1,536	1,868	4,245	10,701	18,361	27,562	26,936	14,883	7,228	3,727	17,115	3,082	10,098			
	M2 -Dev 2020	3,304	2,489	2,208	2,348	4,052	9,379	16,472	26,332	26,475	14,992	7,822	4,638	16,283	3,801	10,042	-5%	23%	-1%
	M3 -Dev 2040	3,390	2,509	2,179	2,322	3,457	8,817	15,736	25,917	26,532	14,895	7,659	4,583	15,892	3,774	9,833	-7%	22%	-3%
	M3cc - Dev 2040	3,684	2,668	2,320	2,329	2,984	7,413	14,418	24,653	28,093	20,028	10,560	5,234	16,265	4,466	10,365	-5%	45%	3%
Strung Treng	M1 - EDS 2007	3,210	2,311	2,010	2,440	5,286	12,476	21,921	33,569	33,152	19,343	9,000	4,780	20,958	3,958	12,458			
	M2 -Dev 2020	4,590	3,432	2,882	3,042	4,765	10,443	19,110	31,463	32,405	19,622	9,975	6,230	19,635	5,026	12,330	-6%	27%	-1%
	M3 -Dev 2040	4,727	3,512	2,898	3,012	4,068	9,702	18,183	30,968	32,530	19,584	9,887	6,279	19,172	5,052	12,112	-9%	28%	-3%
	M3cc - Dev 2040	5,083	3,722	3,041	2,981	3,488	8,176	16,553	29,734	34,073	25,127	13,188	7,051	19,525	5,844	12,685	-7%	48%	2%
Kratie	M1 - EDS 2007	3,485	2,544	2,172	2,514	5,196	12,514	22,181	34,626	34,990	21,416	10,203	5,369	21,820	4,381	13,101			
	M2 -Dev 2020	4,881	3,673	3,053	3,133	4,739	10,495	19,393	32,427	34,192	21,630	11,142	6,793	20,479	5,446	12,963	-6%	24%	-1%
	M3 -Dev 2040	4,946	3,734	3,008	3,064	4,193	9,835	18,405	31,984	34,396	21,682	11,102	6,702	20,083	5,426	12,754	-8%	24%	-3%
	M3cc - Dev 2040	5,337	3,933	3,162	3,046	3,758	8,257	16,650	30,736	35,752	27,156	14,562	7,605	20,385	6,274	13,330	-7%	43%	2%

Figure 6-1 Change in Monthly Flow Main Scenarios Chiang Saen to Kratie (IQQM results)

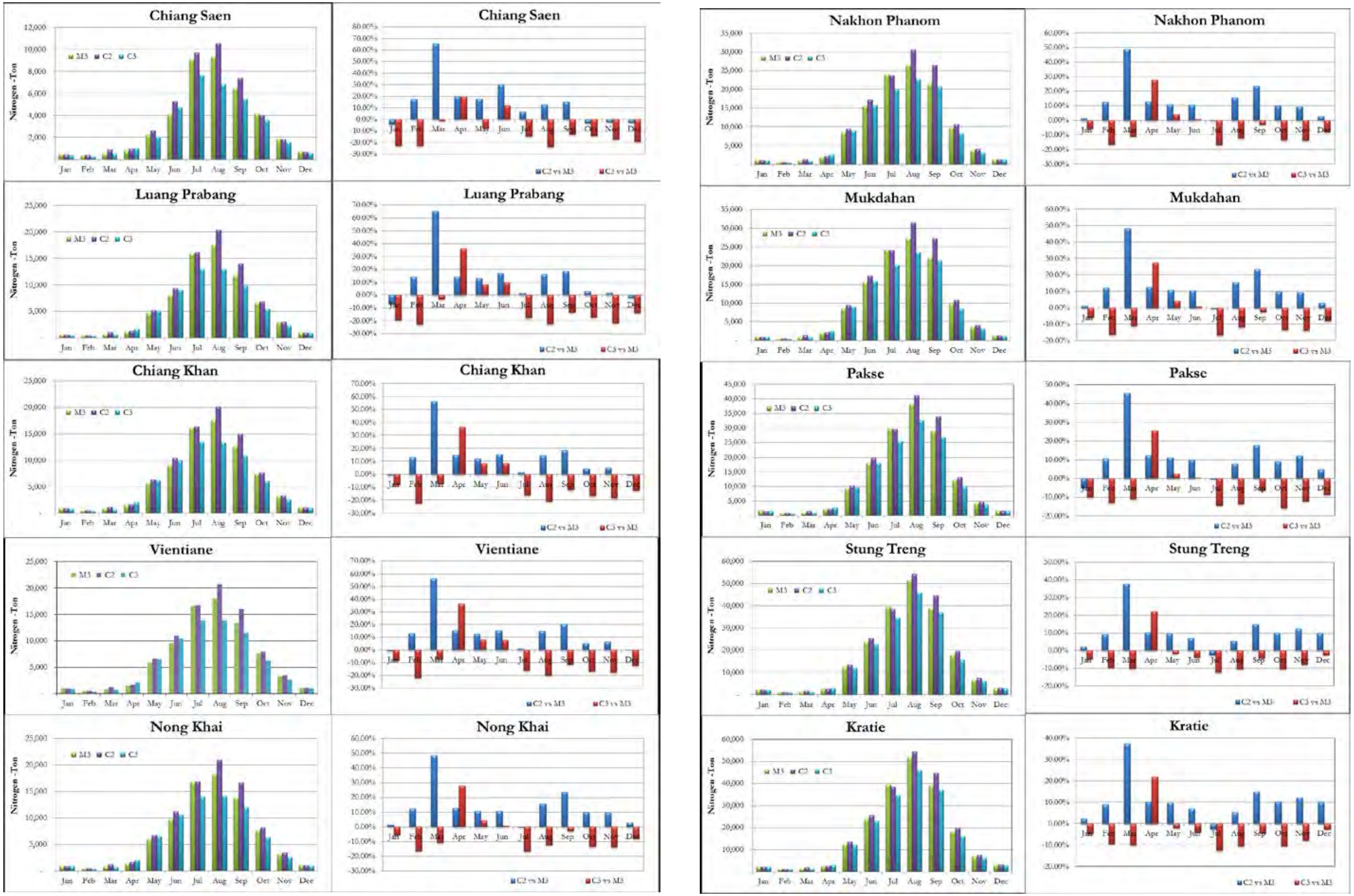


Figure 6-2 Change in Flow at Main Stations for Climate Change Sub Scenarios

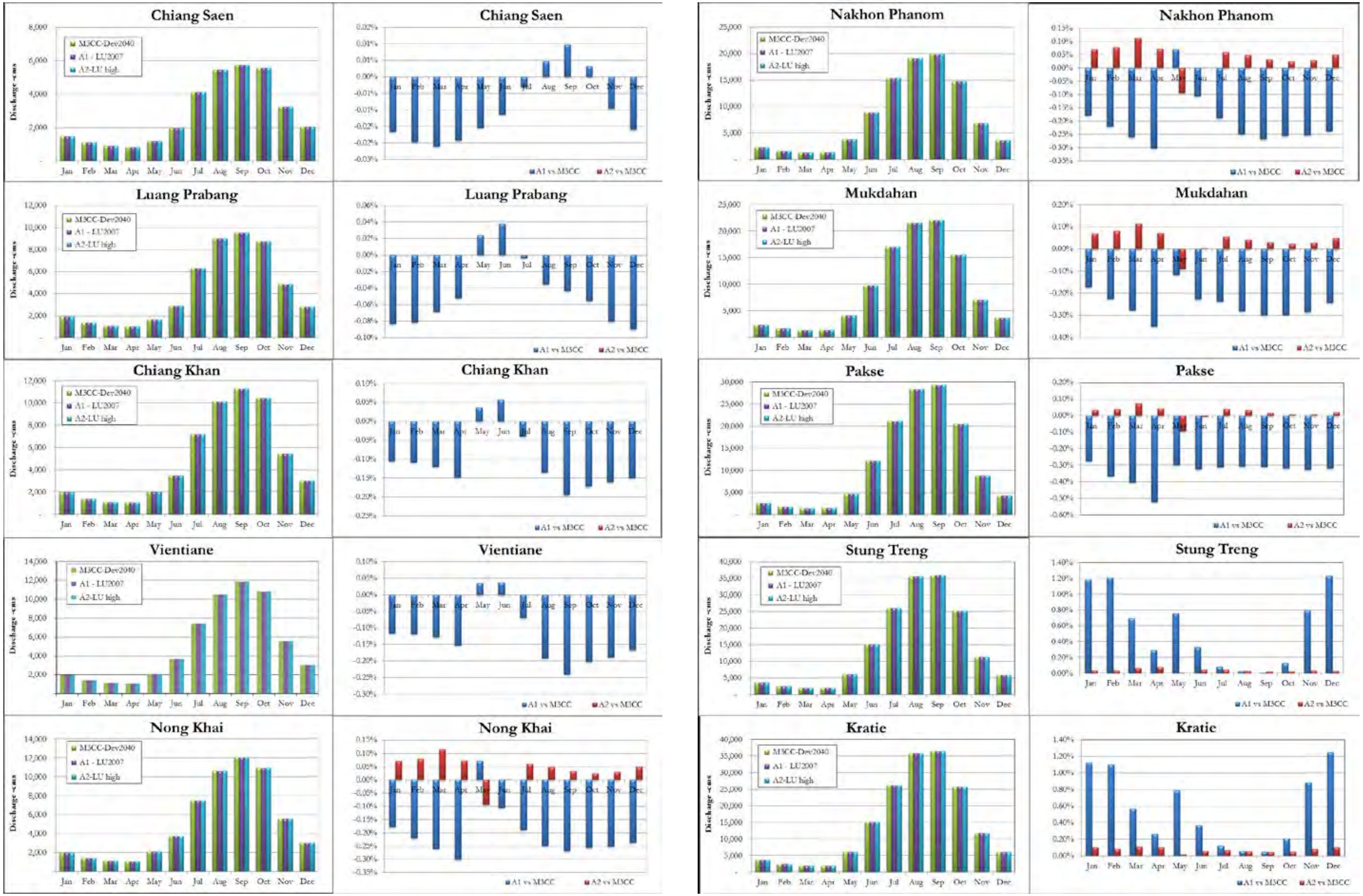
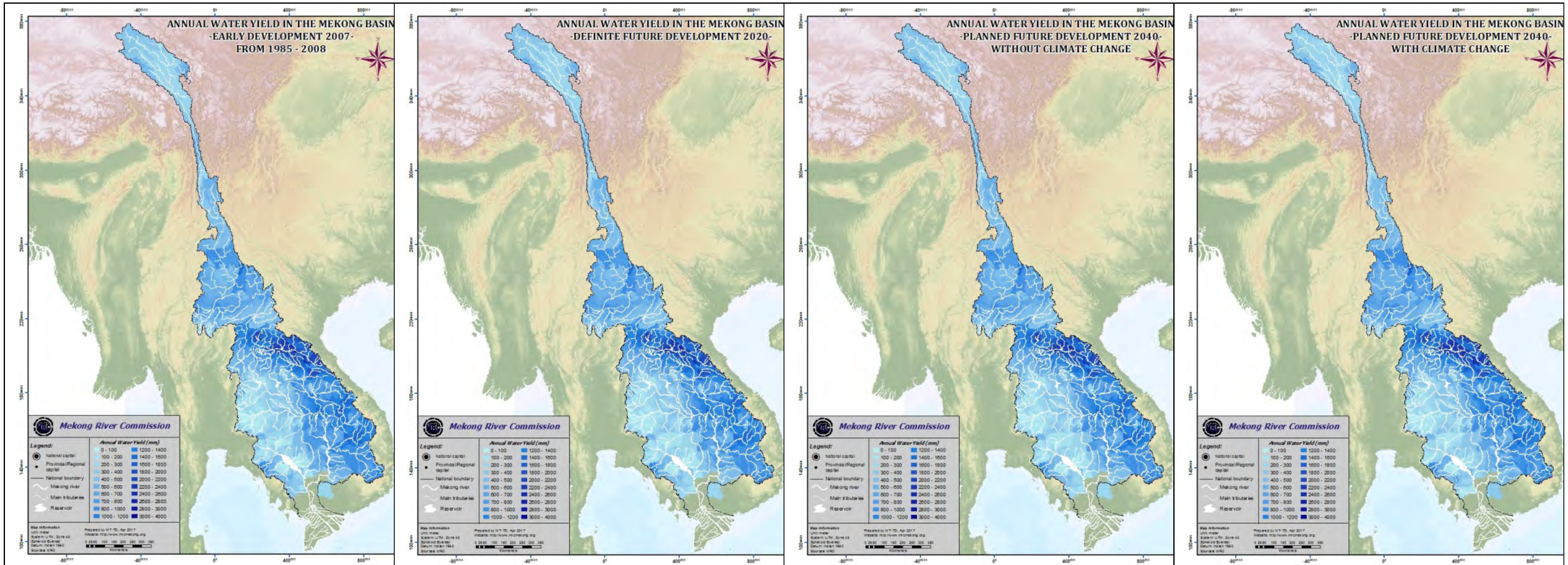
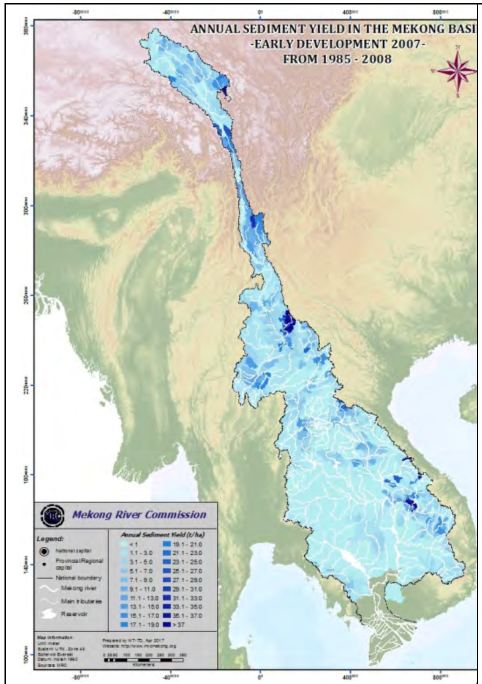


Figure 6-3 Change in Flow at Key Stations for Land Use Change Sub Scenarios

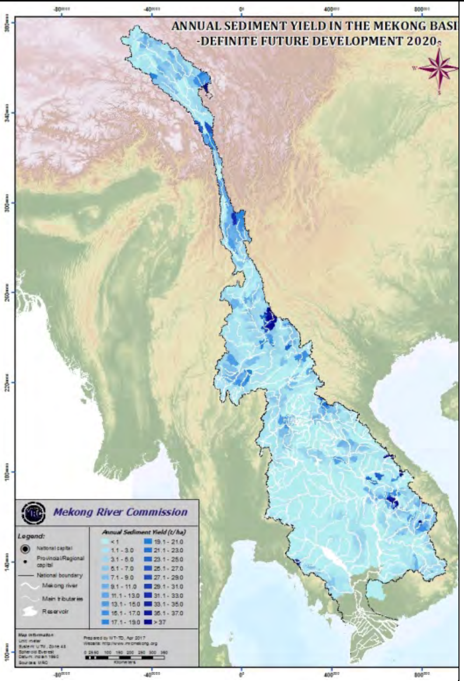


Scenario: M1 (EDS 2007)	Scenario: M2 (DEV 2020)	Scenario: M3 (DEV 2040) without CC	Scenario: M3-CC (DEV 2040) with CC

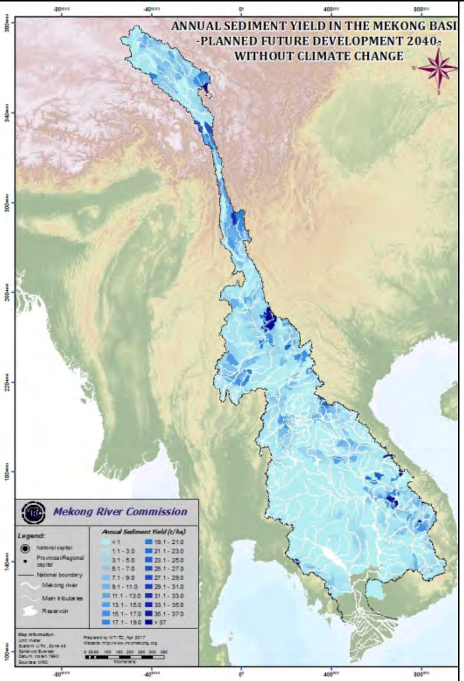
Figure 6-4 Annual Water Yield from SWAT 2007, 2020 and 2040 with and without Climate Change



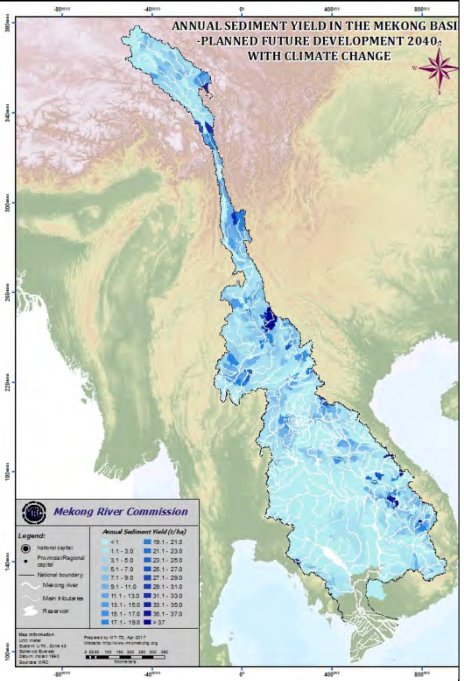
Scenario: M1 (EDS 2007)



Scenario: M2 (DEV 2020)

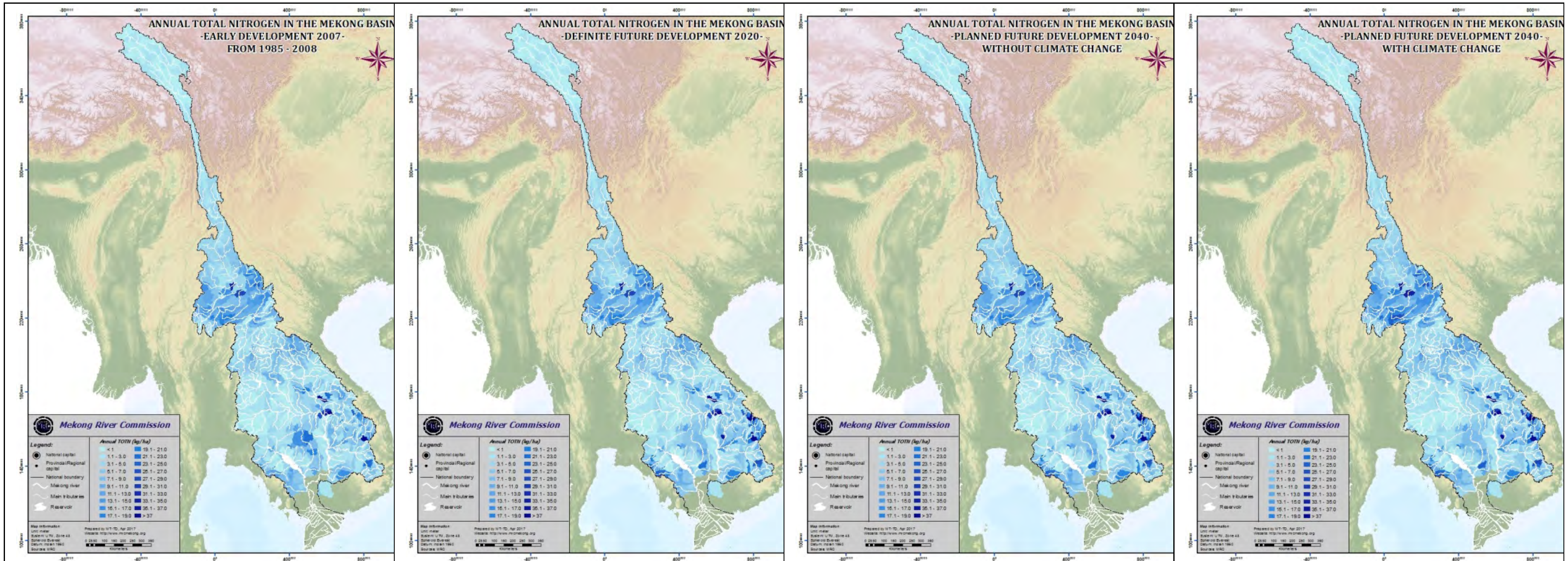


Scenario: M3 (DEV 2040) without CC



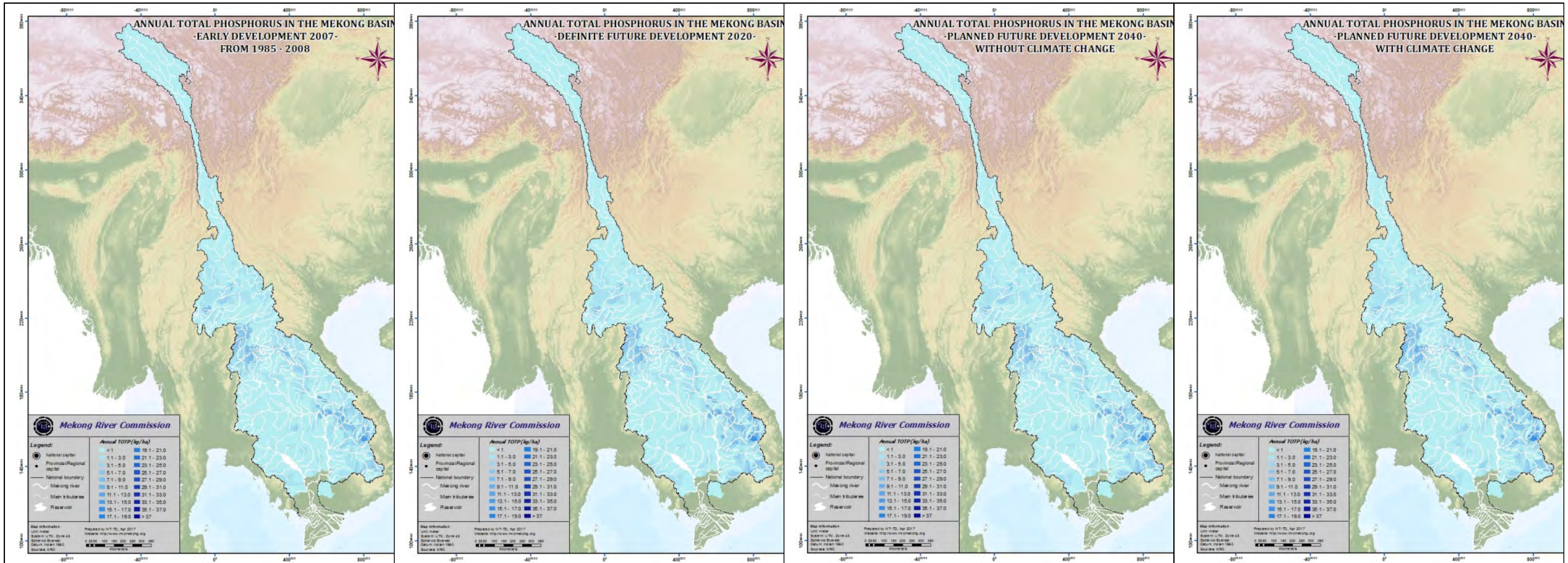
Scenario: M3-CC (DEV 2040) with CC

Figure 6-5 Annual Sediment Yield from SWAT 2007, 2020 and 2040 with and without Climate Change



Scenario: M1 (EDS 2007)	Scenario: M2 (DEV 2020)	Scenario: M3 (DEV 2040) without CC	Scenario: M3-CC (DEV 2040) with CC

Figure 6-6 Annual Organic Nitrogen from SWAT 2007, 2020 and 2040 with and without Climate Change



Scenario: M1 (EDS 2007)	Scenario: M2 (DEV 2020)	Scenario: M3 (DEV 2040) without CC	Scenario: M3-CC (DEV 2040) with CC

Figure 6-7 Annual Organic Phosphorus from SWAT 2007, 2020 and 2040 with and without Climate Change

Table 6-3 Comparing Flow, Sediment, Nitrogen and Phosphorus from SWAT model at key station for Sub Scenario C2 and C3 with Main Scenario M3

Flow*	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit: cms	M3	2,845	4,206	4,769	4,905	4,959	7,933	8,611	10,969	13,708	13,932
	C2	3,040	4,457	5,053	5,197	5,254	8,359	9,053	11,417	14,175	14,407
	C3	2,407	3,613	4,152	4,280	4,330	7,073	7,722	9,844	12,496	12,672
Sediment **	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Million Ton	M3	92	108	112	116	117	130	132	147	174	174
	C2	113	132	137	141	142	156	156	171	198	198
	C3	70	83	87	91	92	103	107	123	151	151
Total Nitrogen**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Ton	M3	40,284	71,471	76,186	78,917	80,253	115,357	117,453	147,720	200,232	201,575
	C2	45,098	79,632	84,614	88,018	89,601	129,204	131,624	160,984	214,547	215,954
	C3	34,763	61,733	67,272	69,886	71,154	105,569	107,815	133,367	184,093	185,163
Total Phosphorus**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Ton	M3	4,614	7,626	10,919	11,686	10,710	14,342	15,370	20,283	35,880	35,779
	C2	5,144	8,539	12,212	12,976	11,980	15,867	16,936	21,996	37,940	37,870
	C3	4,247	6,531	9,924	10,668	9,645	12,981	13,888	18,401	34,077	33,963

Per cent change of flow (cms), Sediment flux (Mil Ton), Total Nitrogen (T) and Total Phosphorus (T) between C2, C3 and M3 by Season

Flow*	SCN	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit: cms	C2 vs M3	7%	6%	6%	6%	6%	5%	5%	4%	3%	3%
	C3 vs M3	-15%	-14%	-13%	-13%	-13%	-11%	-10%	-10%	-9%	-9%
Sediment **	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Million Ton	C2 vs M3	23%	22%	22%	22%	22%	20%	19%	16%	14%	14%
	C3 vs M3	-23%	-23%	-22%	-22%	-22%	-21%	-19%	-16%	-13%	-13%
Total Nitrogen**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Ton	C2 vs M3	12%	11%	11%	12%	12%	12%	12%	9%	7%	7%
	C3 vs M3	-14%	-14%	-12%	-11%	-11%	-8%	-8%	-10%	-8%	-8%
Total Phosphorus**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	MDH	PKS	STT	KRE
unit - Ton	C2 vs M3	11%	12%	12%	11%	12%	11%	10%	8%	6%	6%
	C3 vs M3	-8%	-14%	-9%	-9%	-10%	-9%	-10%	-9%	-5%	-5%

Flow *: the result come from SWAT only with condition of no dam and water use demand, Further calculation for consider HP and irrigation is in IQQM model

Sediment, TOTN and TOTP ** : the result come from SWAT model only, not yet acount for Dam Trapping that will estimated in Source model

Table 6-4 Comparing Flow, Sediment, Nitrogen and Phosphorus from SWAT model at key station for Sub Scenario A1 and A2 with Main Scenario M3

The Comparison of flow (cms), Sediment flux (Million Ton), Total Nitrogen (Ton) and Total Phophorus (Ton) between M1, M2 , M3 and M3cc from SWAT model

Flow*	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit: cms	M3cc	2,807	4,262	4,893	5,050	5,111	8,270	8,978	11,433	14,218	14,447
	A1	2,807	4,260	4,887	5,042	5,104	8,252	8,954	11,397	14,253	14,488
	A2	2,807	4,262	4,893	5,050	5,111	8,273	8,981	11,435	14,223	14,455
Sediment **	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Million Ton	M3cc	91.68	108.05	112.59	116.61	117.19	129.28	131.13	146.70	167.56	167.62
	A1	91.61	107.86	112.39	116.37	116.96	129.31	131.33	146.97	173.30	173.36
	A2	91.57	107.78	112.31	116.27	116.86	129.51	131.62	147.30	173.57	173.64
Total Nitrogen**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Ton	M3cc	40,363	71,596	76,238	78,943	80,283	115,158	117,252	147,338	189,737	191,070
	A1	40,326	71,555	76,238	78,958	80,298	115,304	117,399	147,621	200,024	201,368
	A2	40,284	71,471	76,186	78,917	80,253	115,357	117,453	147,720	200,232	201,575
Total Phosphorus**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Ton	M3cc	4,628	7,651	10,922	11,689	10,716	14,280	15,298	20,173	33,560	33,525
	A1	4,618	7,635	10,913	11,680	10,707	14,311	15,335	20,233	35,825	35,724
	A2	4,614	7,626	10,919	11,686	10,710	14,342	15,370	20,283	35,880	35,779

Percent change of flow , Sediment flux , Total Nitrogen and Total Phophorus between M1, M2 , M3 and M3cc from SWAT model

Flow*	SCN	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit: cms	A1 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	A2 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Sediment **	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Million Ton	A1 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%
	A2 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	4%	4%
Total Nitrogen**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Ton	A1 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%
	A2 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	6%	5%
Total Phosphorus**	Scenario	CSN	LPB	CKN	VTE	NKI	NKP	NDH	PKS	STT	KRE
unit - Ton	A1 vs M3cc	0%	0%	0%	0%	0%	0%	0%	0%	7%	7%
	A2 vs M3cc	0%	0%	0%	0%	0%	0%	0%	1%	7%	7%

Flow *: the result come from SWAT only with condition of no dam and water use demand, Further calculation for consider HP and irrigation is in IQQM model

Sediment, TOTN and TOTP ** : the result come from SWAT model only, not yet acount for Dam Trapping that will estimated in Source model

6.1.1 Irrigation

Irrigation of both rice and non-rice crops are simulated in IQQM (whereas in SWAT the total cropped area is simulated including the large rain fed areas of rice). The area used in the model by country is summarised in Table 5.4. The water demands for these areas are given in Table 5.5 and the 'sustainable are' as defined in IQQM as the area appropriate for a moderate drought are shown in Table 5.6. It can be seen that the model predicts quite significant reductions in sustainable area for irrigation in some months as compared with the total irrigation area. More details by province are given Annex/Volume 4.

For Sub Scenarios the water demand/irrigation diversions are shown in Table 5.9. It can be seen that there is a mild increase in demand with wetter climate change and a decrease in possible diversion with the drier C3 scenario. Without the planned irrigation development (Scenario I1) there are decreased diversions relative to M3.

Table 6-5 Seasonal Irrigation areas by country in each main scenario

Country	Early Development Scenario (Existing 2007)			Definite Future (Ind. 2020 plans)			Planned Development Scenario (ind. 2040 plans)		
	Irrigated in Wet Season (Ha)	Irrigated in Dry Season (Ha)	Total Area	Irrigated in Wet Season (Ha)	Irrigated in Dry Season (Ha)	Total Area	Irrigated in Wet Season (Ha)	Irrigated in Dry Season (Ha)	Total Area
Cambodia	290,050	273,132	563,182	478,430	398,931	877,361	1,065,862	767,512	1,833,374
Lao PDR	209,116	125,964	335,080	309,068	196,775	505,843	597,893	402,514	1,000,407
Thailand	776,980	229,950	1,006,930	1,544,296	594,558	2,138,855	1,810,650	655,752	2,466,402
Viet Nam	2,463,438	1,988,240	4,451,678	2,350,290	1,971,753	4,322,043	2,307,490	1,928,848	4,236,338
Total LMB	3,739,584	2,617,285	6,356,869	4,682,084	3,162,017	7,844,101	5,781,895	3,754,626	9,536,521

Table 6-6 Monthly Irrigation Water Diversion (MCM) by country in each main scenario

Monthly Average Total Diversion (MCM) for EDS 2007 M1													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cambodia	515	415	409	491	326	217	118	24	3	15	25	403	2,961
Laos	342	278	184	64	51	407	152	29	41	365	552	438	2,904
Thailand	443	413	348	141	491	778	1,603	1,106	1,059	1,312	329	342	8,365
Vietnam	4,039	3,842	1,683	5,104	1,623	679	367	453	150	23	2,892	4,259	25,112
Monthly Average Total Diversion (MCM) for Dev2020 M2													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cambodia	692	562	539	600	473	359	213	50	6	26	43	536	4,098
Laos	562	452	313	100	117	623	202	34	54	490	817	723	4,487
Thailand	773	566	564	327	715	1,149	2,579	1,942	1,818	2,351	724	687	14,195
Vietnam	4,070	3,867	1,697	4,857	1,526	652	350	429	142	24	2,841	4,183	24,640
Monthly Average Total Diversion (MCM) for Dev2040 M3													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cambodia	1,057	873	883	1,011	1,052	895	616	240	7	28	46	931	7,638
Laos	1,226	999	615	184	243	1,167	371	57	99	924	1,567	1,518	8,969
Thailand	1,266	1,006	892	601	1,271	1,621	3,283	2,456	2,183	2,990	1,023	1,144	19,736
Vietnam	3,974	3,775	1,657	4,830	1,556	678	364	413	137	24	2,767	4,090	24,266
Monthly Average Total Diversion (MCM) for Dev2040 M3 (CC)													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cambodia	1,087	885	898	1,008	1,071	933	703	252	7	24	46	937	7,851
Laos	1,257	1,043	698	291	330	1,312	391	68	55	611	1,608	1,571	9,237
Thailand	1,374	1,075	929	637	1,252	1,611	3,172	2,479	1,698	2,107	1,003	1,169	18,507
Vietnam	4,150	3,861	1,967	5,128	1,623	641	383	410	112	18	2,727	4,055	25,076

Table 6-7 Monthly Sustainable Areas for Irrigation by country in each main scenario

Monthly Average Sustainable Areas (Ha) for EDS 2007 M1													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max area
Cambodia	249,908	191,358	175,337	410,139	210,669	209,113	225,940	146,240	16,827	16,827	16,827	290,605	410,139
Laos	80,424	92,244	91,446	91,022	48,153	206,465	205,617	205,617	205,617	234,077	282,586	111,246	282,586
Thailand	165,436	158,574	131,330	79,870	368,705	569,177	800,018	770,287	761,207	761,207	297,072	180,812	800,018
Vietnam	1,874,317	1,850,564	1,837,860	3,271,002	1,423,366	1,911,575	1,904,129	2,072,120	648,261	648,261	2,489,391	2,393,372	3,271,002

Monthly Average Sustainable Areas (Ha) for Dev2020 M2													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max area
Cambodia	347,196	259,092	239,647	615,896	335,927	332,798	362,591	235,540	29,797	29,797	29,797	426,665	615,896
Laos	128,658	144,416	143,188	142,823	119,053	305,413	303,803	303,803	303,803	342,312	380,523	168,188	380,523
Thailand	330,929	296,019	230,377	150,717	669,393	980,637	1,593,846	1,533,374	1,511,113	1,511,113	755,238	433,499	1,593,846
Vietnam	1,841,313	1,823,833	1,812,968	3,175,207	1,365,386	1,837,072	1,829,726	1,988,145	622,389	622,389	2,425,165	2,351,939	3,175,207

Monthly Average Sustainable Areas (Ha) for Dev2040 M3													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max area
Cambodia	544,469	416,776	385,488	1,110,321	559,740	555,419	587,251	374,552	31,831	31,831	31,831	730,972	1,110,321
Laos	254,605	286,209	284,474	283,850	255,835	590,622	587,382	587,382	587,382	663,117	729,547	330,816	729,547
Thailand	494,953	454,333	366,282	263,244	1,062,561	1,429,217	2,237,768	2,128,138	2,100,076	2,100,076	1,022,444	643,058	2,237,768
Vietnam	1,803,706	1,786,301	1,775,476	3,116,483	1,331,476	1,768,164	1,762,943	1,911,809	579,926	579,926	2,342,223	2,279,584	3,116,483

Monthly Average Sustainable Areas (Ha) for Dev2040 M3 (CC)													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max area
Cambodia	564,455	427,083	389,527	1,074,961	495,782	492,236	524,065	330,926	31,799	31,799	31,799	737,095	1,074,961
Laos	254,318	286,080	284,314	283,639	255,389	588,449	584,066	584,066	584,066	659,804	728,075	329,862	728,075
Thailand	519,187	474,369	378,568	259,767	1,053,118	1,419,478	2,226,158	2,123,459	2,097,061	2,097,061	1,021,808	657,572	2,226,158
Vietnam	1,804,906	1,788,043	1,777,218	3,104,492	1,312,818	1,749,108	1,743,385	1,892,146	579,028	579,028	2,341,735	2,279,552	3,104,492

Table 6-8 Proportion of Sustainable to total Irrigation Area by country in each main scenario (assumes no significant new water diversions)

Monthly Average Sustainable Areas (%) for EDS 2007 M1													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aaverage
Cambodia	84%	68%	63%	75%	73%	72%	74%	73%	100%	100%	100%	98%	82%
Laos	95%	95%	94%	94%	97%	99%	98%	98%	98%	99%	99%	96%	97%
T%iland	89%	81%	79%	88%	97%	97%	98%	98%	98%	98%	98%	97%	93%
Vietnam	94%	93%	92%	93%	88%	90%	90%	91%	98%	98%	98%	96%	93%

Monthly Average Sustainable Areas (%) for Dev2020 M2													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aaverage
Cambodia	79%	64%	59%	73%	70%	69%	71%	71%	100%	100%	100%	97%	79%
Laos	92%	92%	91%	91%	98%	99%	98%	98%	98%	99%	99%	93%	96%
T%iland	68%	58%	53%	58%	94%	95%	96%	98%	98%	98%	98%	90%	84%
Vietnam	93%	92%	92%	94%	89%	91%	91%	91%	98%	98%	98%	96%	94%

Monthly Average Sustainable Areas (%) for Dev2040 M3													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aaverage
Cambodia	67%	54%	50%	62%	52%	52%	53%	53%	100%	100%	100%	90%	69%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	99%	99%	89%	94%
T%iland	70%	61%	57%	65%	94%	95%	96%	98%	98%	98%	98%	91%	85%
Vietnam	94%	93%	92%	93%	86%	89%	89%	89%	98%	98%	98%	96%	93%

Monthly Average Sustainable Areas (%) for Dev2040 M3 (CC)													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aaverage
Cambodia	70%	55%	50%	60%	46%	46%	48%	47%	100%	100%	100%	91%	68%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	98%	99%	89%	94%
T%iland	73%	64%	59%	64%	94%	95%	96%	97%	98%	98%	97%	93%	86%
Vietnam	94%	93%	92%	92%	85%	88%	88%	89%	98%	98%	98%	96%	93%

Table 6-10 Total Irrigation Water Demand from Sub Scenario A1, A2, C2, C3, I1, I2, H1a, H1b, H2 and H3

Total Irrigation Water demand - MCM

		Total Irrigation Water demand - mcm											
Country	BDP Sub area	SCN M3cc	SCN M3	sub SCN A1	sub SCN A2	sub SCN C2	sub SCN C3	sub SCN I1	sub SCN I2	sub SCN H1a	sub SCN H1b	sub SCN H2	sub SCN H3
Cambodia	6C	13	13	13	13	14	13	13	13	13	13	13	13
	7C	55	55	55	55	59	55	52	55	55	55	55	55
	8C	22	21	22	22	22	22	4	22	22	22	22	22
	9C	1,012	938	1,055	1,025	1,079	973	667	1,012	993	1,012	1,012	1,012
	10C*	3,500	3,465	3,480	3,500	3,557	3,578	1,077	3,500	3,500	3,500	3,500	3,500
	11C*	89	84	87	89	88	90	42	89	89	89	89	89
Laos	1L	438	430	438	438	476	415	215	552	438	438	438	438
	3L	32	32	32	32	35	30	12	35	32	32	32	32
	4L	2,427	2,384	2,422	2,427	2,687	2,365	987	3,426	2,386	2,427	2,427	2,427
	6L	839	798	839	839	872	812	231	1,209	684	839	839	839
	7L	916	866	916	916	933	870	43	1,240	779	916	916	916
Thailand	2T	355	370	354	355	392	368	254	436	355	355	355	355
	3T	1,170	1,240	1,170	1,170	1,399	1,267	539	1,373	1,170	1,170	1,170	1,170
	5T	5,677	5,970	5,676	5,677	6,443	5,800	2,204	5,592	5,677	5,677	5,677	5,677
Vietnam	7V	1,583	1,524	1,631	1,584	1,564	1,501	1,583	1,583	1,389	1,583	1,583	1,583
	10V*	13,847	13,422	13,861	13,847	14,152	13,695	14,603	13,847	13,847	13,847	13,847	13,847
	11V*	3,061	2,975	3,072	3,061	3,107	3,065	3,153	3,061	3,061	3,061	3,061	3,061
	Country	SCN M3cc	SCN M3	sub SCN A1	sub SCN A2	sub SCN C2	sub SCN C3	sub SCN I1	sub SCN I2	sub SCN H1a	sub SCN H1b	sub SCN H2	sub SCN H3
	Cambodia	4,691	4,577	4,712	4,704	4,819	4,732	1,854	4,691	4,673	4,691	4,691	4,691
	Laos	4,652	4,510	4,647	4,652	5,003	4,492	1,489	6,462	4,318	4,652	4,652	4,652
	Thailand	7,201	7,580	7,199	7,201	8,235	7,435	2,997	7,402	7,201	7,201	7,201	7,201
	Vietnam	18,491	17,921	18,564	18,492	18,823	18,260	19,338	18,491	18,297	18,491	18,491	18,491
	Total	35,036	34,589	35,123	35,049	36,879	34,919	25,679	37,047	34,489	35,036	35,036	35,036

Table 6-9 Total Diversion from Sub Scenario A1, A2, C2, C3, I1, I2, H1a, H1b, H2 and H3

Total Diversion - MCM

		Total Diversion (mcm)											
Country	BDP Sub area	SCN M3cc	SCN M3	sub SCN A1	sub SCN A2	sub SCN C2	sub SCN C3	sub SCN I1	sub SCN I2	sub SCN H1a	sub SCN H1b	sub SCN H2	sub SCN H3
Cambodia	6C	22	22	22	22	24	22	22	22	22	22	22	22
	7C	92	92	92	92	98	91	87	92	92	92	92	92
	8C	37	35	37	37	36	36	6	37	37	37	37	37
	9C	1,687	1,564	1,759	1,708	1,798	1,623	1,112	1,687	1,656	1,687	1,687	1,687
	10C*	5,833	5,775	5,799	5,833	5,927	5,962	1,793	5,833	5,833	5,833	5,833	5,833
	11C*	148	140	145	148	147	151	70	148	148	148	148	148
Laos	1L	882	868	882	882	961	839	435	1,108	881	882	882	882
	3L	65	64	65	65	71	62	25	72	65	65	65	65
	4L	4,832	4,761	4,822	4,832	5,378	4,732	1,967	6,789	4,752	4,832	4,832	4,832
	6L	1,659	1,578	1,659	1,659	1,727	1,608	457	2,379	1,360	1,659	1,659	1,659
	7L	1,799	1,699	1,799	1,799	1,833	1,708	86	2,427	1,536	1,799	1,799	1,799
Thailand	2T	732	769	731	732	815	768	528	901	732	732	732	732
	3T	2,405	2,570	2,405	2,405	2,911	2,637	1,132	2,837	2,405	2,405	2,405	2,405
	5T	15,370	16,397	15,368	15,370	17,754	15,976	6,111	15,135	15,370	15,370	15,370	15,370
Vietnam	7V	2,109	2,030	3,222	3,130	3,091	2,968	3,130	3,129	2,750	3,129	2,109	3,129
	10V*	17,033	16,509	17,343	17,326	17,706	17,134	18,271	17,326	17,326	17,326	17,033	17,326
	11V*	3,829	3,722	3,843	3,829	3,887	3,834	3,944	3,829	3,829	3,829	3,829	3,829
	Country	SCN M3cc	SCN M3	sub SCN A1	sub SCN A2	sub SCN C2	sub SCN C3	sub SCN I1	sub SCN I2	sub SCN H1a	sub SCN H1b	sub SCN H2	sub SCN H3
	Cambodia	7,818	7,628	7,854	7,840	8,030	7,885	3,090	7,818	7,788	7,818	7,818	7,818
	Laos	9,237	8,969	9,226	9,237	9,970	8,948	2,970	12,775	8,593	9,237	9,237	9,237
	Thailand	18,507	19,736	18,504	18,507	21,481	19,381	7,770	18,873	18,507	18,507	18,507	18,507
	Vietnam	22,972	22,261	24,409	24,285	24,685	23,936	25,344	24,284	23,905	24,284	22,972	24,284
	Total	58,535	58,594	59,992	59,870	64,166	60,151	39,174	63,751	58,794	59,847	58,535	59,847

6.1.2 Hydropower Production

The IQQM outputs for energy produced from hydropower stations clearly depends on the number of stations operational and thus there is significant variation between scenarios by each country as shown in Table 5.11 -5.16 for tributaries, while Mainstream dams can be seen in Table 5.14.

Table 6-11 Tributary Hydropower Energy Production by country in each main scenario

Monthly Average Energy Production (GWh) for EDS 2007 M1													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cambodia	0	0	0	0	0	1	1	1	1	1	1	1	6
Laos	208	159	164	183	268	455	513	556	556	555	391	296	4,304
Thailand	30	18	18	20	34	70	109	136	158	154	107	52	906
Vietnam	309	204	165	130	164	280	412	681	740	704	499	433	4,723
Monthly Average Energy Production (GWh) for Dev 2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cambodia	302	204	153	139	208	370	609	873	935	964	663	472	5,891
Laos	2,068	1,506	1,445	1,296	1,701	2,704	3,732	4,441	4,495	3,994	2,924	2,513	32,819
Thailand	25	15	15	16	29	65	103	131	153	149	99	47	849
Vietnam	680	404	322	271	380	591	818	1,227	1,276	1,407	1,071	900	9,347
Monthly Average Energy Production (GWh) for Dev 2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cambodia	267	173	133	112	181	354	602	840	893	920	615	419	5,508
Laos	2,555	1,936	1,903	1,734	2,168	3,235	4,435	5,274	5,306	4,724	3,558	3,064	39,891
Thailand	32	22	23	21	32	69	104	132	155	150	104	55	899
Vietnam	679	404	322	271	379	590	817	1,227	1,276	1,406	1,071	900	9,341
Monthly Average Energy Production (GWh) for Dev 2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Cambodia	275	180	136	108	160	323	586	838	899	935	626	431	5,497
Laos	2,647	2,021	2,002	1,794	2,125	3,059	4,304	5,198	5,307	4,826	3,676	3,148	40,107
Thailand	35	23	24	22	31	65	94	126	155	161	119	62	919
Vietnam	717	437	345	273	371	570	811	1,239	1,298	1,450	1,131	946	9,587

Table 6-12 Tributary Hydropower Evaporation by country in each main scenario

Monthly Average Evaporation (MCM) for EDS 2007 M1													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	0	0	0	0	(0)	(0)	(0)	(0)	(0)	(0)	0	0	(0)
Laos	42	41	38	20	(61)	(136)	(168)	(166)	(84)	16	42	43	(31)
Thailand	115	106	97	60	(40)	(65)	(93)	(171)	(159)	21	107	116	8
Vietnam	5	5	4	3	(5)	(7)	(13)	(17)	(11)	(2)	3	4	(3)
Monthly Average Evaporation (MCM) for Dev 2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	136.28	133.58	125.42	66.60	(100.96)	(154.58)	(256.98)	(366.82)	(315.85)	(91.91)	61.59	107.64	(54.67)
Laos	210.67	191.54	166.08	85.34	(272.38)	(585.17)	(849.54)	(924.13)	(424.75)	58.64	206.72	212.32	(160.39)
Thailand	106.44	97.86	88.17	54.37	(37.89)	(62.67)	(89.13)	(160.54)	(151.39)	19.97	100.86	108.93	6.25
Vietnam	20.12	20.16	17.71	9.95	(15.99)	(25.22)	(45.04)	(62.42)	(46.47)	(16.28)	5.62	14.21	(10.30)
Monthly Average Evaporation (MCM) for Dev 2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	229.52	236.77	228.52	133.18	(198.53)	(312.60)	(510.28)	(676.22)	(537.66)	(129.13)	116.08	184.61	(102.98)
Laos	299.00	267.20	224.57	103.35	(342.29)	(696.86)	(1,070.83)	(1,199.61)	(575.85)	61.16	288.44	305.12	(194.72)
Thailand	129.45	122.11	116.38	76.60	(46.81)	(82.06)	(104.01)	(192.49)	(167.86)	25.97	116.53	126.38	10.02
Vietnam	20.12	20.16	17.70	9.95	(15.98)	(25.21)	(45.03)	(62.41)	(46.47)	(16.28)	5.62	14.21	(10.30)
Monthly Average Evaporation (MCM) for Dev 2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	247.58	254.29	282.41	204.19	(156.68)	(326.69)	(486.59)	(695.80)	(601.64)	(204.98)	129.34	187.43	(97.26)
Laos	327.48	296.60	297.33	214.15	(276.62)	(620.74)	(1,157.80)	(1,173.21)	(768.46)	(160.01)	330.95	329.91	(196.70)
Thailand	142.59	134.20	144.85	119.32	(24.84)	(63.68)	(93.57)	(187.56)	(226.37)	(60.67)	128.95	135.94	12.43
Vietnam	21.88	21.93	22.10	15.83	(12.12)	(26.03)	(45.30)	(65.47)	(54.01)	(22.76)	6.58	14.78	(10.22)

Table 6-13 Tributary Hydropower Release and Spill by country in each main scenario

Monthly Average Release and Spill (MCM) for EDS 2007 M1													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	4	1	1	0	3	10	20	31	33	27	17	9	13
Laos	890	710	704	722	1,668	3,645	5,468	6,829	5,283	2,481	1,361	1,172	2,578
Thailand	733	409	577	618	943	2,406	3,890	7,057	9,932	7,522	3,362	1,542	3,249
Vietnam	1,564	994	810	691	1,199	2,102	3,439	6,045	5,591	4,426	2,946	2,247	2,671
Monthly Average Release and Spill (MCM) or Dev 2020 M2													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	4,131	2,723	1,915	1,847	3,323	6,221	10,440	19,199	20,608	17,117	9,611	7,156	8,691
Laos	7,238	5,289	4,969	4,661	7,836	16,428	29,736	41,711	32,736	18,258	11,566	8,985	15,785
Thailand	575	341	455	436	729	2,191	3,468	6,462	9,302	6,819	3,006	1,378	2,930
Vietnam	4,365	2,635	2,099	1,842	3,027	4,967	7,290	13,225	14,012	12,575	8,084	6,404	6,710
Monthly Average Release and Spill (MCM) for Dev 2040 M3													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	4,120	2,668	1,884	1,672	3,151	6,445	11,392	20,622	21,535	17,563	9,672	7,080	8,984
Laos	9,582	7,285	7,163	6,952	11,129	20,498	36,310	51,981	42,281	23,971	15,291	11,864	20,359
Thailand	1,586	1,324	1,265	1,138	1,891	3,524	4,389	7,714	10,923	8,000	4,158	2,642	4,046
Vietnam	4,362	2,635	2,098	1,836	3,020	4,957	7,282	13,219	14,006	12,566	8,080	6,402	6,705
Monthly Average Release and Spill (MCM) Dev 2040 M3 (CC)													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	4,283	2,860	1,944	1,572	2,616	5,753	10,846	20,809	22,704	19,639	10,234	7,400	9,222
Laos	10,137	7,816	7,716	7,227	10,184	17,925	34,841	50,774	46,199	32,346	17,714	12,703	21,299
Thailand	1,693	1,344	1,288	1,107	1,681	3,006	3,624	6,874	11,161	10,927	6,196	3,334	4,353
Vietnam	4,559	2,742	2,173	1,781	2,777	4,774	7,270	13,720	15,096	14,130	8,723	6,709	7,038

Table 6-14 Tributary Inflow by country in each main scenario

Monthly Average Inflow (m3/s) for EDS 2007 M1													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	1	0	0	0	1	4	7	12	13	10	6	3	13
Laos	138	104	101	172	652	1,710	2,328	2,572	1,966	850	392	216	2,498
Thailand	166	69	84	142	372	1,026	1,546	2,957	4,102	2,782	1,171	426	3,249
Vietnam	538	373	280	254	485	859	1,364	2,298	2,156	1,640	1,098	778	2,671
Monthly Average Inflow (m3/s)for Dev 2020 M2													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	1,213	816	540	635	1,506	2,891	4,425	7,514	7,974	6,158	3,339	2,221	3,269
Laos	1,720	1,333	1,197	1,436	3,530	7,957	12,651	16,373	12,768	6,181	3,515	2,297	5,913
Thailand	104	44	47	80	314	953	1,352	2,734	3,871	2,513	1,022	362	1,116
Vietnam	1,441	950	708	669	1,195	2,013	2,918	5,119	5,485	4,697	3,027	2,228	2,537
Monthly Average Inflow(m3/s) for Dev 2040 M3													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	1,214	808	541	595	1,501	2,983	4,683	7,896	8,248	6,287	3,369	2,214	3,361
Laos	2,208	1,767	1,702	2,125	4,876	10,003	15,905	20,731	16,506	8,201	4,599	2,929	7,629
Thailand	512	497	399	407	762	1,415	1,646	3,125	4,389	2,947	1,529	866	1,541
Vietnam	1,440	949	707	667	1,192	2,009	2,914	5,117	5,483	4,694	3,026	2,227	2,535
Monthly Average Inflow (m3/s) for Dev 2040 M3 (CC)													
Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Cambodia	1,268	854	547	513	1,217	2,778	4,530	7,993	8,708	7,092	3,623	2,329	3,454
Laos	2,421	1,944	1,792	1,978	4,172	8,772	15,498	20,283	18,194	11,793	5,663	3,291	7,983
Thailand	545	501	395	376	645	1,173	1,331	2,793	4,583	4,141	2,285	1,130	1,658
Vietnam	1,503	987	728	633	1,073	1,936	2,921	5,321	5,909	5,296	3,285	2,347	2,662

Table 6-15 Tributary Hydropower Current Volume by country in each main scenario

Monthly Average Current Volume (MCM) for EDS 2007 M1													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	1	0	0	0	0	1	1	1	1	1	1	1	13
Laos	6,119	5,601	5,107	4,729	4,607	5,313	6,530	7,340	7,579	7,536	7,249	6,724	2,498
Thailand	4,821	4,432	4,024	3,634	3,507	3,742	4,041	4,737	5,853	6,194	5,862	5,381	3,249
Vietnam	814	705	626	577	585	721	899	1,088	1,157	1,149	1,084	947	2,671
Monthly Average Current Volume (MCM) for Dev 2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	11,402	10,427	9,689	9,261	9,414	10,621	12,187	13,902	14,593	14,536	13,736	12,564	11,861
Laos	45,901	43,351	41,238	39,739	39,891	43,685	48,621	52,744	54,717	54,208	51,831	48,894	47,068
Thailand	4,349	3,979	3,594	3,235	3,156	3,425	3,676	4,314	5,452	5,784	5,419	4,939	4,277
Vietnam	3,125	2,704	2,427	2,261	2,256	2,514	2,926	3,561	3,930	4,074	3,935	3,616	3,111
Monthly Average Current Volume (MCM) for Dev 2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	11,555	10,506	9,690	9,229	9,525	10,956	12,595	14,250	14,909	14,828	13,966	12,769	12,065
Laos	76,507	72,877	69,776	67,582	67,565	72,279	79,127	85,457	88,320	87,810	84,772	80,605	77,723
Thailand	5,452	5,160	4,858	4,618	4,630	4,872	4,982	5,517	6,400	6,589	6,308	5,938	5,444
Vietnam	3,124	2,703	2,425	2,259	2,253	2,512	2,925	3,560	3,930	4,074	3,934	3,615	3,109
(MCM)Monthly Average Current Volume Dev 2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	11,849	10,717	9,811	9,208	9,273	10,651	12,451	14,219	14,960	14,987	14,260	13,085	12,123
Laos	78,622	74,919	71,569	68,800	67,872	71,668	78,463	85,043	88,224	88,787	86,638	82,643	78,604
Thailand	5,913	5,587	5,242	4,931	4,828	4,938	4,940	5,408	6,440	7,040	6,790	6,397	5,704
Vietnam	3,258	2,813	2,518	2,322	2,263	2,462	2,893	3,571	3,976	4,159	4,067	3,768	3,173

Table 6-16 Tributary Hydropower Storage Area by country in each main scenario

Monthly Average Storage Area (Ha) for EDS 2007													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	22.14	13.37	9.50	7.86	11.22	19.49	25.94	27.30	27.65	27.41	26.84	25.34	20.34
Laos	38,166.67	36,757.43	35,379.46	34,293.60	34,177.82	36,350.24	39,628.64	41,782.49	42,433.97	42,256.86	41,218.97	39,803.17	38,520.78
Thailand	98,629.43	93,004.22	86,781.81	80,806.35	78,579.95	81,952.31	85,911.66	95,931.15	112,717.42	117,765.43	113,244.01	106,700.12	96,001.99
Vietnam	4,387.23	4,266.87	4,171.82	4,123.82	4,141.81	4,299.40	4,489.29	4,695.04	4,770.18	4,751.48	4,674.42	4,528.74	4,441.68
Monthly Average Storage Area (Ha) for Dev 2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	114,943	108,679	104,165	101,779	103,350	111,275	120,964	131,497	135,811	135,255	129,922	122,699	118,362
Laos	207,082	196,811	190,859	188,945	191,585	208,427	227,074	241,003	246,413	243,490	232,817	219,721	216,186
Thailand	89,915	84,478	78,678	73,127	72,252	76,487	79,612	88,635	106,002	110,678	105,552	98,711	88,677
Vietnam	18,814	17,084	15,975	15,393	15,571	16,697	18,228	20,351	21,702	22,303	21,946	20,877	18,745
Monthly Average Storage Area (Ha) for Dev 2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	201,717	195,562	191,103	188,716	191,031	199,474	208,714	218,451	222,509	221,800	216,320	209,356	205,396
Laos	281,279	267,154	258,089	254,559	257,084	277,538	304,540	328,013	336,462	332,706	317,871	298,568	292,822
Thailand	112,197	108,499	105,224	101,938	101,606	104,571	106,101	111,824	122,919	125,931	122,714	118,087	111,801
Vietnam	18,811	17,083	15,971	15,390	15,564	16,692	18,224	20,349	21,700	22,300	21,946	20,875	18,742
Monthly Average Storage Area (Ha) for Dev 2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
Cambodia	203,517	196,736	191,699	188,464	189,339	197,590	207,944	218,337	222,895	222,866	218,176	211,348	205,743
Laos	288,332	273,661	262,930	257,318	256,996	274,714	302,111	326,739	336,410	336,281	324,483	305,585	295,463
Thailand	118,715	114,716	110,933	107,115	105,161	106,189	106,399	111,045	123,698	132,112	128,993	124,219	115,774
Vietnam	19,209	17,350	16,168	15,460	15,467	16,460	18,100	20,364	21,844	22,589	22,372	21,369	18,896

Table 6-17 Mainstream Hydropower in Main Scenarios 2020 M2

Dam Name	Energy Production- GWh												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
MS_Don sahong	34	30	29	32	37	81	121	192	193	113	62	41	964
MS_Xayabuly	384	272	272	257	388	559	761	953	916	855	641	539	6,795
Dam Name	Evap Volume - MCM												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual AVG
MS_Don sahong	8	7	7	4	(6)	(9)	(15)	(17)	(11)	(0)	6	7	(2)
MS_Xayabuly	2	2	1	1	(2)	(2)	(5)	(6)	(4)	0	1	2	(1)
Dam Name	Release and Spill - MCM												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual AVG
MS_Don sahong	1,420	1,113	1,144	1,171	1,516	3,190	5,711	8,044	7,787	6,053	3,040	1,803	3,499
MS_Xayabuly	5,169	3,711	3,732	3,531	5,200	7,618	15,437	24,496	21,857	14,853	9,612	6,900	10,176
Dam Name	Inflow - m3/s												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual AVG
MS_Don sahong	533	459	430	453	564	1,227	2,127	2,997	3,000	2,260	1,175	676	1,325
MS_Xayabuly	1,910	1,519	1,393	1,363	1,961	2,956	5,789	9,147	8,431	5,546	3,696	2,544	3,855
Dam Name	Current Volume -MCM												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual AVG
MS_Don sahong	591	591	591	591	591	590	591	591	591	591	591	591	591
MS_Xayabuly	565	546	543	542	575	616	690	724	726	726	718	630	633
Dam Name	Storage Area - Ha												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual AVG
MS_Don sahong	5,310	5,310	5,310	5,310	5,310	5,296	5,310	5,311	5,310	5,311	5,310	5,310	5,309
MS_Xayabuly	2,697	2,560	2,535	2,529	2,766	3,060	3,573	3,804	3,818	3,818	3,763	3,162	3,174

Table 6-18 Tributary Hydropower Production Climate Change Sub Scenarios

Impact of Climate Change

Country	Annual Energy Production- GWh			Country	Annual Inflow - m3/s		
	SCN M3	Sub SCN C2	Sub SCN C3		SCN M3	Sub SCN C2	Sub SCN C3
Cambodia	5,508	5,529	5,384	Cambodia	3,361	3,400	3,282
Laos	39,891	40,348	38,764	Laos	7,629	7,931	7,063
Thailand	899	875	806	Thailand	1,541	1,497	1,297
Vietnam	9,341	9,443	9,497	Vietnam	2,535	2,569	2,592
Country	Annual Evap Volume - MCM			Country	Annual Current Volume -MCM		
	SCN M3	Sub SCN C2	Sub SCN C3		SCN M3	Sub SCN C2	Sub SCN C3
Cambodia	(103)	(90)	(97)	Cambodia	12,065	12,144	11,961
Laos	(195)	(177)	(185)	Laos	77,723	78,325	76,396
Thailand	10	21	12	Thailand	5,444	5,458	5,034
Vietnam	(10)	(9)	(11)	Vietnam	3,109	3,129	3,140
Country	Annual Release and Spill - MCM			Country	Annual Storage Area - Ha		
	SCN M3	Sub SCN C2	Sub SCN C3		Sub SCN A1	Sub SCN A1	Sub SCN A1
Cambodia	8,984	9,071	8,766	Cambodia	205,396	205,770	204,679
Laos	20,359	21,135	18,849	Laos	292,822	294,136	288,870
Thailand	4,046	3,915	3,400	Thailand	111,801	112,099	106,433
Vietnam	6,705	6,793	6,855	Vietnam	18,742	18,778	18,778

Table 6-19 Tributary Hydropower Production Land Use Change and Irrigation Sub Scenarios

Impact of Landuse Change

Country	Annual Energy Production- GWh			Country	Annual Inflow - m3/s		
	SCN M3CC	Sub SCN A1	Sub SCN A2		SCN M3CC	Sub SCN A1	Sub SCN A2
Cambodia	5,497	5,603	5,503	Cambodia	3,454	3,569	3,460
Laos	40,107	39,977	40,259	Laos	7,983	7,966	7,998
Thailand	919	918	919	Thailand	1,658	1,657	1,658
Vietnam	9,587	9,912	9,587	Vietnam	2,662	2,753	2,662
Country	Annual Evap Volume - MCM			Country	Annual Current Volume -MCM		
	SCN M3CC	Sub SCN A1	Sub SCN A2		SCN M3CC	Sub SCN A1	Sub SCN A2
Cambodia	(97)	(98)	(97)	Cambodia	12,123	12,265	12,130
Laos	(197)	(197)	(197)	Laos	78,604	78,540	78,750
Thailand	12	12	12	Thailand	5,704	5,704	5,704
Vietnam	(10)	(10)	(10)	Vietnam	3,173	3,307	3,173
Country	Annual Release and Spill - MCM			Country	Annual Storage Area - Ha		
	SCN M3CC	Sub SCN A1	Sub SCN A2		Sub SCN A1	Sub SCN A1	Sub SCN A1
Cambodia	9,222	9,524	9,236	Cambodia	205,743	206,553	205,798
Laos	21,299	21,253	21,339	Laos	295,463	295,221	295,766
Thailand	4,353	4,350	4,353	Thailand	115,774	115,771	115,774
Vietnam	7,038	7,278	7,038	Vietnam	18,896	19,264	18,896

Impact of Irrigation change

Country	Annual Energy Production- GWh			Country	Annual Inflow - m3/s		
	SCN M3cc	Sub SCN I1	Sub SCN I2		SCN M3cc	Sub SCN I1	Sub SCN I2
Cambodia	5,497	5,497	5,497	Cambodia	3,454	3,455	3,454
Laos	40,107	40,438	39,981	Laos	7,983	8,079	7,944
Thailand	919	922	921	Thailand	1,658	1,334	1,658
Vietnam	9,587	9,613	9,587	Vietnam	2,662	2,664	2,662
Country	Annual Evap Volume - MCM			Country	Annual Current Volume -MCM		
	SCN M3cc	Sub SCN I1	Sub SCN I2		SCN M3cc	Sub SCN I1	Sub SCN I2
Cambodia	(97)	(97)	(97)	Cambodia	12,123	12,121	12,123
Laos	(197)	(196)	(197)	Laos	78,604	78,929	78,496
Thailand	12	11	12	Thailand	5,704	4,926	5,666
Vietnam	(10)	(10)	(10)	Vietnam	3,173	3,180	3,173
Country	Annual Release and Spill - MCM			Country	Annual Storage Area - Ha		
	SCN M3cc	Sub SCN I1	Sub SCN I2		SCN M3cc	Sub SCN I1	Sub SCN I2
Cambodia	9,222	9,225	9,222	Cambodia	205,743	205,729	205,743
Laos	21,299	21,548	21,194	Laos	295,463	297,300	294,882
Thailand	4,353	3,505	4,352	Thailand	115,774	100,066	115,237
Vietnam	7,038	7,044	7,038	Vietnam	18,896	18,910	18,896

Table 6-20 Hydropower Generation in Tributaries for Hydropower Sub Scenarios

Impact of Hydropower dam

Country	Annual Energy Production- GWh				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	5,497	6	5,497	5,497	5,497
Laos	40,107	3,534	40,124	40,107	40,124
Thailand	919	919	919	919	919
Vietnam	9,587	3,466	9,587	9,587	9,587

Country	Annual Inflow - m3/s				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	3,454	5	3,454	3,454	3,454
Laos	7,983	872	7,983	7,983	7,983
Thailand	1,658	1,658	1,658	1,658	1,658
Vietnam	2,662	273	2,662	2,662	2,662

Country	Annual Evap Volume - MCM				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	(97)	(0)	(97)	(97)	(97)
Laos	(197)	(32)	(197)	(197)	(197)
Thailand	12	12	12	12	12
Vietnam	(10)	(2)	(10)	(10)	(10)

Country	Annual Current Volume -MCM				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	12,123	1	12,123	12,123	12,123
Laos	78,604	6,297	78,642	78,604	78,642
Thailand	5,704	5,704	5,704	5,704	5,704
Vietnam	3,173	665	3,173	3,173	3,173

Country	Annual Release and Spill - MCM				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	9,222	13	9,222	9,222	9,222
Laos	21,299	2,338	21,299	21,299	21,299
Thailand	4,353	4,353	4,353	4,353	4,353
Vietnam	7,038	723	7,038	7,038	7,038

Country	Annual Storage Area - Ha				
	SCN M3cc	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
Cambodia	205,743	20	205,743	205,743	205,743
Laos	295,463	38,817	295,551	295,463	295,551
Thailand	115,774	115,774	115,774	115,774	115,774
Vietnam	18,896	3,151	18,896	18,896	18,896

Table 6-21 Estimated Hydropower Production in IQQM Model for Mainstream Dams (Note IQQM model does not include backwater effects that will affect Hydropower production – refer to Hydropower sector analysis report)

Dam name	Annual Energy Production- GWh									
	Sub SCN A1	Sub SCN A2	Sub SCN C2	Sub SCN C3	Sub SCN I1	Sub SCN I2	Sub SCN H1a	Sub SCN H1b	Sub SCN H2	Sub SCN H3
MS_Ban Kum	8,268	8,276	8,361	8,152	8,533	8,212	-	-	8,276	10,391
MS_Don sahong	964	964	964	964	964	964	-	-	964	964
MS_Luangprabang	4,792	4,792	4,853	4,733	4,810	4,782	-	-	4,792	5,562
MS_Latsua (Phou Ngoy)	5,533	5,537	5,570	5,436	5,647	5,508	-	-	5,536	6,776
MS_Pakbeng	4,745	4,746	4,998	4,228	4,763	4,736	-	-	4,746	5,209
MS_Paklay	7,432	7,435	7,525	7,298	7,463	7,419	-	-	7,435	8,109
MS_Sambor	10,613	10,608	10,743	10,562	10,692	10,591	-	-	10,608	10,911
MS_Sanakham	3,331	3,332	3,348	3,302	3,334	3,330	-	-	3,332	3,312
MS_Sangthong-Pakchom	5,107	5,108	5,173	4,989	5,129	5,097	-	-	5,108	5,845
MS_Stung Treng	3,930	3,928	4,005	3,913	4,009	3,923	-	-	3,938	3,444
MS_Xayabuly	6,802	6,803	6,954	6,644	6,832	6,787	-	-	6,803	7,710

The domestic and industrial water demands are also estimated in the IQQM models and results are presented in the report. The total domestic and industrial demand in the LMB is estimated as around 105m^3/s for 2007 and this increases in line with population and per capita use in scenarios. Although small relative to Mekong flow and other uses this is a key requirement of the Mekong resource.

6.1.3 Flood Flows in the Upper Basin above Kratie

Analysing the IQQM outputs for flow at key stations for Annual flood peaks (AMAX) gives an indication of the change in mean annual flood peak under different scenarios and the relative change of the high flood peak in the simulation series relative to the annual maximum.

The annual maximum is related to the expected channel size and thus an indication of likely tendency for change due to the flow regime, a smaller mean annual flood for example will mean that the main river will tend to aggrade and become narrower. With an increased ratio to the extreme flood this will then make high floods more damaging.

Table 6-22 Change in flood peaks in IQQM model.

Scenario	Annual Flood	Chiang Saen	Luang Prabab	Nong Khai	Mukdahan	Pakse	Stung Treng
EDS	Mean	9,651	15,902	19,282	31,382	38,183	45,843
M2	Mean	9,158	14,932	18,069	29,808	36,713	43,588
M3 (NoCC	Mean	9,158	13,879	17,372	28,972	36,463	43,622
M3 (CC)	Mean	10,252	15,439	20,356	31,800	39,683	46,734
EDS	Max	13,668	24,882	25,434	38,042	48,119	62,581
M2	Max	12,312	24,559	25,183	37,221	47,814	61,466
M3 (NoCC	Max	12,315	20,697	21,295	36,395	45,569	62,351
M3 (CC)	Max	21,913	27,419	44,696	51,515	60,997	69,770

It can be seen in the Table 5.22 that there is generally a decline in the mean annual flood for M2 and M3 but with climate change there is less change in mean flood but a big increase in the high flood events.

6.2 eWater Source Modelling

6.2.1 Source Modelling of Sediment Flux for Main Scenarios

The Source Model includes the same aspects of Water Resource model as IQQM but for the purpose of the Council Study is being used for output of the water borne flux of sediment, Total Nitrogen and Total Phosphorus. The trapping of sediment and nutrient in the reservoirs is a key element in simulating the effect of dams. For example, the flux from the Upper Basin as monitored and modelled at Chiang Saen changes the loads significantly in the mainstream LMB.

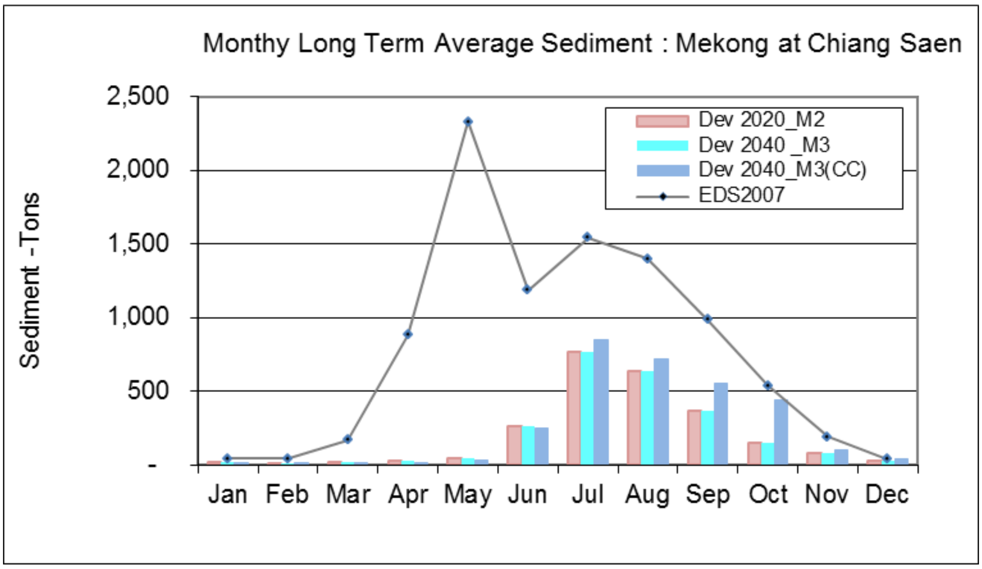


Figure 6-8 Projected Change in mean Monthly Sediment Concentration at Chiang Saen

Relatively simple but proven techniques are used to achieve this in Source. For **trapping of sediment** the equation of Brune (1953) is used that relates the inflows to storage capacity and delivers an average trapping efficiency. This same technique is used in many other studies such as Kummu (2010), MRC/Thorne (2011), Kondolf (2014) and has proven to give a good indication of yearly trapping efficiency relating only inflow volume to reservoir capacity.

The **proportion of nutrient** adsorbed to sediment is specified for total nitrogen and total phosphorus so the amount of sediment settled in a reservoir is used to calculate the proportion of nitrogen and phosphorus passing. The discharge of nutrients in effluent from the major urban conurbations is also included in the model. The calculation is relatively conservative as some nutrients may later be released, especially from abiotic conditions of low oxygen prevail in a reservoir. The trapping calculation results for each dam were output in terms of volumes of sediment trapped in Millions of tonnes/year averaged over the simulation period as shown in the table below.

Table 6-23 Sediment trapped for each dam (Mt/year) averaged over the simulation period from the Source Model, no mitigation measures included.

Reservoir	Sediment Trapped (Mt/year) M3 No CC	Sediment Trapped (Mt/year) M3 CC	Location
2401 MaoWei Dam	1.042	0.989	China Main
2382 DaHuaQiao Dam	0.996	0.920	China Main
2380 HuangDeng Dam	5.000	4.616	China Main
1893 Jinghong Dam	0.743	1.066	China Main
1889 Nuozhadu Dam	6.853	9.268	China Main
1877 Dachaoshan Dam	0.873	1.043	China Main
1868 Manwan Dam	0.773	0.859	China Main
1864 Xiaowan Dam	13.334	14.337	China Main
1857 Gonggouqiao Dam	1.608	1.664	China Main
1116 TuaBa Dam	13.143	11.454	China Main
1114 Li Di Dam	1.824	1.590	China Main
1077 WuNongLong Dam	16.354	13.997	China Main
2469 NamFeung1 Dam	0.307	0.397	Laos Trib
2467 NamFeung2 Dam	0.145	0.187	Laos Trib
2465 NamFeung3 Dam	0.121	0.157	Laos Trib
2447 XeXamnoy5 Dam	0.677	0.694	Laos Trib
2444 Nam Phak _Houykatam Dam	0.367	0.366	Laos Trib
2442 Xekatam Dam	0.771	0.791	Laos Trib
1987 Nam Ou1 Dam	0.977	1.075	Laos Trib
1980 NamOu2 Dam	0.700	0.766	Laos Trib
1972 NamOu3 Dam	1.246	1.361	Laos Trib
1960 Nam Ou4 Dam	0.764	0.860	Laos Trib
1924 NamOu5 Dam	0.671	0.777	Laos Trib
1918 Nam Ou6 Dam	0.477	0.550	Laos Trib

Reservoir	Sediment Trapped (Mt/year) M3 No CC	Sediment Trapped (Mt/year) M3 CC	Location
1011 Se Xou Dam	0.103	0.118	Laos Trib
1005 NamKong1 Dam	0.080	0.111	Laos Trib
0999 Nam Kong 2 Dam	0.128	0.134	Laos Trib
0984 Nam Ngum 1 Dam	0.122	0.165	Laos Trib
0975 Nam Ngum 2 dam	0.005	0.006	Laos Trib
0968 Nam Pay Dam	0.000	0.000	Laos Trib
0961 Xekaman 1 Dam	0.295	0.474	Laos Trib
0955 Xekaman 2A Dam	0.039	0.041	Laos Trib
0951 Xekaman 2B Dam	0.199	0.234	Laos Trib
0946 Xekaman 4A Dam	0.037	0.051	Laos Trib
0926 Xekong3D Dam	0.895	0.952	Laos Trib
0914 Sekong3U Dam	0.542	0.576	Laos Trib
0908 Sekong4 Dam	0.390	0.462	Laos Trib
0901 Dak Emul Dam	0.041	0.047	Laos Trib
0895 Huai Lamphan Dam	0.279	0.296	Laos Trib
0878 Se Don2 Dam	0.451	0.470	Laos Trib
0872 XeSet2 Dam	0.125	0.121	Laos Trib
0869 Xe Set 3 Dam	0.160	0.155	Laos Trib
0863 Sebangnouan Dam	0.022	0.024	Laos Trib
0846 Sebanghieng 2 Dam	3.326	3.924	Laos Trib
0840 Selanong1 Dam	0.454	0.535	Laos Trib
0831 Selanong 2 Dam	0.312	0.367	Laos Trib
0821 Nam Thuen1 Dam	1.513	1.790	Laos Trib
0814 Nam Mouan Dam	0.550	0.607	Laos Trib
0797 Xe Neua Dam	0.067	0.072	Laos Trib
0781 Nam Nghiep Dam	0.468	0.537	Laos Trib
0773 Nam Ngiew Dam	0.133	0.153	Laos Trib
0770 Nam Pot Dam	0.049	0.053	Laos Trib
0764 Nam Chain Dam	0.179	0.193	Laos Trib
0758 Nam Phak Dam	0.051	0.056	Laos Trib
0752 Nam Nga Dam	0.085	0.103	Laos Trib
0746 Nam Ngao Dam	0.010	0.014	Laos Trib
0740 Nam Phoun Dam	0.162	0.217	Laos Trib
0734 Nam Pui Dam	0.173	0.236	Laos Trib
0721 Nam Mang 1 Dam	0.257	0.293	Laos Trib
0717 NTheun- HinBoun Dam	0.013	0.016	Laos Trib
0714 TH G8 Dam	0.316	0.375	Laos Trib
0708 Nam Theun 4 Dam	0.131	0.156	Laos Trib
0672 HouayHo Dam	1.430	1.310	Laos Trib
0669 Xenamnoy Dam	0.832	0.812	Laos Trib
0642 Hin Bun1 Dam	0.201	0.232	Laos Trib
0631 Hin Bun 2 Dam	0.001	0.001	Laos Trib

Reservoir	Sediment Trapped (Mt/year) M3 No CC	Sediment Trapped (Mt/year) M3 CC	Location
0531 Nam San 3B Dam	0.037	0.037	Laos Trib
0528 Nam San 3 Dam	0.042	0.038	Laos Trib
0510 Nam Suang1 Dam	0.214	0.361	Laos Trib
0506 Nam Suang2 Dam	0.818	1.259	Laos Trib
0500 Nam Beng Dam	0.014	0.020	Laos Trib
0494 NamPha Dam	1.209	1.487	Laos Trib
0484 NamTha Dam	0.903	1.235	Laos Trib
0476 Nam Mang3 Dam	0.006	0.008	Laos Trib
0473 Nam Ngum 3 Dam	0.004	0.004	Laos Trib
0459 Nam Ngum 4 Dam	0.002	0.002	Laos Trib
0453 Nam Ngum5 Dam	0.001	0.000	Laos Trib
0345 Nam Ou7 Dam	0.964	1.156	Laos Trib
0335 Xekaman 3 Dam	0.102	0.131	Laos Trib
0310 Sekong5 Dam	0.056	0.077	Laos Trib
0290 NamLik1 Dam	0.015	0.018	Laos Trib
0279 Nam Song diversion weir	0.001	0.001	Laos Trib
0229 Nam Leuk Dam	0.001	0.002	Laos Trib
0168 Se Pon 3 Dam	0.898	1.065	Laos Trib
0141 Nam Thuen 2 Dam	0.149	0.165	Laos Trib
0065 Nam Lik 2 Dam	0.105	0.121	Laos Trib
0050 Nam Khan 2 Dam	0.186	0.278	Laos Trib
0044 Nam Khan 3 Dam	0.374	0.349	Laos Trib
2331 LatSua Dam	3.847	4.564	Laos/Thai Main
2322 Ban Koum Dam	8.330	9.796	Laos/Thai Main
2240 Pakchom Dam	2.518	3.289	Laos/Thai Main
2230 Sanakham Dam	0.244	0.318	Laos/Thai Main
2223 Paklay Dam	3.963	5.116	Laos/Thai Main
2211 Sayaburi Dam	3.052	3.923	Laos/Thai Main
2197 LPB Dam	7.253	9.451	Laos/Thai Main
2191 PakBeng dam	5.995	7.731	Laos/Thai Main
0665 DonSaHong Dam	0.856	0.973	Laos/Thai Main
2092 LSS2+LSP2 Dam	0.858	0.889	Cambodia Trib
2082 Lower Sre Pok 3 Dam	1.991	2.150	Cambodia Trib
2028 Lower Se San 3 Dam	2.076	2.194	Cambodia Trib
1047 Prek Liang 1 Dam	0.095	0.086	Cambodia Trib
1044 Prek Liang 2 Dam	0.724	0.648	Cambodia Trib
0662 O Chum 2 Dam	0.021	0.022	Cambodia Trib
0447 Lower Sre Pok 4 Dam	0.864	0.916	Cambodia Trib
2365 Sambor Dam	10.627	12.036	Cambodia Main
2357 Strungtreng Dam	0.567	0.664	Cambodia Main
2156 Pak Mun Dam	0.755	0.997	Thailand Trib
0684 Lam Pao Dam	1.214	1.405	Thailand Trib

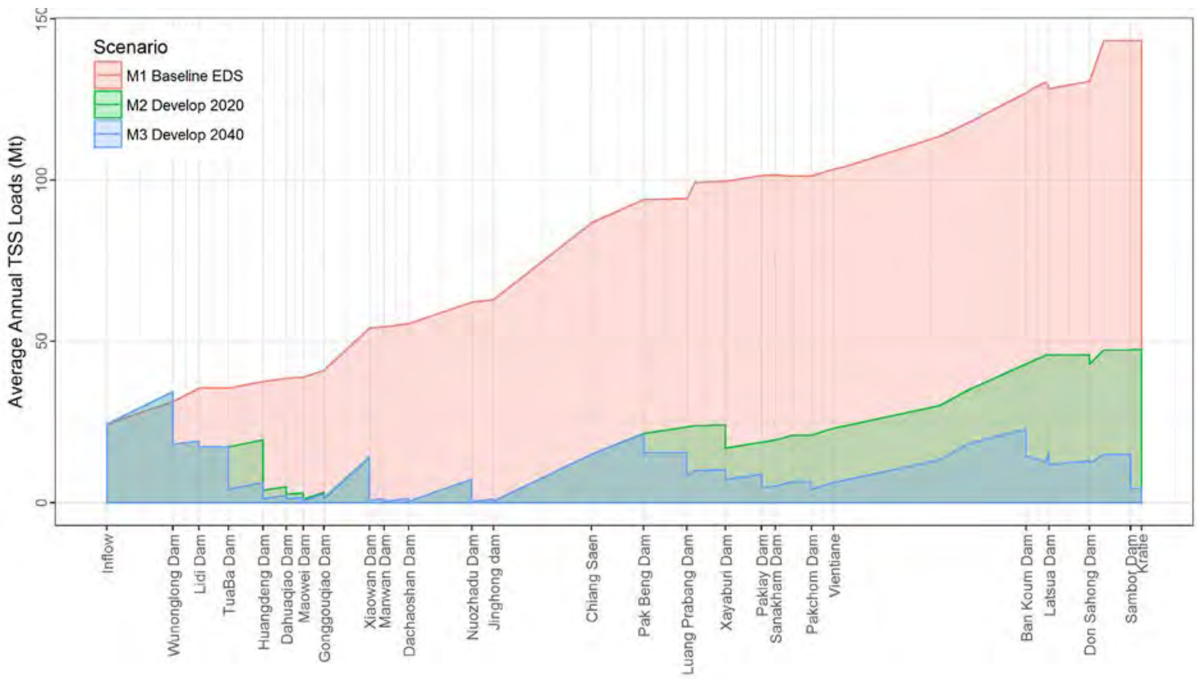
Reservoir	Sediment Trapped (Mt/year) M3 No CC	Sediment Trapped (Mt/year) M3 CC	Location
0616 Nam Un Dam	0.026	0.037	Thailand Trib
0599 Huai Luang Dam	0.045	0.058	Thailand Trib
0580 Lam Phra Plerng Dam	0.080	0.104	Thailand Trib
0317 Upper Mun Reservoir	0.094	0.108	Thailand Trib
0297 Lam Nang Rong Dam	0.015	0.016	Thailand Trib
0265 Ubol Ratana Dam	0.918	1.550	Thailand Trib
0256 Chulabhorn Dam	0.031	0.049	Thailand Trib
0235 Nam Pung Dam	0.023	0.029	Thailand Trib
0221 Sirindhorn Dam	0.166	0.165	Thailand Trib
0209 Lam Ta Kong Dam	0.052	0.071	Thailand Trib
0649 DrayHlinh2 Dam	0.006	0.007	Vietnam Trib
0433 Srepok4 Dam	0.087	0.096	Vietnam Trib
0430 Srepok3 Dam	0.856	0.931	Vietnam Trib
0411 BuonKop Dam	0.328	0.358	Vietnam Trib
0405 Tourash Dam	0.391	0.434	Vietnam Trib
0393 Sesan4A-Res	0.000	0.000	Vietnam Trib
0390 Se San 4 Dam	2.274	2.445	Vietnam Trib
0384 Se San 3A Dam	0.855	0.908	Vietnam Trib
0378 Sesan3 Dam	1.605	1.700	Vietnam Trib
0371 Yali Dam	1.309	1.418	Vietnam Trib
0354 Kontum Dam	0.005	0.006	Vietnam Trib
0200 Dray Hlinh1 Dam	0.000	0.000	Vietnam Trib
0188 Plei Krong Dam	1.367	1.467	Vietnam Trib

The highest trapping is generally in the Upper Basin where storage is highest relative to inflow, some dams in UMB may have a limited capacity and will fill their storage at which point trapping reduces. However, in the China region this is likely to mean more trapping in the large Xiowan and Nouzhudu dams rather than increasing sediment flux to the LMB.

By plotting the three main scenarios as a long profile the difference between scenarios and the base early development may be seen for 2020 and 2040 without climate change. It can be seen that there is a dramatic loss of sediment compared to the base line even for the 2020 Scenario for which the average passing is reduced from around 150 Million tonnes/year to below 50 Mt/y in M2 scenario of 2020 (Figure 5.9).

Figure 6-9 Comparison of average annual TSS loads on the Mekong (and Langcang) River under the three main scenarios.

The trapping of sediment in reservoirs is summarised in Figure 5.10. For the baseline condition



M1, 143 Mt/yr of the sediment flux generated in the basin based through Kratie towards the delta was simulated. This is reduced for 2020 (M2) to only 47.4 % of the natural value and for M3 and M3CC to less than 4 % for the 2040 scenarios of full dam development. Considering climate change there is slightly more inflow of sediment but there is very little change in the amount passing Sambor in 2040.

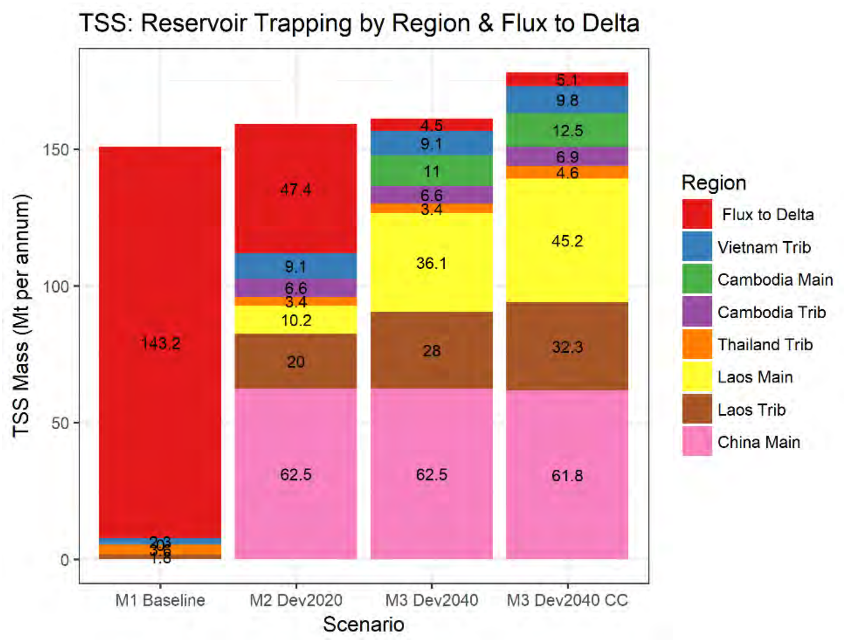


Figure 6-10 Reservoir Sediment Trapping by Region Main Scenarios

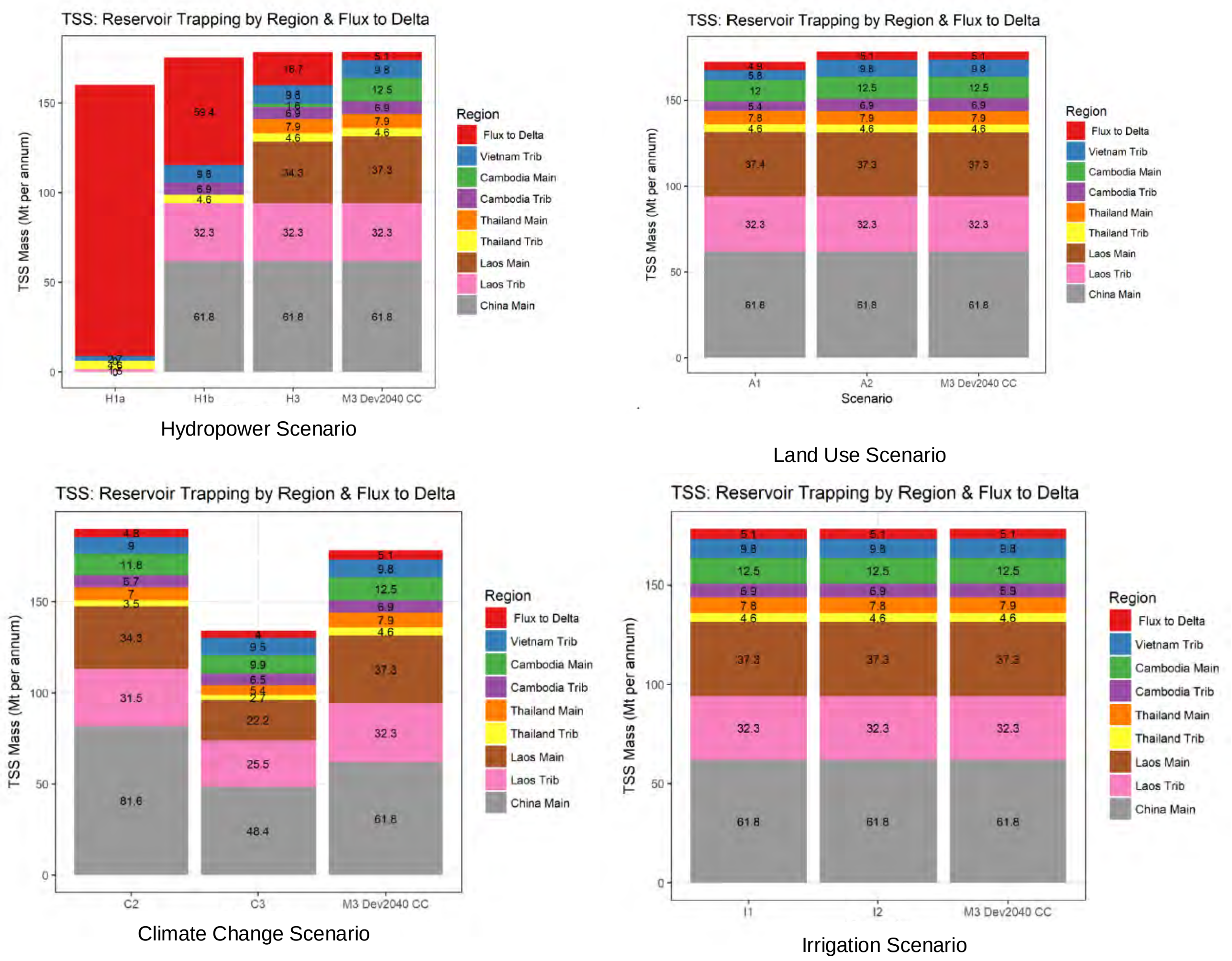


Figure 6-11 Reservoir Sediment Trapping for Hydropower, Land Use, Irrigation and Climate Change Sub Scenarios.

6.2.2 Sensitivity Analysis of Sediment Trapping Efficiency in Mainstream Dams for 2040

As the loss of sediment flux to the delta is so high, a sensitivity analysis was undertaken in Source using both Brune and ISIS simulation and developer results for trapping efficiency estimates for mainstream dams. Three scenarios are run for the Dev2040 M3 Main Scenario changing ONLY trapping in mainstream dams:

1. Sediment trapping for mainstream dams as calculated via the standard Brune algorithm
2. Minimum of 5% sediment trapping as indicated may be achieved by the Xayaburi Project developer in presentations in consultation (March 2017), or the Brune result
3. Maximum of 50% sediment trapping as indicated as possible from the ISIS results for mainstream dams, or the Brune result if that is higher.

Sambor dam is unchanged in the sensitivity test as this mainstream dam is larger and thus of a different character than other run off river mainstream dams. Values used are as shown in the Table 5.24 below.

Table 6-24 Sediment Trapping Efficiency Sensitivity Tests

N^0	Reservoir	Location	Countries	Brune TE (%)	TE Lower Bound %	TE Upper Bound (%)
1	0665 DonSaHong dam	MS	Laos	53.60	5.00	53.60
2	2191 PakBeng dam	MS	Laos	28.10	5.00	50.00
3	2197 LPB Dam	MS	Laos	46.40	5.00	50.00
4	2211 Sayaburi Dam	MS	Laos	30.00	5.00	50.00
5	2223 Paklay Dam	MS	Laos	45.00	5.00	50.00
6	2230 Sanakham Dam	MS	Laos	4.70	4.70	50.00
7	2240 Pakchom Dam	MS	Thailand	37.90	5.00	50.00
8	2322 Ban Koum Dam	MS	Laos	36.40	5.00	50.00
9	2331 LatSua Dam	MS	Laos	24.50	5.00	50.00
10	2357 Strungtreng Dam	MS	Cambodia	4.70	4.70	50.00
11	2365 Sambor Dam	MS	Cambodia	71.10	71.10	71.10

6.2.3 Sediment Trapping Sensitivity Results for Changes in LMB Mainstream dams

The three scenarios are compared with the Baseline 2007 ND results for reference and trapping in tributary and Chinese dams is unchanged in the simulation as seen in Table 5.25.

The results are presented in tabular form below and show that although there could be a more than doubling of the sediment flux with a high pass through of sediment in the dams above Sambor, the sediment flux passing through Sambor is still very low compared to the natural condition.

The high trapping in Sambor relative to all other proposed LMB mainstream dams is clearly highlighted as seen in Figure 5.12.

Table 6-25 Results of Sensitivity test in Source on Trapping Efficiencies for LMB Mainstream dams on sediment flux below Sambor/Kratie

N^0	Scenario	Average Annual Sediment Load at Kratie (Mt)
1	M1 Baseline EDS	143.00
2	M3 Develop 2040 - Low Trap	10.85
3	M3 Develop 2040 - Brune	4.32
4	M3 Develop 2040 -High Trap	2.00

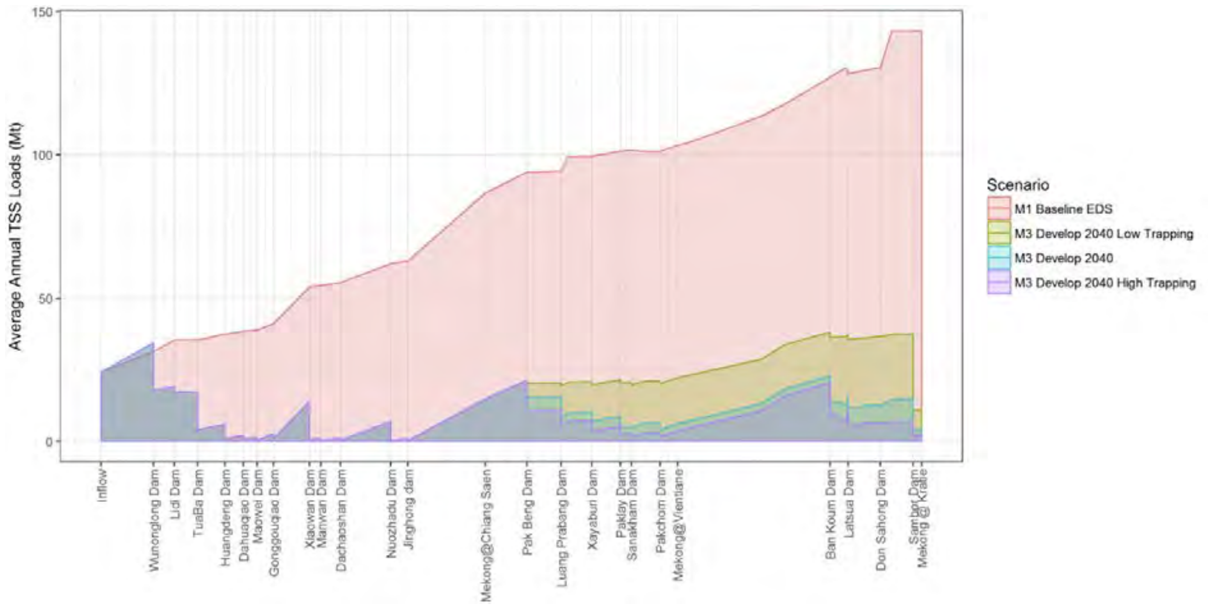


Figure 6-12 Long Profile of sediment flux in base case and with trapping scenarios for 3 sensitivity test cases

6.2.4 Modelling of Nutrient Fluxes

The accumulation of Total Nitrogen and Total Phosphorus as observed by MRC Water Quality Monitoring was reproduced in the calibrated SWAT model and outputs transferred into the Source model for Scenarios with the addition of the effluent.

It is necessary to model the proportion of nutrient attached to sediment seen in **Table 5.26** as some will deposit in the reservoirs with the sediment (and it is assumed they will not be released again in the short term or if they are they will be vented or consumed locally in algal blooms etc).

Table 6-26 Proportion of Total Nitrogen and Total Phosphorus used in Source Model

Method of Calculation	**Total Nutrient Attached to Sediment**	
	TOTP (%)	**TOTN (%)**
Analysis of change in sediment in loads at Chiang Saen after construction of large dams	52	42
Derived from chemical analyses available in the EP data	50	32
VNMC/DHI	50	
Used in Source Model	50	40

The Source results for nutrients are thus closely linked with the sediment trapping reducing the nutrient flux to the delta. However, there is a greater flux of nutrient than sediment as the dissolved part of total Nitrogen and Total Phosphorus will pass through reservoirs and thus there is a higher flux downstream as seen in Figure 5.13.

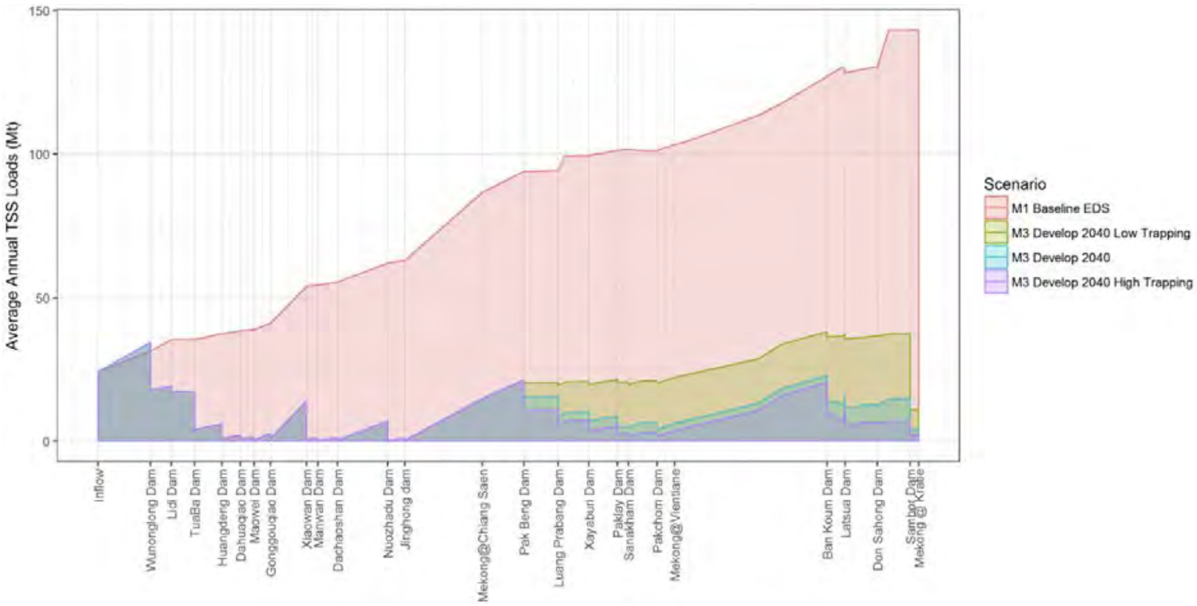


Figure 6-13 Overall Trapping of Sediment and pass through in Mainstream Mekong below Kratie

It is fully appreciated that this is a simplification of the actual processes but is a reasonable starting point before embarking on a full water quality simulation that would require more detailed simulation of oxygen and biological process in the water and in the bed sediments that is not possible within the time and resources of this stage of the Council Study.

Because the dissolved component is not trapped in the reservoirs, the total Nitrogen and Total Phosphorus passing downstream are reduced significantly but not as much as the sediment as shown in Figure 5.14. Water borne Total Nitrogen is reduced from around 200,00 tonnes/year to around 70,000 tonnes /year or around 1/3rd of the original value, much of which will be dissolved unless additional sediment can be mobilised downstream of Sambor dam. Similarly for Phosphorus the reductions in TOTP are around 2/3 and of 35,000 tonnes/year only 11,000 tonnes 1/3 continues downstream of Sambor.

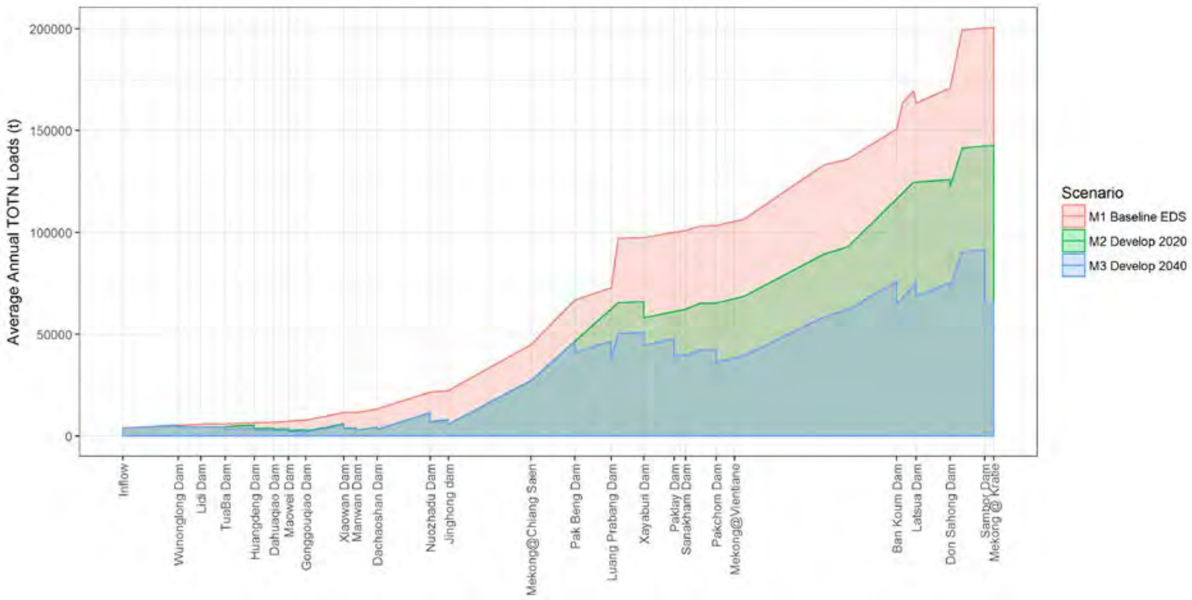


Figure 6-14 Change in Total Nitrogen passing downstream for main scenarios

6.3 ISIS modelling

The hydrodynamic modelling using ISIS gives a finer level of detail for flow, water level, sediment movement and nutrients than the Water resource models SWAT, IQQM and Source. The ISIS model for example uses separate definitions of sediment by size class and simulates the behaviour of each size class together with detailed definition of the river geometry. This is carried out at cross sections every 4km in the main river from Chiang Saen to the sea and for each gated spillway at each mainstream dam. The flow to floodplains, mapping and analysis is also based on the ISIS results. Only a summary of the key results are given here and more detail is presented in the Annexes 6 and 7. The models upstream of Kratie are thus primarily concerned with the detailed simulation of the proposed mainstream dams, the sediment movements and changes in flood characteristics. The lower model is more concerned on the flow in the mainstream and Tonle Sap system and the tidally influenced Mekong Delta that is also impacted by seas level rise as well as changes in flow, sediment and nutrient from upstream.

6.3.1 Changes in Flow and Water level downstream of Kratie

Under the MRC Procedures for maintaining flow in the Mekong there is provision for maintaining an acceptable level of reversal of the Tonle Sap which contributes around half of the expanded volume of the Lake in the wet season. Due to the complexities of the system only the hydrodynamic model is able to simulate this effect.

Whilst previous studies have generally only analysed flows at Key Stations above Kratie it is important to consider the changes in flows downstream of the Tonle Sap confluence as well as close to the trans-border area between Cambodia and Vietnam. Without considering the change in outflow from the Tonle Sap or the major expansion of irrigation within Cambodia for example then the result may be misleading. It could then be argued that the 'development space' of BDP2 does not properly account for a loss of flow from the Great Lake and concentrates only on gauges above Kratie.

The volume of the reversal of the Tonle Sap for different scenarios and different years is a key concern for future water resource management and thus is specifically mentioned in the procedures for maintenance of flow. The change in flow to the Great Lake is strongly influenced by changes in the flow increase in the Mekong early in the wet season. The increased reservoir storage available in future scenarios is generally at a low level at this time and thus there is a natural tendency to allow reservoirs to fill to improve power generation capability. This early refill has consequences for the reversal of the Tonle Sap and as shown in the Table 5.27 below.

The change in flow volume averages 8%, 5% and 9% reduction with more extreme dry years suffering a more severe reduction of up to 10%. This severe case (M3 CC) results in a minimum volume of only 55% of the average reversal volume which PMFM would indicate should be investigated further. In reality during dry years local inflows are also greatly reduced and thus the water level is more severely affected than the above percentages might suggest.

Table 6-27 Flow Volumes for Reversal of the Tonle Sap in different Scenarios

	Reversal of Tonle Sap			
	Km3 at Prek Kdam			
	M1 EDS 2007	M2 2020	M3 Dev. 2040	M3 CC 2040
1985	34.8	31.7	32.4	31.4
1986	38.9	35.5	33.6	34.8
1987	31.1	26.8	27.5	26.1
1988	23.7	21.0	21.8	20.1
1989	26.7	22.7	23.7	22.7
1990	38.6	36.4	38.7	36.3
1991	39.3	36.0	34.6	35.2
1992	28.2	24.9	23.8	24.1
1993	30.9	27.9	26.4	26.9
1994	39.6	37.7	38.6	37.5
1995	39.0	34.5	33.2	34.0
1996	43.5	41.4	42.7	41.2
1997	37.8	35.3	35.2	35.3
1998	27.8	24.5	23.4	23.4
1999	27.6	26.0	28.6	25.5
2000	41.0	40.2	41.5	40.4
2001	45.5	44.1	44.7	44.4
2002	49.0	46.9	47.5	47.1
2003	34.0	31.0	32.5	30.5
2004	40.7	37.3	38.5	37.1
2005	48.4	45.9	46.4	45.3
2006	36.4	34.4	39.7	34.1
2007	32.8	29.2	40.1	29.7
2008	36.7	32.4	33.8	31.8
Average	36.34	33.48	34.54	33.12
Change		8%	5%	9%
Max	49.0	46.9	47.5	47.1
		6%	4%	5%
Min	23.7	21.0	21.8	20.1
		8%	5%	10%
Min relative to 2007 Average	65%	58%	60%	55%

The flows at key stations Kampong Cham, Phnom Penh, Tan Chau and Chau Doc are summarised in Tables and Figure below for each main scenario.

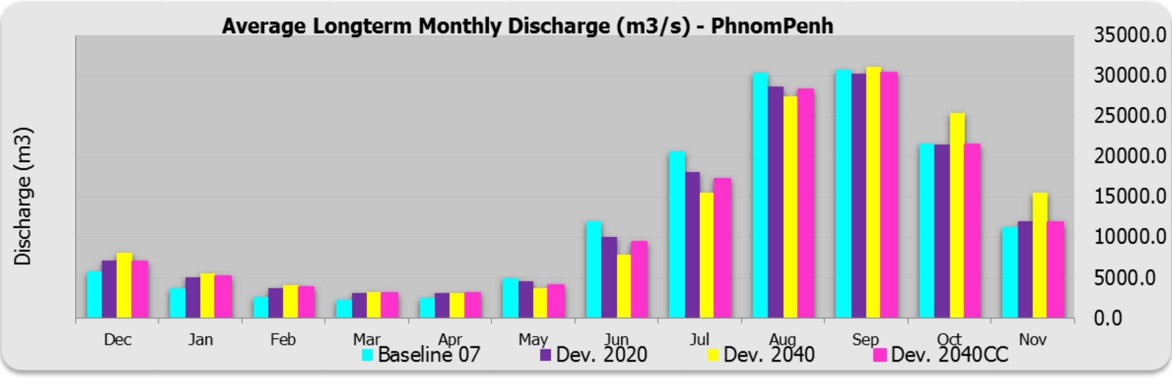


Figure 6-15 Flow at Phnom Penh station for each main scenario

Table 6-28 The flows at key stations for each main scenario

	Average Longterm Monthly Discharge (m3/s) - Kampong Cham			
	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	5622.0	6952.6	7792.1	6880.9
Jan	3604.2	4970.8	5441.8	5043.2
Feb	2599.1	3709.6	3993.8	3790.5
Mar	2187.0	3058.6	3186.5	3030.0
Apr	2479.7	3101.9	3041.1	3034.4
May	5097.3	4666.6	3704.6	4134.9
Jun	12380.0	10374.3	8127.2	9707.6
Jul	21677.6	18897.1	16212.0	17934.8
Aug	33466.8	31192.5	29588.8	30748.3
Sep	34419.3	33465.2	34692.2	33649.4
Oct	21899.8	21966.1	27165.2	22006.6
Nov	10636.0	11469.9	14926.6	11423.5
Wet season	22413.3	21227.5	21785.3	20911.7
Dry season	3598.2	4410.0	4526.6	4319.0

	Change of Average Longterm Monthly Discharge (m3/s) - Kampong Cham		
	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	1330.6	2170.1	1258.9
Jan	1366.6	1837.6	1439.0
Feb	1110.5	1394.7	1191.4
Mar	871.6	999.5	843.0
Apr	622.2	561.4	554.7
May	-430.8	-1392.7	-962.4
Jun	-2005.7	-4252.8	-2672.4
Jul	-2780.5	-5465.6	-3742.7
Aug	-2274.3	-3878.0	-2718.5
Sep	-954.1	272.9	-769.9
Oct	66.3	5265.3	106.8
Nov	833.9	4290.6	787.4
Wet season	-1185.7	-627.9	-1501.6
Dry season	811.8	928.4	720.8

	Average Longterm Monthly Discharge (m3/s) - PhnomPenh			
	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	5776.4	7068.6	8012.8	7005.5
Jan	3658.3	5019.9	5501.2	5086.3
Feb	2629.8	3730.8	4022.8	3814.1
Mar	2188.9	3056.4	3190.8	3032.5
Apr	2474.6	3098.0	3047.5	3032.8
May	4949.4	4567.2	3658.4	4066.0
Jun	11956.4	10047.6	7877.3	9404.0
Jul	20645.3	18079.6	15514.7	17158.9
Aug	30402.7	28667.0	27394.9	28288.1
Sep	30791.7	30243.5	31103.3	30398.3
Oct	21533.4	21500.5	25351.9	21523.4
Nov	11197.7	11948.8	15453.8	11895.1
Wet season	21087.9	20081.2	20449.3	19778.0
Dry season	3612.9	4423.5	4572.2	4339.6

	Change of Average Longterm Monthly Discharge (m3/s) - PhnomPenh		
	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	1292.2	2236.4	1229.1
Jan	1361.6	1842.9	1428.1
Feb	1101.0	1393.0	1184.3
Mar	867.5	1001.9	843.6
Apr	623.4	572.9	558.2
May	-382.2	-1291.0	-883.3
Jun	-1908.8	-4079.1	-2552.3
Jul	-2565.8	-5130.7	-3486.4
Aug	-1735.6	-3007.8	-2114.5
Sep	-548.3	311.6	-393.4
Oct	-32.9	3818.5	-10.0
Nov	751.1	4256.1	697.4
Wet season	-1006.7	-638.6	-1309.9
Dry season	810.6	959.3	726.7

	Average Longterm Monthly Discharge (m3/s) - NekLuong			
	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	10292.7	11048.9	12468.4	10986.0
Jan	6722.1	7723.2	8620.5	7746.6
Feb	4522.3	5510.2	6163.9	5562.2
Mar	3056.1	3949.0	4368.8	3921.9
Apr	2735.7	3400.9	3542.4	3348.8
May	4387.3	4245.8	3724.3	3943.5
Jun	9164.1	7971.5	6519.2	7529.6
Jul	15057.2	13404.6	11633.4	12779.8
Aug	22068.1	20645.7	19516.8	20287.4
Sep	25241.3	24287.8	23991.3	24192.1
Oct	22913.3	22465.3	24283.5	22422.1
Nov	15906.9	16122.7	18957.4	16063.9
Wet season	18391.8	17482.9	17483.6	17212.5
Dry season	5286.0	5979.7	6481.4	5918.2

	Change of Average Longterm Monthly Discharge (m3/s) - NekLuong		
	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	756.3	2175.7	693.3
Jan	1001.1	1898.4	1024.5
Feb	987.9	1641.6	1039.9
Mar	893.0	1312.7	865.9
Apr	665.3	806.7	613.2
May	-141.5	-663.1	-443.8
Jun	-1192.6	-2644.9	-1634.5
Jul	-1652.6	-3423.7	-2277.4
Aug	-1422.4	-2551.4	-1780.7
Sep	-953.5	-1250.0	-1049.2
Oct	-448.0	1370.2	-491.2
Nov	215.8	3050.4	157.0
Wet season	-908.9	-908.2	-1179.3
Dry season	693.7	1195.3	632.2

	Average Longterm Monthly Discharge (m3/s) - TanChau			
	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	9741.5	10437.1	11722.0	10380.0
Jan	6343.7	7292.4	8139.9	7310.8
Feb	4260.4	5204.9	5824.9	5251.1
Mar	2849.4	3708.7	4105.5	3676.7
Apr	2540.8	3185.6	3313.4	3125.7
May	4121.1	3996.8	3503.0	3708.4
Jun	8586.5	7497.6	6138.5	7083.4
Jul	13784.2	12387.3	10818.0	11834.4
Aug	18938.5	17934.8	17117.4	17670.8
Sep	21098.1	20449.1	20217.0	20381.1
Oct	19660.5	19324.4	20492.9	19293.0
Nov	14617.1	14788.9	16894.9	14747.1
Wet season	16114.2	15397.0	15279.8	15168.3
Dry season	4976.1	5637.6	6101.4	5575.5

	Change of Average Longterm Monthly Discharge (m3/s) - TanChau		
	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	695.6	1980.5	638.5
Jan	948.7	1796.2	967.1
Feb	944.5	1564.5	990.7
Mar	859.3	1256.1	827.3
Apr	644.8	772.6	584.9
May	-124.3	-618.1	-412.7
Jun	-1089.0	-2448.0	-1503.2
Jul	-1397.0	-2966.3	-1949.8
Aug	-1003.7	-1821.1	-1267.7
Sep	-649.0	-881.1	-717.0
Oct	-336.1	832.4	-367.5
Nov	171.9	2277.8	130.0
Wet season	-717.2	-834.4	-945.9
Dry season	661.4	1125.3	599.3

	Average Longterm Monthly Discharge (m3/s) - ChauDoc			
	Baseline 07	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	1586.7	1762.7	2243.5	1747.8
Jan	702.7	886.9	1074.1	883.4
Feb	350.5	494.0	578.8	484.4
Mar	209.4	315.2	342.7	291.1
Apr	163.2	234.0	228.4	209.3
May	386.6	358.0	292.5	319.2
Jun	1147.8	925.6	680.3	847.6
Jul	2446.7	2036.7	1625.0	1892.5
Aug	4532.8	4022.5	3652.6	3892.4
Sep	5713.2	5368.5	5167.1	5322.2
Oct	5461.4	5261.4	5653.5	5244.0
Nov	3454.0	3469.4	4362.9	3449.0
Wet season	3792.6	3514.0	3523.6	3441.3
Dry season	566.5	675.1	793.4	655.8

	Change of Average Longterm Monthly Discharge (m3/s) - ChauDoc		
	Dev. 2020	Dev. 2040	Dev. 2040CC
Dec	176.1	656.9	161.2
Jan	184.2	371.5	180.7
Feb	143.5	228.3	133.8
Mar	105.7	133.3	81.7
Apr	70.8	65.2	46.0
May	-28.6	-94.0	-67.4
Jun	-222.2	-467.5	-300.2
Jul	-409.9	-821.6	-554.1
Aug	-510.3	-880.2	-640.4
Sep	-344.7	-546.1	-391.0
Oct	-200.0	192.1	-217.4
Nov	15.5	908.9	-4.9
Wet season	-278.6	-269.1	-351.3
Dry season	108.6	226.9	89.3

It can be seen that in the critical month of April there is an increase of around 650-800m^3/s at Kampong Cham down to Tan Chau for Scenario M2 and M3 without climate change but with climate change this increase reduces back to 600m^3/s. In May there is a decrease in flows at a critical time for salinity intrusion in the delta such that early dry season crops may be threatened in dry years.

For Sub Scenarios there are significant changes in flow, water levels and other parameters that are dependent on the scenario selected and location considered similar to the main scenarios. For example at Phnom Penh and Prek Kdam under the Hydropower Sub scenarios, as shown in Figure 5.16 flow in May-August decline and reversal of the Tonle Sap is lowered.

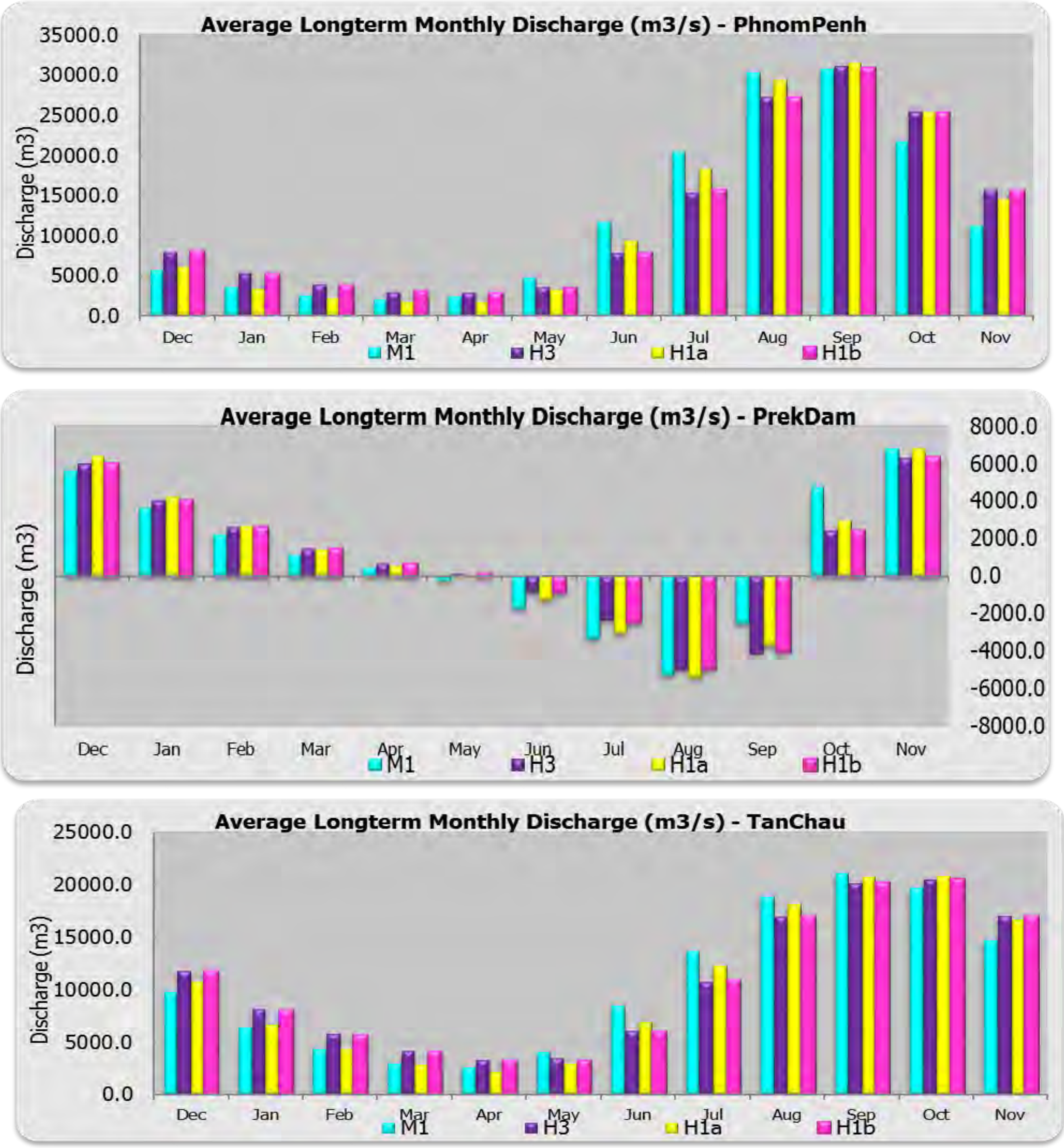


Figure 6-16 Change in Monthly Average Flow at Phnom Penh, Tan Chau and reversal of the Tonle Sap at Prek Kdam for Hydropower Sub Scenarios

The full ISIS output volume provides further detailed information for all stations and sub scenarios.

6.3.2 *Salinity Intrusion Modelling*

The threshold for salinity in drinking water is around 1mg/l whereas for irrigation of crops it is around 4mg/l so when modelling these thresholds have been analysed for areas affected. In line with the increasing flows from upstream if there are no other changes then the saline affected area should decrease a little unless the seas level rise overcomes this positive effect.

Considering the situation in a dry year such as 1998 then it was found that areas affected by salinity under different scenarios would be as shown below (Table 5.29).

Table 6-29 The salinity in year 1998 for different scenarios

Duration	THE SALTY AREA (THRESHOLD 1G/L-1DAY) IN YEAR 1998			
	Baseline 1998	Dev 2020	Dev 2040	Dev 2040CC
None Salty	14,593.4	15,953.4	16,254.4	16,539.9
1 - 7 days	927.5	1,076.5	889.6	818.0
8 - 14 days	578.5	616.8	525.0	645.9
15 - 30 days	1,103.2	953.4	1,224.3	1,111.5
1 - 2 months	2,537.0	2,197.6	1,991.7	1,958.9
2 - 3 months	2,788.9	2,757.4	2,028.5	2,037.8
3 - 4 months	2,460.0	2,822.5	3,419.2	3,424.8
4 - 5 months	15,213.7	13,824.6	13,869.4	13,665.3

Duration	THE SALTY AREA (THRESHOLD 4G/L-1DAY) IN YEAR 1998			
	Baseline 1998	Dev 2020	Dev 2040	Dev 2040CC
None Salty	19,901.3	21,199.6	21,225.1	21,439.3
1 - 7 days	1,186.3	1,231.7	1,049.8	1,063.6
8 - 14 days	619.8	554.3	823.8	970.2
15 - 30 days	1,797.2	775.9	1,486.6	1,469.4
1 - 2 months	3,389.6	1,481.3	3,109.3	2,855.4
2 - 3 months	1,995.5	1,779.6	1,655.5	1,660.7
3 - 4 months	2,801.5	2,951.6	2,651.4	2,595.0
4 - 5 months	8,511.0	10,228.2	8,200.6	8,148.6

Other years and analysis of sub scenarios are included in the ISIS Annex 7.

6.3.3 *Flood Modelling and Analysis*

Flooding in the lower basin has been analysed in 2 ways: firstly looking at specific years and secondly to analyse the flood peaks in a statistical way. The latter approach is being advanced with the Flood Sector team. The WUP Fin modelling also approximates the flooding for the purpose of estimating floodplain deposition changes for the BioRA team.

Analysing the most severe flood event in the time series, which is estimated at approximately 1:20 years, the change in flooded areas and duration for the future scenarios are given in Table 5.30 below.

FLOOD DEPTH	CHANGE OF THE MAXIMUMFLOOD DEPTH IN COMPARE WITH BASELINE 2000 (1000ha)		
	Dev 2020	Dev 2040	Dev 2040CC
None Flood	-9.56	71.22	35.88
0.0 - 0.5 m	-17.99	16.21	-7.55
0.5 - 1.0 m	52.53	-13.03	-25.22
1.0 - 1.5 m	20.52	2.51	12.70
1.5 - 2.0 m	15.48	16.88	-2.76
2.0 - 2.5 m	-4.53	-8.72	1.41
2.5 - 3.0 m	-23.09	-26.40	-10.02
3.0 - 3.5 m	-19.85	-22.64	-12.52
3.5 - 4.0 m	-0.72	2.12	0.63
> 4.0 m	-12.78	-38.15	7.46

Table 6-30 Change in Flood Area and depth for a severe 1:20 Flood

It can be seen that without climate change the scenarios for 2020 (M2) and 2040 (M3) are projected to result in less deep floods that also translate to shorter duration of flooding. However, taking account of climate change flooding increases in most categories. Considering a more average flood year as shown in Table 5.31 the deeper floods increase significantly.

FLOOD DEPTH	CHANGE OF THE MAXIMUMFLOOD DEPTH IN COMPARE WITH BASELINE 2007 (1000ha)		
	Dev 2020	Dev 2040	Dev 2040CC
None Flood	-353.39	127.83	-259.97
0.0 - 0.5 m	-121.03	32.54	-219.73
0.5 - 1.0 m	56.45	6.16	-35.16
1.0 - 1.5 m	-22.59	-37.92	-30.64
1.5 - 2.0 m	-6.96	25.50	-14.78
2.0 - 2.5 m	-62.09	-72.04	23.54
2.5 - 3.0 m	5.70	6.45	158.17
3.0 - 3.5 m	-44.66	-35.86	41.40
3.5 - 4.0 m	16.96	24.93	50.57
> 4.0 m	531.62	-77.58	286.62

Table 6-31 Change in Flood Depths for an Average Flood Event

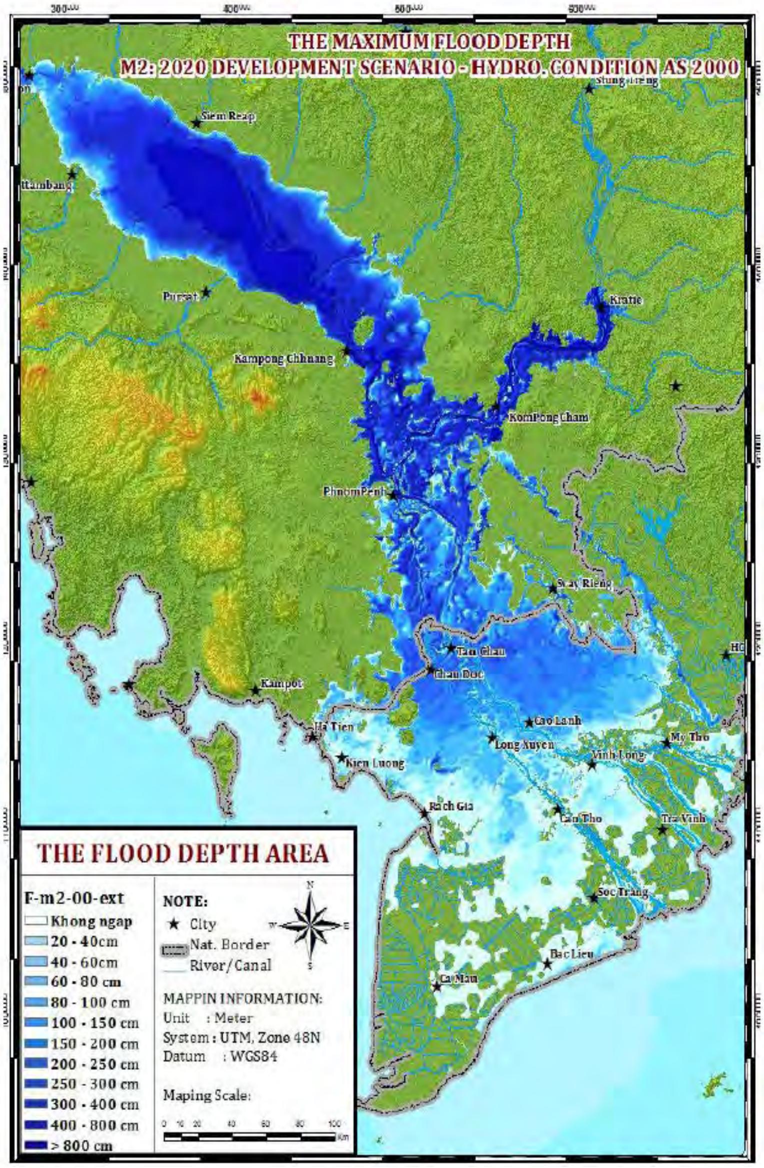


Figure 6-17 Flood Map for M2 scenario

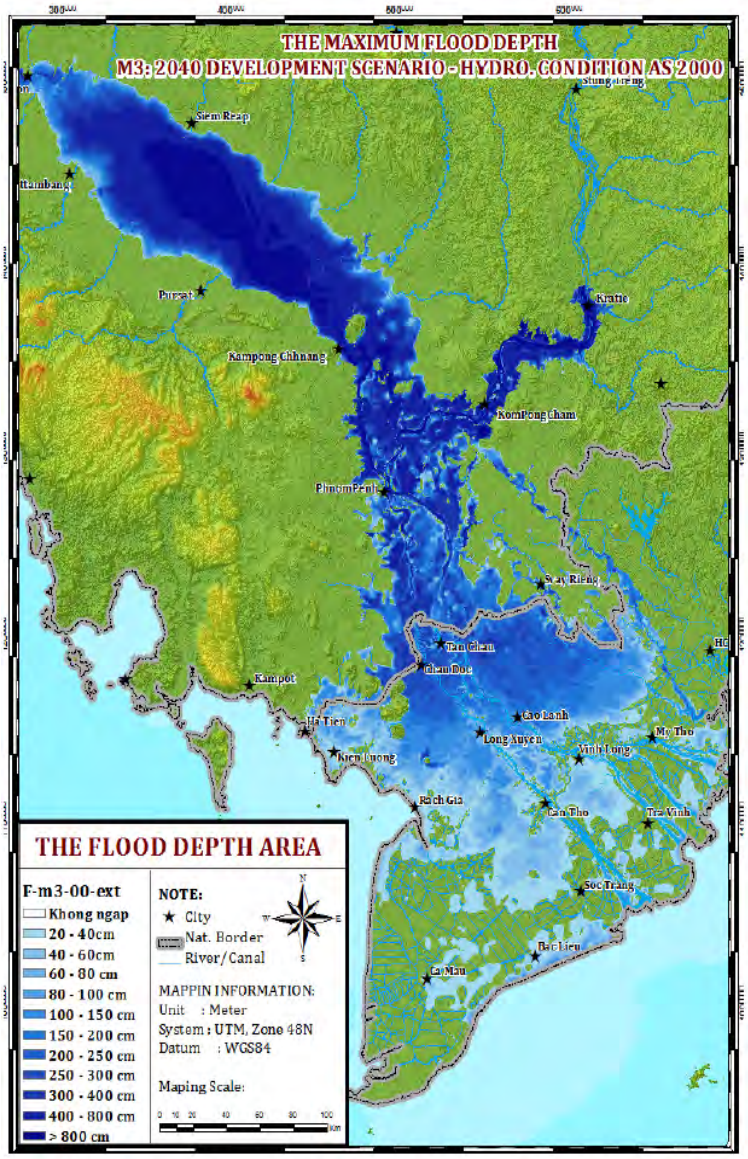


Figure 6-18 Flood Map for 1:20 year event M3 CC scenario

6.3.4 Sediment Modelling in ISIS for Mainstream Dams

The ISIS models for the Chiang Saen to Pakse and Pakse to Kratie reaches were set up to run as a mobile bed sediment model with defined sediment flux at each inflow and definition of the sediment gradings, areas of hard bed etc. Significant improvements over the previous sediment calibration were made ensuring the long term stability of the channel and through adjustment of the transport formulae. In the sediment transport modelling the full range of sediment in transport in the Mekong: sand and gravel transport utilised the Engelund Hanson formulation and the silt/clay fraction uses a specialist formulation for silt transport named the Westrich-Jurashic formula (ISIS Sediment 2001).

A comparison with observation is given below for Pakse and Kratie at the outlet of each model.

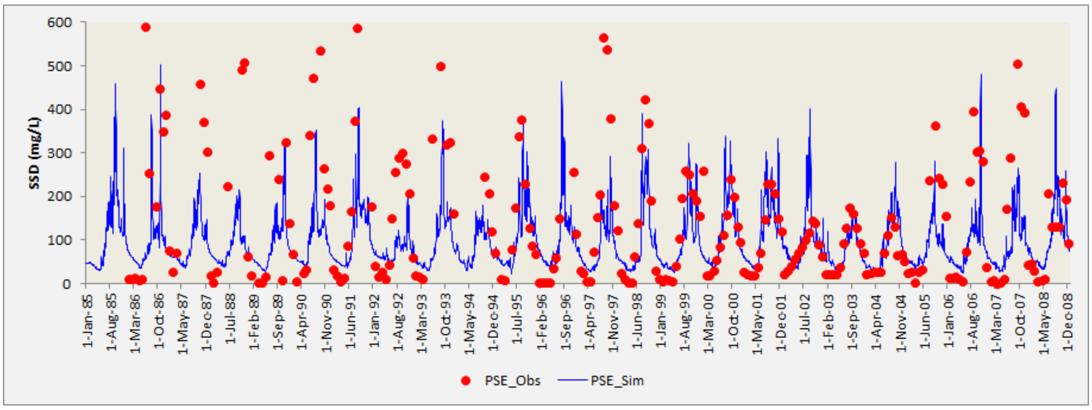


Figure 6-19 ISIS Sediment Calibration for Pakse

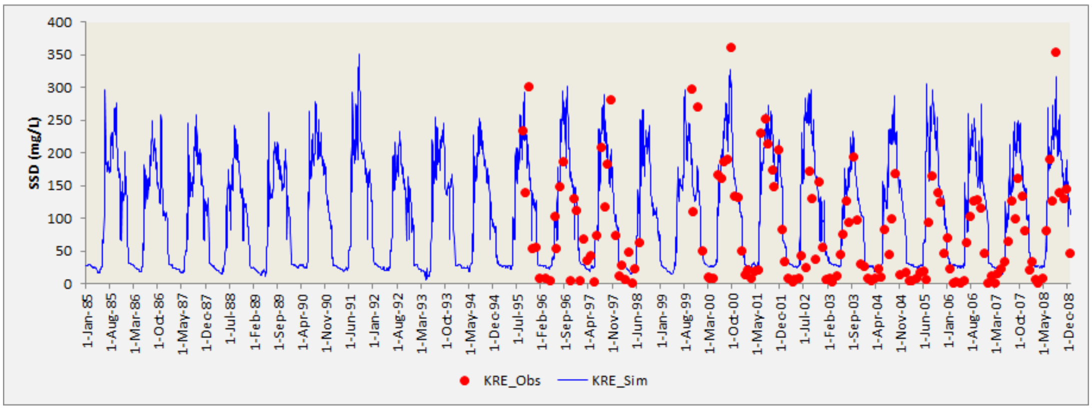


Figure 6-20 ISIS Sediment Calibration for Kratie

The mainstream dams were then introduced into the sediment models using controlled values and gates for the spillway and turbine releases.

The model predicts significant siltation in the mainstream reservoirs formed by the significant backwater from the hydropower dams. The annual average and variability in sediment concentration at Stung Treng for the different scenarios are shown below.

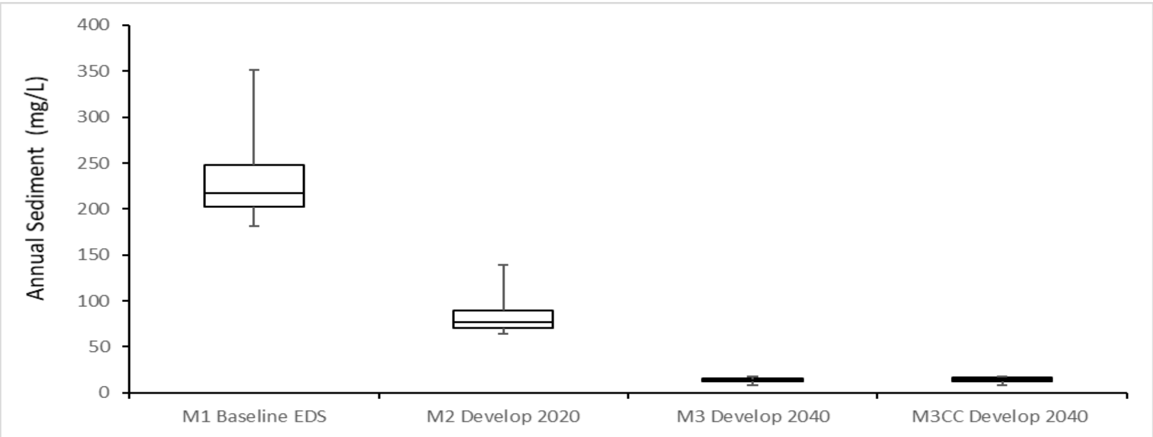


Figure 6-21 Annual Average Sediment Concentration at Stung Treng for main scenarios.

Converting the concentrations into average sediment discharges the variation at key stations is given below for Chiang Saen to Kratie and in Table 6-32. It is noteable that there is little difference between the Source Result for scenario flows at Kratie and specifically the expected

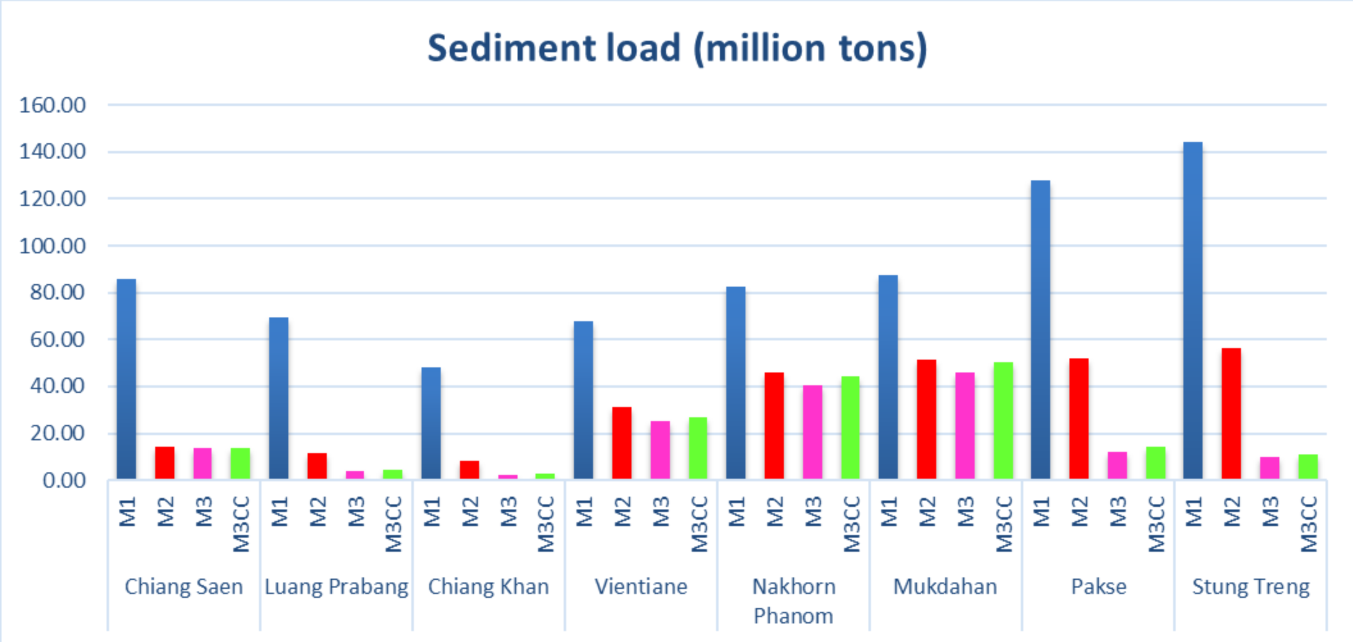


Figure 6-22 Average Sediment Flux at Key Stations for main scenarios from the ISIS model

reduction at Kratie is 97% the same as estimated in Source.

Similarly there is a significant reduction in sediment flux and concentration for sub scenarios such as illustrated below.

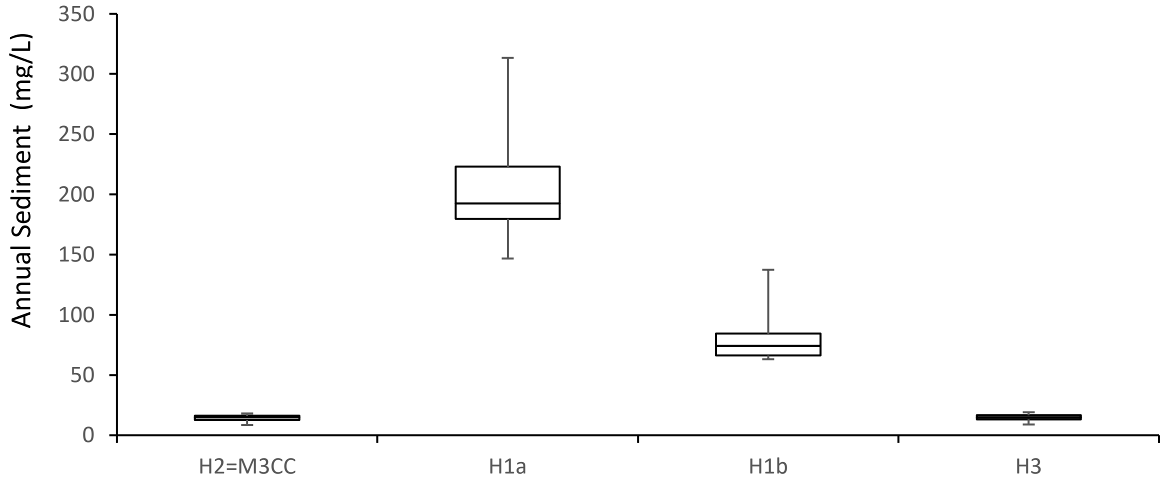


Figure 6-23 Annual Sediment Concentration at Stung Treng for Hydropower Scenarios at Stung Treng

Further details of results are given in the ISIS Report, Modelling Volume 6.

Table 6-32 Predicted Sediment flux for main scenarios at Key Stations from ISIS model

Million Tons/year	Scenario	Wet Season	Dry Season	Annual
Chiang Saen	M1	76.6	9.2	85.7
	M2	13.8	0.4	14.1
	M3	13.6	0.4	14.0
	M3CC	13.2	0.3	13.5
Luang Prabang	M1	64.7	4.6	69.2
	M2	11.0	0.3	11.3
	M3	3.7	0.1	3.8
	M3CC	4.3	0.1	4.4
Chiang Khan	M1	47.3	0.7	48.0
	M2	8.0	0.1	8.2
	M3	2.3	0.0	2.3
	M3CC	2.8	0.0	2.9
Vientiane	M1	66.2	1.8	68.0
	M2	29.5	1.5	31.0
	M3	23.8	1.5	25.3
	M3CC	25.6	1.5	27.1
Nakhorn Phanom	M1	81.3	1.3	82.6
	M2	45.0	0.9	45.9
	M3	39.9	0.8	40.8
	M3CC	43.6	0.8	44.5
Mukdahan	M1	83.5	4.2	87.6
	M2	46.2	5.1	51.3
	M3	40.8	5.3	46.2
	M3CC	44.9	5.7	50.6
Pakse	M1	116.4	11.7	128.1
	M2	50.1	1.7	51.8
	M3	11.8	0.4	12.2
	M3CC	13.7	0.4	14.1
Stung Treng	M1	135.6	8.4	144.0
	M2	54.9	1.6	56.5
	M3	9.8	0.1	10.0
	M3CC	10.8	0.1	10.9
Million Tons	**Scenario**	**Wet Season**	**Dry Season**	**Annual**
Kratie	M1	139.6	5.6	145.2
	M2	49.4	1.6	51.0
	M3	4.2	0.4	4.6
	M3CC	4.5	0.4	4.9

	Scenario	Wet Seasor	Dry Season	Annual
Chiang Saen	**M1**			
	M2	-82%	-96%	-84%
	M3	-82%	-96%	-84%
	M3CC	-83%	-97%	-84%
Luang Prabang	**M1**			
	M2	-83%	-93%	-84%
	M3	-94%	-98%	-94%
	M3CC	-93%	-98%	-94%
Chiang Khan	**M1**			
	M2	-83%	-81%	-83%
	M3	-95%	-93%	-95%
	M3CC	-94%	-96%	-94%
Vientiane	**M1**			
	M2	-55%	-16%	-54%
	M3	-64%	-18%	-63%
	M3CC	-61%	-17%	-60%
Nakhorn Phanom	**M1**			
	M2	-45%	-29%	-44%
	M3	-51%	-35%	-51%
	M3CC	-46%	-35%	-46%
Mukdahan	**M1**			
	M2	-45%	22%	-41%
	M3	-51%	28%	-47%
	M3CC	-46%	36%	-42%
Pakse	**M1**			
	M2	-57%	-85%	-60%
	M3	-90%	-97%	-90%
	M3CC	-88%	-97%	-89%
Stung Treng	**M1**			
	M2	-59%	-81%	-61%
	M3	-93%	-98%	-93%
	M3CC	-92%	-99%	-92%
	Scenario	**Wet Seasor**	**Dry Season**	**Annual**
Kratie	**M1**			
	M2	-65%	-71%	-65%
	M3	-97%	-93%	-97%
	M3CC	-97%	-94%	-97%

6.3.5 Sediment Modelling in ISIS for bank erosion, sand mining and overbank sedimentation

The ISIS model was run with a mobile bed and is able to simulate both the widening of the river due to erosion assuming a given stable bank slope and also to simulate the effects of sand mining. Member countries were unable to supply agreed figures for sand mining so this remains a knowledge gap in the modelling work.

The simulation of floodplain sedimentation was however included for the Cambodia floodplain and Vietnam delta and was analysed along with the WUP FIN tools simulation of floodplain deposition.

6.4 WUPFIN Tools Application

6.4.1 Methodology

The modelling approach, calibration and verification are presented in earlier documents "WUP-FIN Baseline Modelling for the Council Study" October 2016 and "BioRA Modelling Baseline Report" October 2016 as well as the DSF modelling reports. The impact modelling approach is based on the MRC DSF and eWater SOURCE results and extended for additional triple bottom line (environment, social and economic) indicators based on the WUP-FIN 3D hydrodynamic and productivity model and the IWRM modelling framework. These frameworks have a 15 year history of being developed, applied and verified at the MRC for the Mekong assessment. In addition, the models have been extensively re-calibrated and verified during the Council Study. Besides these frameworks the triple bottom line modelling relies on the MRC Tonle Sap Dai fishery data as well as empirical productivity data from the Amazon for similar flood pulsing system (ref. Prof. Junk, Max Planck Institute).

The impact assessment has been conducted separately for the upper Mekong. It should be emphasized that the triple bottom line modelling is integrated with the DSF and relies fully on its hydrological, hydrodynamic and sediment results. Specifically no WUP-FIN modelling has been conducted on the upper part other than supporting Xe Bang Fai floodplain sedimentation calibration for BioRA.

6.5 WUPFIN Tools: Summary of Applications

The majority of work was completed using results from DSF Tools as input and WUPFIN approaches for impact assessment for the discipline and thematic support including:

- Production of scenario results for BioRA focal areas
- Processing of the modelling results, specifically fish and crops, for social and economic analysis for the SIMVA zones
- Analysis for the 2020 scenario and Sub-scenario analysis
- Coastal assessment
- Development of additional information products for the discipline and thematic teams.

The fisheries production assessment in the WUP FIN modelling report complements BioRA assessment. In the 3D and IWRM fisheries production depends on physical processes (flooding), alluvium transport, primary production (water, nutrients, light penetration and predation) but ecological parameters, fishing pressure, migration, species composition etc. are not considered unlike BioRA.

6.5.1 Impacts on hydrological condition including groundwater

Considering first the inputs to the WUPFIN tools the changes in hydrological and meteorological conditions are first summarized below.

There are variations in rainfall that affect crop evaporative demands though changes are small (Figure 5.19).

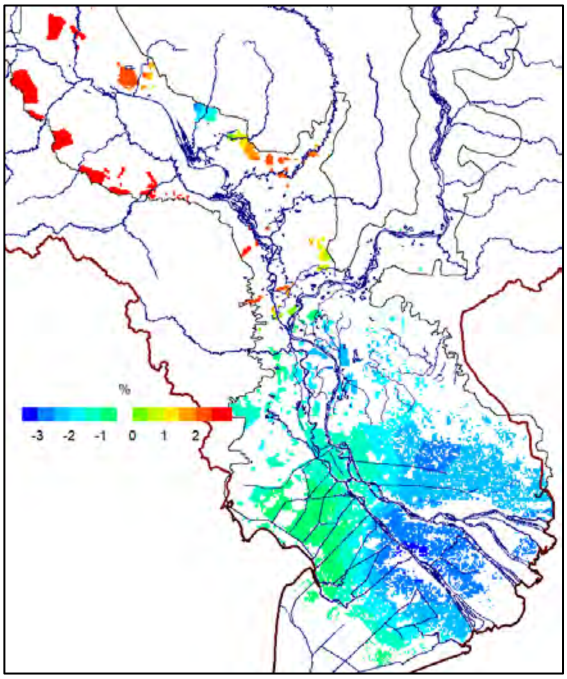


Figure 6-24 Simulated changes in crop evaporative demands

Dry season irrigation demand increases marginally in Tonle Sap basin and decreases marginally in the Cambodian and Vietnam floodplains. The impact of changes is also apparent to groundwater (which is simulated in the WUPFIN tools) due to changing evaporation, rainfall and flood extents as shown below for wet and dry season conditions.

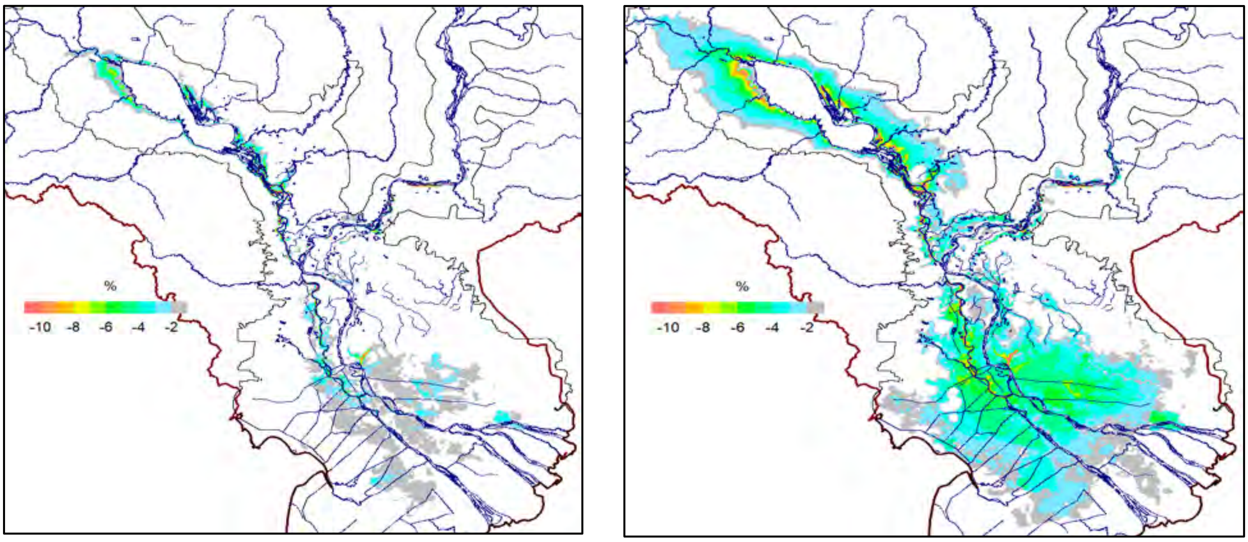
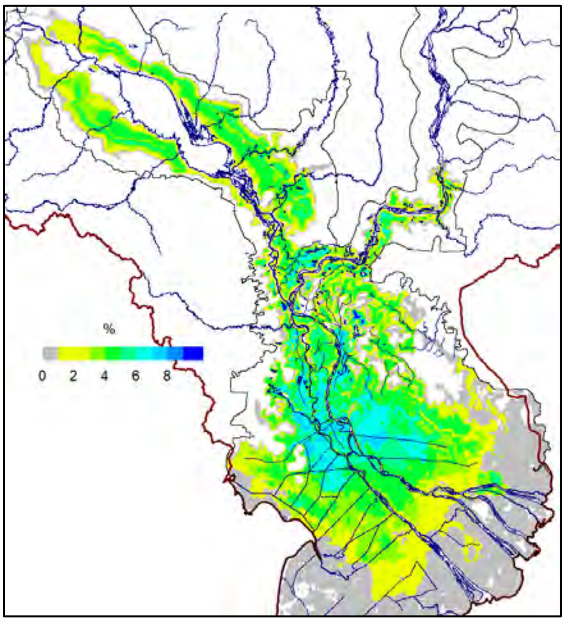


Figure 6-25: 2040 and 2040CC dry season ground water level change. The small change in 2040 is due to flood recharge change. In the 2040CC case also temperature and rainfall have impact.



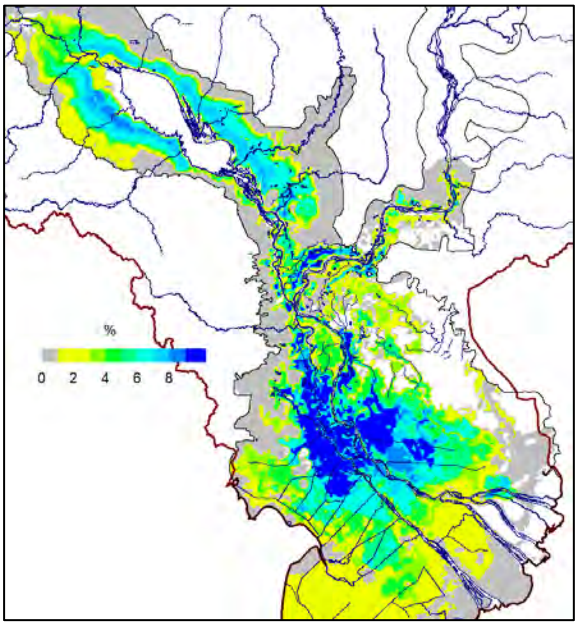


Figure 6-26 2040 and 2040CC wet season ground water level change. The small increase of the level in 2040 is caused by higher average flood depth (higher recharge rate) although flood duration is reduced.

6.5.2 Fisheries Impacts

The impact on fisheries simulated in the EIA 3D model is summarised in Figure 5.23. This takes account of changing flow and sediment conditions on the floodplain and in the Tonle Sap Lake. The Tonle Sap Lake fisheries are heavily impacted though the more dominant floodplain fisheries are impacted but to a lesser extent.

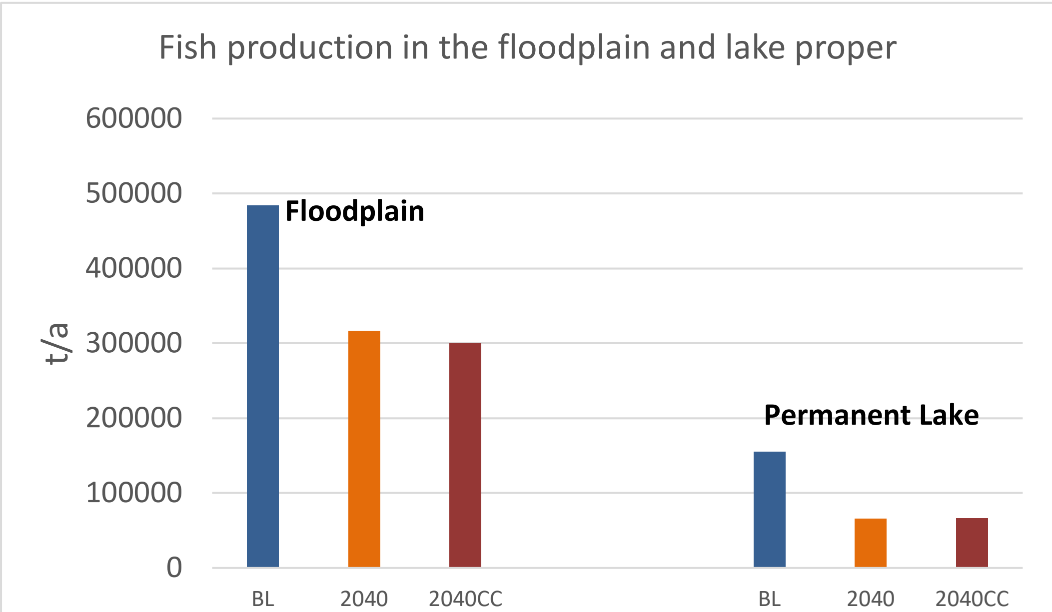


Figure 6-27. Tonle Sap average fisheries production for the floodplain and permanent (dry season) lake.

The impacts are significant on wild fisheries within the lake (around a 50% decline is projected) and in the other parts of the floodplain and delta impacts are also high is also illustrated in the Figures below.

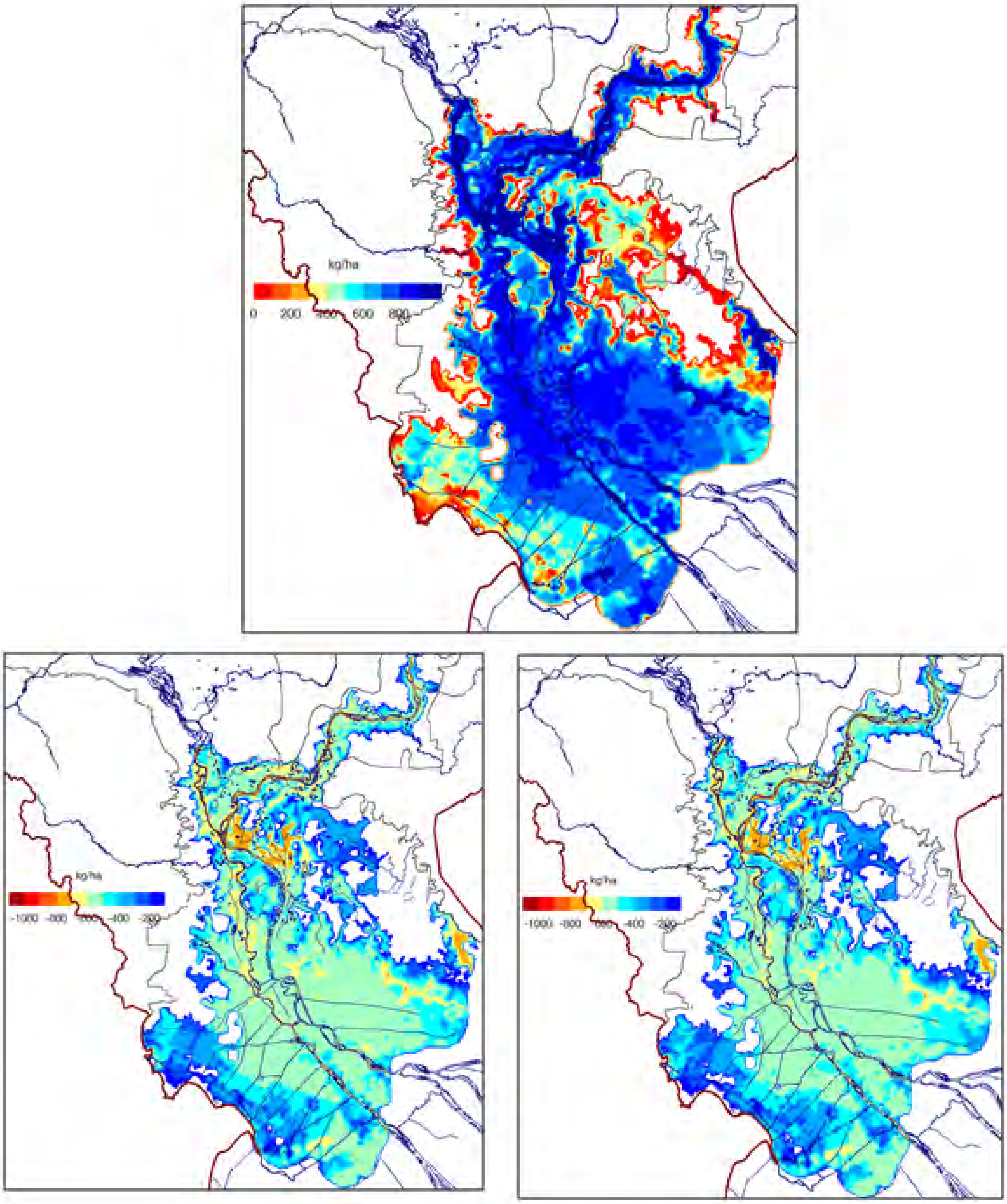


Figure 6-28 Fisheries production for the floodplain and delta.

The coastal fisheries are also impacted by the loss in sediment and nutrients. The modelling of this impact shows a large impact that is projected again to reduce total fisheries by the order of 50% and those directly supported by the Mekong plume to largely collapse by an order of magnitude.

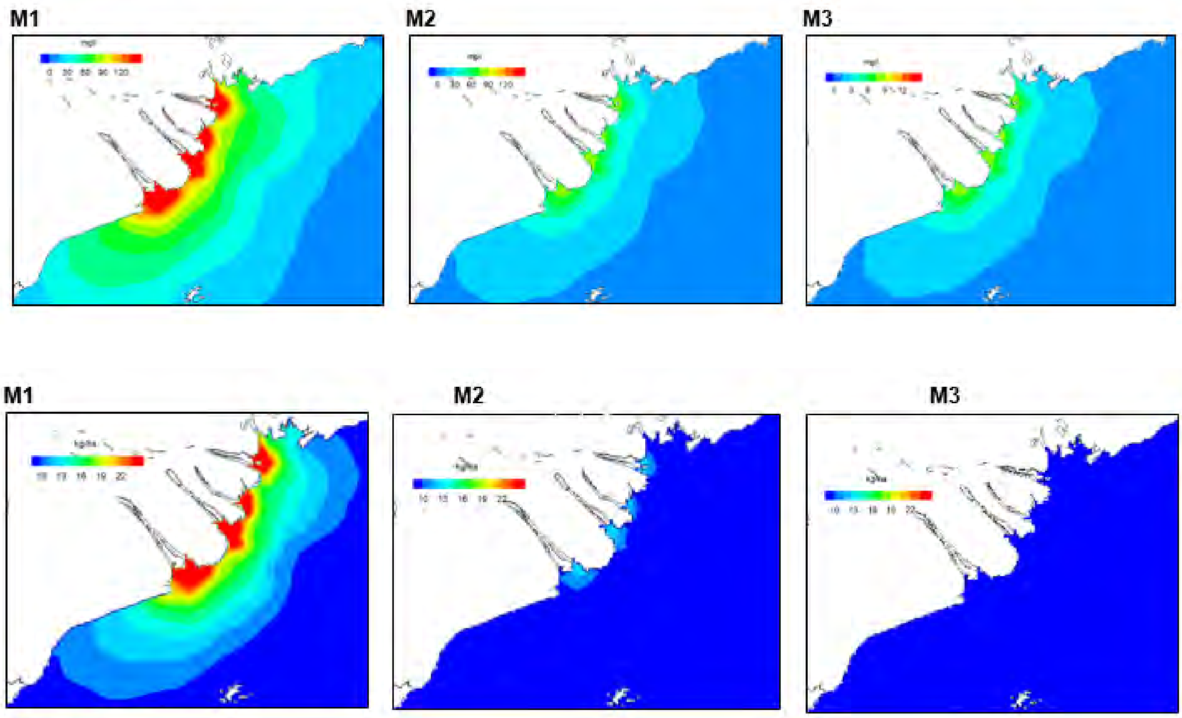


Figure 6-29 Change in Mekong Sediment Plume (upper) and resulting change in coastal fisheries productivity anticipated (lower).

6.5.3 Impacts on crops

There are a number of ways that crops are impacted by future changes:

1. Decreased peak flooding in an average year has a significant positive impact, up to 50%, potentially enhancing rice production during flood season.
2. Decreased fertile sediment and organic material (alluvium) deposition has significant, in large areas 20%, decreasing impact on cropping areas. However, this can be compensated by fertilizers and agricultural soil management.
3. Drought conditions change marginally, up to one month. Both decrease and increase are indicated.

These are indicated in Figure 5.26 and 5.27 below and will be detailed for thematic teams' analysis.

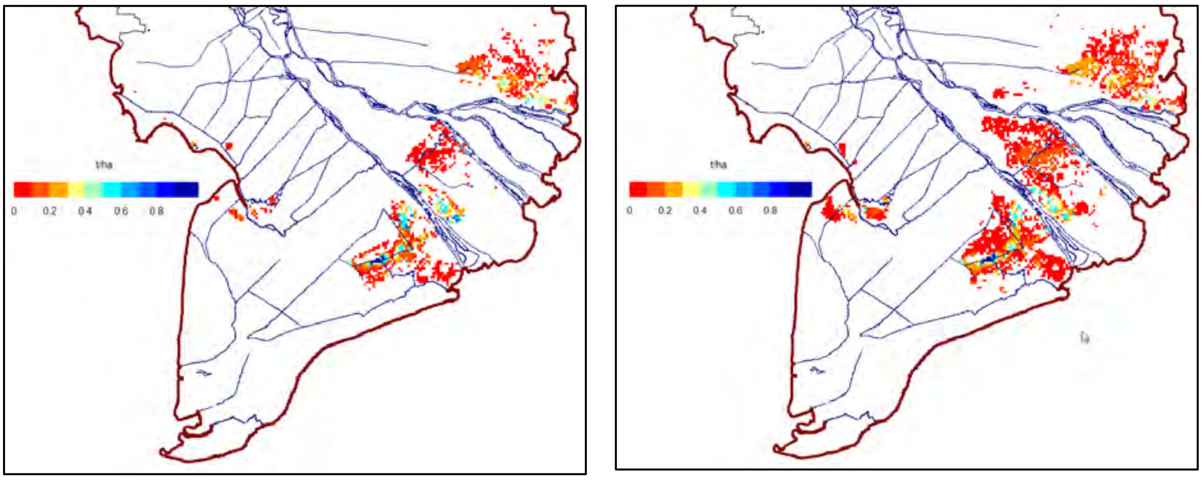


Figure 6-30 Baseline average dry season irrigated rice production (top) and change in 2040 (left) and 2040CC (right) scenarios. No CO2 impact included.

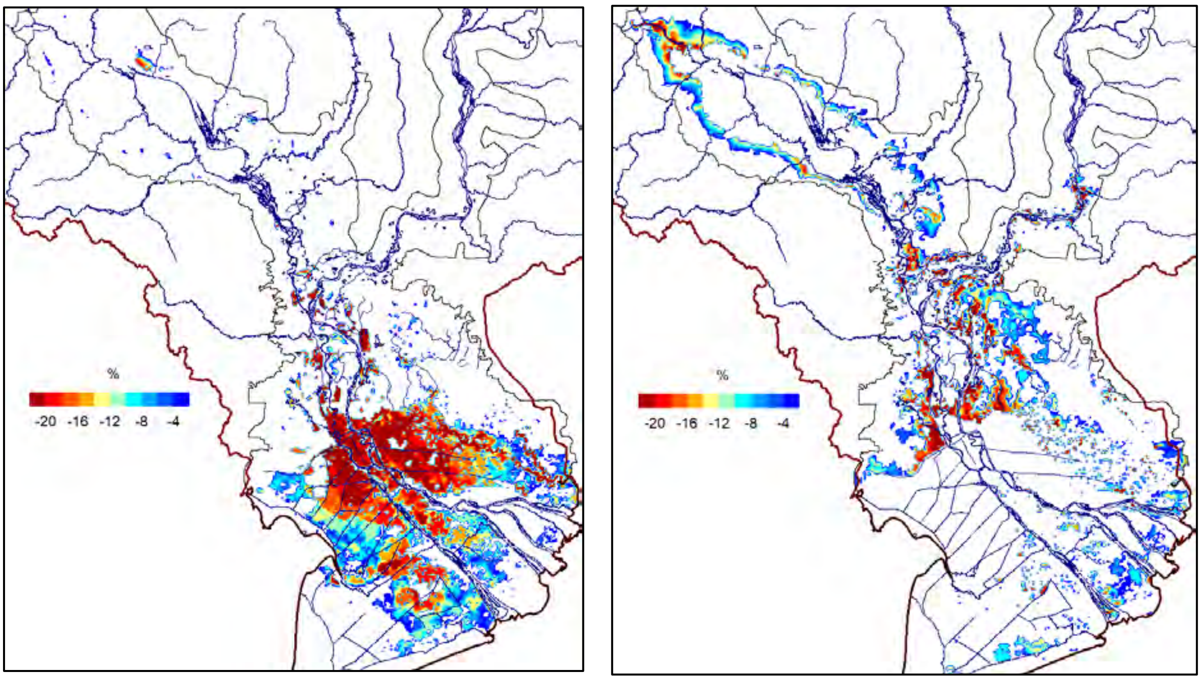


Figure 6-31 2040 scenario alluvium (fertile sediment) reduction impact on rice growth. No water stress (full water availability) assumed

6.5.1 Coastal Erosion

The changing sediment regime at the coast will impact on the coast including a loss of sediment for supporting mangrove, loss of the historic growth of the Cau Mau tip and minor accretion elsewhere. Ultimately as steepening of the sub aqueous delta that will aggravate coastal erosion and the need for further protective works. The coastal modelling has included an initial estimate of effects but further study is needed.

7 Conclusions and Recommendations

A comprehensive exercise of modelling support for the Council Study has successfully calibrated against field measurements, linked and extended the DSF modelling package with Source and WUPFIN Tools to produce a hydrological, sediment and nutrient flux assessment for the main Council Study Scenarios.

7.1 Key findings

The Key findings of the modelling may be summarised:

1) The most significant change anticipated is the 97% reduction in sediment flux to the delta under both of the 2040 Scenarios with or without climate change impact. A large part of this reduction is the trapping of sediments in dams of the Upper Basin and in tributary dams of the LMB. Proposed Mainstream dams, especially Sambor in Cambodia, reduce the total amount of sediment that is free to pass downstream further.
2) The effect on total nitrogen and phosphorus from upstream will also be severe with reductions of around 2/3rd.
3) The reversal of the Tonle Sap will be significantly reduced due to refilling of upstream dams early in the dry season.
4) Flooding in both the upper and lower parts of the basin will increase noticeably in the more extreme cases. Some decrease in average flood peaks may cause the channel to adjust morphologically.
5) Bank erosion issues will increase significantly especially downstream of Sambor.
6) Irrigated area increases are expected primarily in Lao PDR and Cambodia but these have a limited impact on the flow in the mainstream.
7) Mainstream dams simulations are still showing significant trapping of sediments proportionally although the total amount of finer sediment reaching the mainstream is significantly reduced. This offers some potential that working with ISH a mitigation solution can be identified.
8) Operation of dams to mitigate the adverse effect of upstream storage and climate change on the Tonle Sap reversal can be considered under sub scenarios.

7.2 Uncertainties and Knowledge Gaps

The Council Study has demonstrated how the MRC Modelling suite may be used and extended to support a comprehensive study of the complex interactions of physical developments, social changes and economic development of water resources in the Mekong basin can be assessed. There remain some key knowledge weaknesses, data gaps and potential improvements that could be made. Specifically the integration of the different disciplines for a true IWRM assessment needs to be done in a strong multidisciplinary team with close contact to a wide variety of expertise within member countries. The dynamic interactions as suggested by Costanza et al following review of the BDP2 outputs have still not been addressed though given the current uncertainties in the pivotal linkages between reservoir operation and sedimentation and the downstream impact this does not appear to be apriority issue from a modelling perspective.

The uncertainty of models depends a lot on the data used and the skill of the user. These have been laid out in the detailed volumes but the impact of uncertainty of for example rates of floodplain sedimentation may be small if the knowledge of the impact on agriculture is more uncertain.

The modelling support to the Council Study was ambitious and has taken forward a comprehensive 'holistic' basin approach to IWRM including far more parameters, indicators and scenarios than previous work. However it must be recognised that there remain a number of knowledge gaps that need to be filled to improve the predictive confidence:

a) The trapping of sediments in **mainstream** dams and efficiency of **mitigation measures** is highly dependent on the size grading of sediments. There are very few measurements of sediment gradings in transport available to use in simulations and it is uncertain whether the conclusion of other studies are correct to assume that the majority of fine material will pass through the mainstream dams with a very low proportion of trapping. The CS finding are more cautious on this aspect as for example a coarser silt would deposit, a finer silt or clay may deposit but be resuspended. The uncertainty of this aspect is high
b) The proportion of nutrients attached to sediment and the release properties and the availability and interaction of mineral and of dissolved components of nutrient needs to be studied further. This aspect is key for prediction of the impact on agriculture and fisheries.
c) The MRC data for modelling of flood defences is a significant constraint
d) The erosion of river bed, banks, estuary and coast is likely to be correct but the rate of change is uncertain.

7.3 Recommendations

The Integrated Modelling Completed for the Council Study has succeeded in demonstrating that Water Resource modelling could be closely integrated with a comprehensive assessment for the water sectors, socioeconomic impact and economics using the DSF tools as the basis of the predictive tools. There are however areas of improvement needed including particularly data, extension of the hydrological series, proving of the WUPFIN tools against data, and dynamically linking with the changes in the economy expected in member countries.

Specifically the modelling should be urgently improved of:

a) Bank erosion processes

b) the complex simulation of operating rules in hydropower mitigation options with sediment transport and morphological bed and planform changes. This is an important potential aspect that needs further study.
e) The mitigation measures expected for Sambor dam were poorly defined during the study but work by others is expected to be available shortly and could be incorporated into the Council Study.
f) The effect of flooding and flood banks on changes in agricultural productivity in the floodplains and delta area needs further detailed study including the effect of temperature as well as flood regime.
g) The modelling horizon of 2040 is relatively short for climate change and sea level rise impact to be seen clearly and further work is needed for a longer time horizon.
h) The potential decline and loss of sediment and nutrient to the lower part of the basin is very high and likely to be outside of any simple correlation model. Thus a better understanding of the effect of sediment and nutrient fluxes to the Tonle Sap lake and the coastal zone in particular is needed. The coastal erosion issue in particular is seen as very important to understand better.
i) The potential for water quality problems in mainstream dams including algal blooms should be investigated including downstream impacts due to the changing sediment and nutrient regime.
j) Development of improved linkages between models in anticipation for capacity building in the use of the Council Study Tools and the integration with biological resource assessment, economics and sociological impact.

8 References

Dai, A., and K.E. Trenberth (2002) Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations. *Journal of Hydrometeorology* 3(6), 660–687.

Goh, E. (2004). *China in the Mekong River Basin: The Regional Security Implications of Resource Development on the Lancang Jiang* (Working Paper 69). Singapore: Institute of Defence and Strategic Studies. Retrieved from http://dr.ntu.edu.sg/handle/10220/4469?show=full.

Horowitz, Arthur J. "Determining annual suspended sediment and sediment associated trace elements and nutrient fluxes." *Science of the total environment* 400 (2008): 315-343.

Kondolf, G.M., Rubin, Z.K. and Minear, J.T., 2014. Dams on the Mekong: cumulative sediment starvation. *Water Resources Research*, *50*(6), pp.5158-5169.

Kummu, M., Lu, X.X., Wang, J.J. and Varis, O., 2010. Basin-wide sediment trapping efficiency of emerging reservoirs along the Mekong. *Geomorphology*, *119*(3), pp.181-197.

Liu, Q, S Liu, H Zhao, L Deng, and C Wang. " Longitudinal Variability of Phosphorus Fractions in Sediments of a Canyon Reservoir Due to Cascade Dam Construction: A Case Study in Lancang River, China." ***PLoS ONE 8(12)***, 2013: e83329.

Liu, Qi, et al. "The phosphorus speciations in the sediments up and down stream of cascade dams along the middle Lancang river." ***Chemosphere***, 2015: 653-659.

MRC. "Draft Working Paper: The sediment and nutrient data available and analysis for the DSF model simulation in the lower Mekong basin." 2016.

MRC. "eWater Source baseline modelling for the Council Study: Final report." 2016.

MRC (2005) *Overview of the hydrology of the Mekong River Basin*, Mekong River Commission, Vientiane, 73p.

Thorne, C, G Annandale, K Jensen, E Jensen, A Green, and J Koponen. ***Review of sediment transport, morphology, and nutrient balance.*** Report to the Mekong River Commission Secretariat prepared as part of the Xayaburi MRCS Prior Consultation Project Review Report, 2011.

VNMC/DHI. "Study on the impacts of mainstream hydropower on the Mekong river. Impact assessment report, Volume 1. Models, model setup and simulations." 2015.