MEKONG RIVER COMMISSION

THE COUNCIL STUDY

Key Messages from the Study on Sustainable Management and Development of the Mekong River Basin, including Impact of Mainstream Hydropower Projects

Version 0.8
(Preliminary and Working Version for Internal Uses Only)

23 November 2017

Disclaimer:

These Council Study reports are considered final drafts prepared by the technical experts and specialists of the Mekong River Commission, through a process of consultation with representatives of member countries. The contents or findings of the reports are not necessarily the views of the MRC member countries but will serve as knowledge base and reference in the work of the MRC and its member countries in their ongoing technical and policy dialogues in ensuring the sustainable development of the Mekong river basin.

The MRC is funded by contribution from its member countries and development partners of Australia, Belgium, European Union, Finland, France, Germany, Japan, Luxembourg, the Netherlands, Sweden, Switzerland, the United States and the World Bank

1. Significance and scope of the study

In November 2011, the Prime Ministers of the Mekong River Commission (MRC) Member Countries agreed to commission a study (the Council Study) on the sustainable management and development of the Mekong River. The study was undertaken by the MRC Secretariat (MRCS) from 2011 to 2017. The objectives of the study were to:

- further develop reliable scientific evidence of positive and negative environmental, social, and economic impacts of water resources developments;
- integrate the results into the MRC knowledge base to enhance the basin development planning process, and;
- promote capacity within, and ensure technology transfer to, the national Mekong committees.

The completed study has met these objectives, fulfilling the mandate articulated by representatives of the Member Countries and stands as a seminal achievement, including development of integrating processes, tools and datasets that can be used to guide future sustainable development of the Mekong Basin.

The main outputs of the study are: (i) an integrated and cumulative assessment of the consequences of current and planned water resource development projects in the Lower Mekong Basin (LMB); (ii) recommendations and key messages for the Member Countries to inform national and collective decision making; iii) enhanced capacity development of Member Countries' technical staff, and; (iv) development of an integrated impact assessment approach and tools for the LMB. This enhanced capacity will assist the MRCS and the Member Countries in their planning, joint development, management and monitoring of the water resources of the LMB.

The key study achievement is an improved capacity to highlight the positive and negative impacts of planned water resource development projects in the LMB across a suite of sustainability dimensions expressed as a set of environmental, social and economic indicators chosen by the Member Countries. Developments included existing and planned mainstream and tributary hydropower projects, expanded agriculture and irrigation schemes, domestic and industrial water, waterway navigation and flood defenses. The assessment framework developed by the study team will allow for the systematic evaluation of the positive and negative impacts associated with planned water resource developments, and in doing so assist Member Countries in their individual and collective deliberations and policy decisions about the future of the LMB.

In accordance with the requests of the Member Countries the Council Study framework will be transferred in its entirety to the countries for independent revision, iteration of the assessments, and for the evaluation of additional scenarios incorporating different future development policies and assumptions. Thus, future capacity building and knowledge transfer to the Member Countries is a primary focus of post-2017 planning.

The study involved:

- six thematic teams, each representing a development thematic area or sector: agricultural land use, domestic and industrial water use, flood protection infrastructure, hydropower, irrigation and navigation;
- five cross-cutting discipline teams: climate change, modelling, bio-resources (BioRA), social and economic; and
- a cumulative impact assessment (CIA) team.

The first step in the study integrated the bio-geo-physical characteristics of the LMB by means of qualitative and quantitative models, which were used to develop and describe a set of water resource development scenarios. Integration across the sustainability dimensions was achieved by using the modelling outputs as the foundation for the environmental, social and economic indicators and outcome assessments. These, in turn, informed the social and economic analyses for the six thematic sectors.

The strength and importance of the study's assessment framework is that it provides a coherent and robust scientific foundation for the assessment of outcomes of water resource developments, combined with accessible, practical methodologies and a knowledge base to support further studies, deliberations and processes. The framework has been designed to be flexible, transparent and repeatable to accommodate improved data management and continued refinements of the assessment tools.

The Council Study considered three main water resource development scenarios over a 24-year projection horizon: (i) the 2007 early development scenario; (ii) the 2020 definite future scenario; and, (iii) the 2040 planned development scenario. These main scenarios aggregate combinations of water resource developments and investments to allow for assessment of their cumulative effects on the environment, social issues and the economy of the Member Countries. The 2007 scenario represents baseline conditions in the LMB and is the scenario against which the others were compared. The 2020 definite future scenario includes all existing, under-construction, and firmly-committed developments in the six sectors (including the Xayaburi and Don Sahong hydropower projects). The 2040 planned development scenario includes 2020 developments plus developments in the six sectors planned for implementation by 2040.

Assessing the cumulative effects of a combination of investments tends to mask impacts associated with individual developments and/or thematic areas. Thus, 12 sub-scenarios were evaluated to isolate sector-specific contributions to the outcomes of the main 2040 scenario. These sub-scenarios comprise reductions or increases in sector-specific investments relative to those in the 2040 scenario for each of agricultural land use, flood protection infrastructure, hydropower and irrigation. A set of three sub-scenarios was also devoted to isolating the impacts of climate change.

2. Overall costs and benefits of development

The Council Study Cumulative Impact Assessment (CIA) summarises the costs and benefits of the water-resource developments included in the scenarios using three main measures: (i) resilience and vulnerability; (ii) sustainability; and, (iii) cross-sector and transboundary trade-offs.

The key conclusions of the CIA are:

- The development plans are likely to combine a group of highly beneficial and a group of non-beneficial hydropower and agricultural expansion projects.
- Hydropower development plans increase energy security and contribute to economic growth, but result in substantial losses in ecosystem services, many of which are transboundary.
- The developments included in the 2020 and 2040 scenarios are likely to reduce resilience and increase vulnerability of rural communities in the LMB, particularly in Lao PDR and Cambodia.
- Poor households along the Mekong River are likely to be most disadvantaged, but the urban poor are also likely to face considerable challenges as fish prices are expected to increase.
- Weather variability, particularly that associated with a drier climate, is likely to exacerbate the expected impacts on poor people.
- The development plans conflate beneficial and non-beneficial hydropower and agricultural expansion projects.
- The trade-offs between hydropower development and fisheries are substantial and require a project-by-project assessment.
- The water resource developments defined by the main scenarios will result in substantial sustainability losses, many of which could be reduced or avoided by adjusting planned investment in hydropower and agriculture.

- In the absence of successful cross-sector benefit sharing, the sustainability index[1] would drop substantially by 6 points from ca 30 points to ca 24 if 2040 development plans were implemented (Cambodia -30%, Lao PDR -28%, Vietnam -23%, and Thailand -17%). The positive and negative impacts of development will be unevenly distributed, with most benefits accruing to energy companies and most impacts experienced by fishing households.
- Effective benefit sharing needs to be designed as a cross-sector mechanism and not a compensation scheme between countries because beneficiaries (e.g. energy companies) and disadvantaged groups (e.g. fishing households) alike are located in all four countries.
- A possible burden sharing mechanism could be a levy, which would need to be approximately 8.6% for tributary dams and 18.9% for mainstream dams to avoid unfair distribution.

One key recommendation from the CIA is to conduct a project-by-project assessment as current development scenarios combine both highly positive and negative hydropower and agriculture projects. Cumulative impacts need to be adequately considered in this process.

Finally, considering the irreversible effects and path dependency of hydropower development in the LMB, it is strongly recommended that current and future energy planning includes consideration of other renewable power generation technologies as these are increasingly being viewed as less environmentally-damaging alternatives to hydropower.

3. Hydrology and Environment

The hydrological, hydraulic, water quality and ecological implications for the LMB of the water resource developments included in the scenarios were modelled using the MRC Decision Support Framework (DSF), which was updated for use in the Council Study, and augmented with SOURCE, WUP-FIN tools and the BioRA Decision Support System (DSS). Together, these tools were used to model:

- Rainfall-runoff in the LMB (SWAT)
- Hydrological regimes on a daily basis (IQQM)
- Sediment and nutrient supply (SOURCE)
- Hydraulic conditions in the river, such as area, depth, velocity, shear stress (ISIS)
- Hydraulic conditions on the riparian floodplains in Lao PDR and Cambodia, the Tonle Sap Lake and the Delta (WUP-FIN)
- Hydraulic conditions along the coast (WUP-FIN)
- Erosion and habitat quality in the rivers (BioRA DSS)
- Extent/abundance of vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals in the rivers, floodplains, Tonle Sap Lake and the Delta (BioRA DSS).

The modelling work done for the Council Study is more extensive and more integrated than anything done previously for the LMB, and as such represents a significant step towards providing systematic and systemic assessments of the physical and biological implications of water resource developments in the basin. Notwithstanding this, the study highlighted a need for further development and integration of the models and tools, filling of critical data gaps and capacity building for the new applications.

The hydrological modelling for the main water resource development scenarios indicated that the impacts on total flow volumes would be subtle, but that predicted changes in seasonal flow patterns are substantive, mainly because of attenuation by reservoirs. Relative to the 2007 baseline, the developments included in the 2020 and 2040 scenarios result in higher dry season flows and lower wet season flows. Related to this, the reversal of the Tonle Sap River is also expected to be delayed. While a reduction in the wet season flood pulse is positive for flood damage, the hydraulic modelling showed that it would seriously limit the duration and extent of inundation of floodplain habitats, particularly on the Xe Bang Fai floodplains, the Cambodian floodplains, the Tonle Sap system and the Delta.

[1] design is based on the Sustainable Development Goals

The sediment and nutrient modelling for the 2020 and 2040 scenarios predicts a substantial loss of sediments and nutrients moving through the system relative to the 2007 baseline, mainly as a result of sediment being trapped in impoundments. Under the level of development in the 2040 scenario, only 4% of the pre-dam era sediment load is expected to reach the Delta. There are a number of opposing drivers for nutrient loads, but despite increases in effluent loads from cities due to population growth, the modelling predicts an overall decline in nutrients in the 2020 and 2040 scenarios.

The ecosystem modelling predicted:

- Trapping of bed and suspended sediments in tributary and mainstream dams will increase bed and bank erosion in the downstream river, and reduce the deposition of nutrient-rich sediment on the floodplains, even in the 2020 scenario.
- The reservoirs associated with the mainstream dams in the 2040 scenario and the 2040CC[2] scenario will convert much of the mainstream Mekong River from Chiang Saen to Kratie[3] into deeper, lake-like habitat that is unsuitable for many of the species that inhabit the river but that will benefit others, such as bivalves, frogs and snails.
- Tributary and particularly mainstream dams will disrupt migration routes essential for the continued occurrence of 30-40% of the species that comprise the Mekong fish communities and 30-40% of the total fish catch.
- The planned 2040 developments will seriously reduce indigenous riparian and wetland vegetation, mostly through inundation associated with the 2040 planned level of development. They will change the composition of algal and invertebrate communities that form the base of the aquatic food chain, thereby affecting the viability for a wide range of animals and plants, change the composition and reduce the biomass of fish assemblages in the LMB, eliminate white fish, and promote invasion by non-native species.
- The fisheries biomass production is expected to decline substantially upstream because of the hydropower dams and their impacts on migration and habitats and primary production. The reduction is 35-40% for the 2020 scenario and 40-80% for the 2040 scenario. Downstream of Kratie, the Tonle Sap annual average fish biomass production is expected to decrease from 350,000 tons to 260,000 tons by 2020 and to 200,000 tons by 2040. Corresponding annual Cambodian Mekong floodplain production is expected to decrease from 280,000 tons to 170,000 tons by 2020 and to 80,000 tons in 2040 (accounting only upstream from Kratie impacts). The annual coastal Mekong plume fish production is expected to decrease from baseline 240,000 tons to 60,000 tons by 2020 and 10,000 tons in 2040 (taking into account only the Mekong nutrient load contribution). BioRA estimated the impact on Delta fish production to be less outspoken, with nutrient reductions partially compensated by locally sustained, often substantial nutrient sources e.g. from urban and agriculture run-off. This approach concluded a reduction by 30% of fish biomass in Vietnam's Mekong by 2040.

These changes will likely extend across the whole basin, but are expected to be felt first and most in the upper reaches of the LMB. To some extent, the Tonle Sap Lake is buffered from development along the Mekong River by direct inflows and rainfall, provided reversal of the Tonle Sap River is fully preserved. The nature and functioning of the lake will be affected, however, by the reduction in sediments supplied by the Mekong River and the blocking of the migration paths of white fish. Similarly, the Vietnam Delta would be cushioned from future changes by the fact that it is already highly modified and controlled, and the fact that higher flows in the dry season could aid fish recruitment. Nonetheless, it will be affected by, inter alia, the change in sediment supply and alterations in the composition and dynamics of fish communities.

The evaluation of the sub-scenarios showed that:

- A wetter climate future will mitigate some of the ecological impacts associated with the 2040 scenario, but only slightly because flood protection measures are expected to limit the

[2] 2040 scenario with climate change
[3] There is a large area from Vientiane to Pakse that is not impounded.

increase in flooding. A drier climate future will exacerbate the ecological impacts associated with the 2040 scenario, especially in the lower parts of the LMB. Climate change may also pose challenges for flood management, with an increase in flood peaks relative to the other scenarios.

- The incremental hydrological, hydraulic and sediment-related impacts associated with agricultural land use, irrigation or floodplain infrastructure developments are masked by the much greater impacts associated with the other sector developments comprising the 2040CC scenario.
- The connectivity-related impacts related to mainstream hydropower dams, such as trapping of sediment, disruption of migration paths and alteration of flow regimes, are substantial and far-reaching, and overshadow those of all other planned water resource developments in the LMB.

4. Climate Change

Hydrological and Climatic Impact

Three climate sub-scenarios were tested, each of which has increased ambient temperatures relative to the 2007 baseline, but different rainfall as this drives climatic uncertainty for water resources. The three scenarios tested are designed to cover the possible range of likely change assuming a medium level of greenhouse gas emissions. The expected sea level rise is also included and is similar for each climate scenario.

The changes in mean flows in the Mekong River are dominated by the developing water infrastructure but variability between years, such as in a peak flood, is strongly influenced by climate change.

Social Impact

Various aspects of social impact are apparent, including the number of people affected by flood or drought. The indicator that best summarises the social impact is food security, which takes into account the differing response of crops and fisheries to changes in the river regime. Food surplus approximates the capacity to manage and adapt to acute food shortages. Increased surpluses correspond with increased capacity. The changes from climate change are generally negative with the impact on fish in the Tonle Sap lake for the dry scenario having the most deleterious impact. The crop modelling assumed a positive impact of increased atmospheric carbon dioxide. However, translation to field conditions remains uncertain.

In general, food sufficiency is adequate in an average year, but in a critically dry year any significant reduction with climate change effects could cause significant problems for the poorest households. An additional strategy to alleviate this will be needed.

Economic Impact

The macroeconomic component of the Council Study considers the effect of different scenarios on a range of issues such as overall Gross Domestic Product (GDP), employment and the impact on different sectors. The most striking finding of the climate change scenarios is that there is a significant reduction in the future GDP under all scenarios, particularly for Cambodia, and particularly if the drier scenario should materialise. Such impacts could seriously damage the prospects of Cambodia sustaining lower middle-income status.

Maximising agricultural production is not necessarily the best cross-sectoral strategy as in all climate change scenarios a higher GDP can be attained if labour is utilised more effectively in other industries.

Some knowledge gaps remain. For example, the combined effect of trapping of sediment in reservoirs, and flow changes associated with climate change or infrastructure is likely to change river geomorphology, but this has not been quantified. Cumulative effects of sufficient magnitude can potentially alter the rate of river adjustment in plan and long section that will increase river bank erosion

and land loss. Sea level rise combined with sediment reductions will also affect coastal flooding, including reduced protection of coastal embankments by natural defences such as mangrove forest.

The Council Study sector-based approach has shown that even to 2040 (a modest planning horizon for climate change) significant impacts from climate change are likely, some of which are due to the transboundary impacts of water resource development coupled with the changing climate. The cumulative impacts of this change need further consideration and further quantification.

5. Socio-Economics

The social and economic component of the Council Study addressed food, water, health, energy and income security, including sector employment and gender equality. Substantial changes, both positive and negative, are anticipated for the 2040 scenario. The changes are not uniformly distributed across the studied corridor of 15 km along the Mekong River and affect Member Countries unevenly, in different ways, and at different times.

Food Security

There is overall sufficient rice and fish production and surplus in the corridor to sustain 100% food security. However, maintaining this will require effective, willing distribution networks and cooperation amongst Member Countries to avoid significant increases in undernourishment in parts of the corridor under the 2020, 2040 and 2040 with climate change scenarios.

Managing fish declines is central to improving food security. Over the whole corridor, a reduction of ca 3,800 tons of fish corresponds to an increase of 1,000 households defined as undernourished in the 2007 scenario. Sensitivity to reductions in fish availability increases in the 2040 scenario where 3,300 tons of fish correspond to an additional 1,000 undernourished households. An increase of 12,500 tons of rice reduces the number of undernourished households by 1,000.

Overall fish catch declines by 43% in the 2040 scenario and by 40% in the 2040 with climate change scenario. The 3% variation in 2040CC is attributed to improved habitat for generalist species in Cambodia and the Delta. Rice production increases by 16% in the 2040 scenario and by 13% under the 2040 with climate change scenario.

The number of undernourished people in Cambodia and Lao PDR increased in the 2040 scenarios, compared to the 2007 baseline and remained relatively stable in Thailand and the Vietnam Delta.

Fish surplus declines to near zero in Lao PDR and in zones in Cambodia away from the Tonle Sap and remains positive in Thailand and Vietnam for the 2040 scenarios. Reduced surplus reduces resilience and the capacity to manage acute food shortfalls. Increased prices are likely to affect poor households. It is unclear if wage and income increases at current rates will provide sufficient compensation.

Increased fish prices introduce an incentive to convert land to aquaculture. The widespread use of antibiotics, deterioration of water quality and possibly reduction of water quantity due to the cumulative effect of dam impoundments will need monitoring and management. Developing agreed aquaculture production standards and monitoring protocols is an opportunity for trans-boundary cooperation.

A 10-11% decrease in rice production due to extreme flood affects 4.5-5.0% of the corridor population. An 11% decrease in rice production due to extreme drought affects 3.1-3.3% of the people. In case of extreme floods and drought (for example the 1995-96 El Niño and 2000-01 floods), Cambodian riparian communities appear to be the most affected. Years are predicted where drought or floods coincide with large fish declines, introducing the potential for acute undernourishment. The effects are likely to be more severe in Cambodia under the 2040 scenario with climate change, requiring careful transboundary planning.

Poverty levels

The 2007 scenario corresponds to the lowest levels of poverty for all zones except 3C in Thailand, 5B in Cambodia, and 6B in Vietnam. Poverty decreased in Lao PDR and Thailand and remained relatively stable in Cambodia and the Vietnam Delta. In the 2040 scenario, poverty increase in Lao PDR was estimated at 1.7-3.7% and in Cambodia at -0.01% to 2.0%. Changes in Thailand and Vietnam were estimated at less than 1%.

Agricultural Production Value

The total dollar value of fish catch across the corridor will decline by $1.57 billion in the 2040 scenario, offset by an increase in rice production worth $0.95 billion. The greatest decline in fish value occurred when comparing the 2007 and 2020 scenarios, suggesting both individual and cumulative assessments of projects needs to be undertaken.

Household Incomes

Aggregate household incomes across the corridor were predicted to decline by $245 million for the 2020 scenario and by $630 million in the 2040 scenario compared to the 2007 scenario. The changes in sector incomes are not uniformly distributed across the Member Countries. The paradox of declining incomes in the face of agriculture expansion in Lao PDR and Cambodia is partially explained by employment shifts from low-paying sectors to higher-value sectors and reduced rice production in the Delta.

Employment

The joint agricultural and secondary sector expansion strategies proposed in the development scenarios potentially introduce conflicting labour demands in the 2020 and 2040 scenarios, associated with the potential of abandoned and underutilized infrastructure. Developing a dynamic modelling approach capable of including key influencing factors, including migration patterns within and outside the corridor, is recommended as a central feature of trans-boundary planning.

Gender

National aspirations of gender equality are generally not reflected in the study assessment and indicate a need for sustained efforts to correct the imbalance. There is a near-complete absence of data and information in the corridor to conduct reliable gender analyses. The MRC can play a central role to correct this imbalance.

Health and Energy Security

Rural electrification levels, i.e. energy security, and access to safe water and sanitation are expected to continue along historical trends and independently of the development scenario investments.

6. Macro-Economics

The development scenarios defined for 2020 and 2040 are likely to combine positive and negative outcomes. At the narrow sector level, much of the hydropower and agricultural expansion appears very positive. At the same time, hydropower is likely to trigger substantial losses in the fisheries sector. Agriculture is likely to receive too much investment and likely to lower macroeconomic growth. Some hydropower and a few selected agricultural expansion projects appear highly beneficial. This requires a project-by-project impact assessment. Substantial risks are linked to climate change as a drier climate change scenario (C3) would trigger substantial losses.

The overall combined macroeconomic gains are not only triggering large cross-sector trade-offs but also losses in natural capital. Small and more focused agricultural extension combined with productivity improvements for existing areas would lead to more sustainable outcomes. Similarly, if certain

hydropower projects could be replaced by more sustainable forms of power generation, important secondary and tertiary sector growth could be achieved without large cross-sector losses[4].

Cambodia

Cambodia shows substantial GDP growth potential and could move its GDP from around $21 billion in 2017 to over $50 billion in 2040. Under 2040 development plans, GDP growth is likely to be lower at around $38.5 billion. This slowdown is largely due to the effect of excessive agricultural expansion and partly due to the decline in fisheries caused by hydropower. Cambodia is likely to experience from a national perspective the highest trade-off: for every dollar gained from hydropower about 62 cents would be lost in fisheries. Climate change that is drier than expected would affect GDP substantially and cause a further decline in fisheries of nearly 15%. The scenario for 2020 with only a subset of selected, highly beneficial agricultural expansion projects is likely to create the highest macroeconomic benefits.

Lao PDR

Overall, Lao PDR shows immense economic growth potential and could increase its GDP from about $17 billion in 2017 to over $42 billion in 2040. However, negative trade-offs associated with the 2040 development plans are likely to slow down GDP growth, leading to a GDP for 2040 of around $30 billion. Some investments included in this study are likely to help realize higher growth while others would counter the growth trajectory.

Many hydropower projects are likely to be very beneficial to the national economy of Lao PDR. However, about 14% of hydropower benefits would be lost in fisheries reductions, which would also trigger substantial food security issues. Most of the hydropower benefits (70-80%) would go to foreign investors from Thailand, China, Malaysia or South Korea. Drier than expected climate change is a major risk and would reduce hydropower benefits by up to $2.2 billion in net present value.

From a macroeconomic perspective, agricultural expansion plans are likely to be too ambitious as workforce demands at current productivity levels would slow down macro-economic growth, particularly planned growth in the manufacturing and services sectors.

Thailand

Thailand could double the GDP of its Mekong Basin areas from about $51 billion in 2017 to over $100 billion in 2040. The 2040 scenarios, however, are likely to realise a lower GDP of $71 billion due to the main negative effect of fish catch reductions. The hydropower-related benefits for Thailand or for Thai companies from mainstream hydropower in Lao PDR are substantial with up to $82 billion in net present value for the 24-year time period. These would coincide with income losses for small households along the Mekong of nearly $7 billion in net present value as fish stocks decline. Investments in secondary and tertiary sectors will be the most critical pillar for successful economic development.

Vietnam

Vietnam has the potential to increase the GDP generated in its Mekong Delta area from about $50 billion in 2017 to about $93 billion in 2040. Proposed development plans for 2040 are likely to realise a lower GDP of $81 billion due to a range of negative development effects. Current strategies to prioritize investments in food processing instead of food production and to stimulate additional secondary and tertiary sector growth (e.g. in the transport sector such as navigation, education) are very promising. The past has shown that challenges for real GDP growth have been experienced as inflation peaks erased much of the economic growth. There is a risk that similar inflation peaks will be repeated as fish and other food prices are likely to increase substantially if hydropower investments are implemented as defined under the 2040 scenario. The LMB-wide trade-offs that hydropower is likely to cause for

[4] Secondary sector refers to industries that produce a finished product by taking outputs of primary industries (agriculture, mining, forestry and fisheries): e.g. manufacturing, electronics, vehicles, solar panels, construction, food processing, textiles industry, The Tertiary sector provides services: the MRC would be part of the tertiary sector as are for example banking, advertising, legal services, transport (navigation), architecture and engineering design and restaurants.

Vietnam's fisheries would be substantial with $1.7 billion in net present value for the 2020 scenario and $3.2 billion for the 2040 scenario. Effective mitigation could involve sustainable expansion of fish farms and substantial investments in secondary and tertiary sectors to reduce community vulnerabilities.

Future growth potential

Future growth potential depends on the availability of input factors. A key input factor is natural capital, in particular if growth in secondary and tertiary sectors (e.g. tourism) is targeted. The analysis of this perspective indicates that agricultural expansion and hydropower would cause a substantial loss of natural capital. The 2020 development plans would cause a decline of natural capital of $55 billion in net present value for a 24-year time period. Two thirds of this loss would be caused by deforestation to expand agricultural areas (actual loss until 2015). The loss of fish across the lower Mekong basin would establish one third of natural capital losses. The 2040 development plans would reverse the trend in loss of natural capital due to reforestation plans, which would increase natural capital by approximately $30 billion in net present value despite a large loss in fish. Thailand would suffer the largest absolute loss in fish related to natural capital (2020 scenario: $21 billion; 2040 scenario: $27 billion), followed by Cambodia (2020 scenario: $16 billion; 2040 scenario: $21 billion).

The loss in natural capital (-$33 billion) equals about one third of the combined effect of 2020 development plans across the four target sectors (+$148 billion). For 2040 plans the combined change in the four target sectors (+$302 billion) would be supported by the increase of natural capital ($30 billion). However, the combination of substantial agricultural expansion and extensive reforestation is highly challenging, in particular as urbanisation rates continue to rise. This challenge could be met by realising only the most beneficial agricultural expansion projects and focussing on efficiency gains in existing areas. Considering the relevance of fish losses for natural capital it is advisable to complete a project-by-project impact assessment of planned hydropower projects and realising only the most beneficial projects with effective mitigation measures would make substantial sustainability improvements.

7. Thematic Sector Development

7.1. Hydropower

Hydropower emerges as the sector with the highest growth in the LMB with a share of 43-49% of the combined sector growth potential. However, it is also linked to controversial trade-offs: about 26% of the hydropower gains would be lost in the fisheries sector under the 2020 scenario and an additional 15% in the 2040 scenario. The sub-scenario assessment with all planned dams to be built, suggests that mitigation measures could reduce the fisheries loss by 11%.

The mainstream schemes do not require active reservoir storage. Analysis of peaking options indicates that storage provides very limited commercial benefit. The reservoirs on the mainstream schemes, as currently envisaged, are created to provide generating head, not storage. The creation of reservoirs obstructs downstream fish migration, traps sediment, affects water quality and increases environmental footprint. Reduction of reservoir size would, therefore, be beneficial.

The LMB would lose 59.8% of the economic benefits in the power generation sector if mainstream dams would not be realized, including the ones that are already under construction. The non-realization of these dams would cause the hydropower sector income to drop by 42.1% in Lao PDR, 75.6% in Thailand, 37.8% in Cambodia, and 47.6% in Vietnam.

The main existing challenge is to attain an effective dialogue with the other countries, including China, who share the Mekong River basin so that transboundary impacts of hydropower development in the basin are minimized. The Governments of the Mekong Member Countries should elaborate an appropriate sustainable hydropower development strategy as foreshadowed in the Strategic Plan 2016-2020 to overcome these challenges and achieve sustainable development for the whole LMB.

The Member Country Governments may strengthen the implementation of such a strategy through governmental prioritization, inter-ministerial coordination, and monitoring and evaluation involving the private sector, civil society and development partners.

The MRC governments might want to consider elaboration of plausible, implementable and effective transboundary actions, e.g. benefit-sharing mechanisms, joint projects, or other mechanisms to manage trade-offs between sectors and countries in the LMB.

7.2. Navigation

In upstream reservoirs, created by hydropower dams, sufficient water depth over the whole year will be created to allow bigger ships to sail in the related stretches of the river. Moreover, studies predict that dams with reservoirs in the Lancang cascade and LMB tributaries will reduce the magnitude of wet season flows and increase the magnitude of dry season flows substantially.

Without the hydropower dam reservoirs, the cost-benefit ratio of necessary river design works (dredging, rapid and reef removal) to allow bigger ships to sail during the whole year would certainly be negative.

The navigation development plan to 2020 and 2040 for the Mekong basin envisages to enable 500-ton vessels travel throughout the year from the Green Triangle to Kratie (requiring a bypass canal with three locks at the Khone Falls). The river stretches between Kratie and Kampong Cham should be navigable by 2,000-ton ships during the whole year, the stretch between Kampong Cham and Phnom Penh by 3,000-ton ships, the stretch between Phnom Penh and Can Tho by 7,000-ton ships and the stretch from Can Tho to the sea by 10,000-ton ships throughout the year. Finally, the Tonle Sap river and lake between Phnom Penh and Chhong Kneas (Siem Reap) should be navigable for boats of 500 tons over the whole year.

To achieve this goal, investments for a total amount of $560 million (23.4 million US$ per year) are estimated, excluding a bypass canal at the Khone Falls with an estimated cost of $525 million. With these investments, waterborne cargo transport in the river would increase 7.3-fold from 22.9 million tons in 2017 to 167.9 million tons in 2040. Similarly, waterborne passenger transport would increase from 70.2 million (of whom 0.8 million tourists) in 2017 to 318.9 million (of whom 6.1 million tourists) in 2040. The net present economic value of the navigation sector would increase from $15.1 billion in 2017 to $76.3 billion in 2040. In 2040, ca $121.6 million income could be generated from river tourism in Mekong countries, compared to $16.3 million today. Employment in the navigation sector would rise from an estimated 750,000 people today to 1,875 million people in 2040.

In the absence of sector investments, inland waterway transport growth in the LMB would be very low and some stretches of the river would see no growth at all or even a decline due to the competition with faster (but more expensive and polluting) road transport. The sustainability of the navigation development in the 2040 scenario depends on the implementation and enforcement of safety measures in the fleet, at ports and on the waterways, and on rigorous environmental and social safeguarding for all development projects.

7.3. Irrigation

Irrigation development increases agricultural production and reduces food security risks in the LMB. However, it will be of paramount importance to improve irrigation efficiency. Irrigation development in Cambodia will contribute to increasing rice production. However, there is low resilience to drought. In particular, the Council Study results highlight a significant decline of soil water in the Tonle Sap watershed and a large decline in irrigated agricultural yields for the dry climate scenario. It is necessary to improve efficiency of storage and delivery and at the farm level, which may involve increasing reservoir storage. Irrigation development in Cambodia may cause increased salinity intrusion, lower water levels and affect water quality in the Vietnam Delta. Future irrigation planning would be improved if the water balance, including irrigation return flows, between Cambodia and Vietnam, and future risks, were jointly examined.

As the available amount of fresh water is limited, it is necessary to efficiently utilize irrigation water by enlarging water storage capacity, rehabilitating irrigation facilities (e.g. dams, headworks, and canals), and improving operation and maintenance of existing facilities.

Hydropower development could reduce the risk of floods and droughts and contribute to enhanced agricultural productivity. Lao PDR would benefit from improved irrigation efficiency to ensure more sustainable water use of the Mekong River.

Irrigation efficiency and sustainability in Thailand need to be improved for sustainable agricultural production by modernizing its irrigation facilities and capacity building for operation and maintenance. The study recommends increasing water storage capacity, reducing water delivery loss, strengthening water flow monitoring in canals, and promotion of participatory irrigation management. Large irrigation development in Thailand may impact on the LMB during the dry season due to reduced downstream water. This impact would need to be analyzed. The Development Scenarios highlight that irrigation sustainability decreases in a dry season. Preventive drought measures need to be considered.

The sustainability of irrigation in Vietnam is higher for all months than in the other Member Countries. However, salinity intrusion is expected to expand due to the decrease in water flow of Mekong River and higher sea levels. Transboundary cooperation would be necessary to mitigate the reduced flows that facilitate salinity intrusion.

Discharge from hydropower increases the flow of the Mekong River during the dry season. However, further irrigation development has the potential to further reduce instream flows. Sustainable irrigation requires the reduction of water delivery loss and the promotion of efficient water use.

7.4. Agriculture and Land use

The development of hydropower in the mainstream has both positive and negative impacts. It is partly beneficial to agriculture as it increases the dry season flows and decreases flood peaks that can reduce the flooded area in the Mekong Delta. Increased and accessible electricity supply has the potential of benefiting the agricultural sector by reducing electricity costs for operating agricultural machinery such as sprinklers or water pumps. In contrast, the 2020 and 2040 scenarios indicate that decreases in sediment and nutrient inputs can reduce soil fertility and reduce rice and fish production. Mitigation measures for fish and sediment management should be considered during the design phase of dam construction and during operation to reduce the impacts on downstream countries.

The Member Countries can mitigate food security risks and reduce labor demand for agriculture by encouraging investments in modern agricultural technologies, including agricultural machinery, new high yielding crop varieties, more efficient irrigation systems, and precision farming. The LMB countries would also benefit from investing in the sustainable development of agro-ecotourism, agro-forestry, and organic farming, with the potential to access expanding demand for “clean” food and to increase farm income.

The drier climate change scenario results highlight reduced rice production in Cambodia, Lao PDR, and Thailand. Increased climate variability and sea level rise would reduce rice production in Vietnam. Member Countries would benefit from climate change adaptation measures in the agricultural sector, e.g. increased water storage capacity, adapted crops or crop calendars, improved soil management and seed varieties with higher flood, drought, and salt resistance.

Modelling results suggest that the expansion of agricultural area, focusing on rainfed rice, and a decrease in forest area have a small impact on flow (changes of up to 0.5%) for the entire assessment area along the Mekong River. However, expansion could cause higher sediment loads and increase the level of peak flows because of lower soil absorption of water. Existing long-term monocultures are degrading soils in all countries.

Relevant for food security is the expansion of agricultural areas in combination with increasing irrigation capacity. This would increase rice production and reduce production variability. Across all development scenarios, aggregate food production is sufficient to meet the current and future food security needs of each Member Country, dependent on purchasing capacity of poor households and efficient distribution networks.

Climate change is likely to cause lower rice production due to non-optimal temperatures, higher evaporation and decreased precipitation. Production declines are predicted for Cambodia, Lao PDR, and Thailand in the climate change scenario that assumes drier conditions. Vietnam is likely to experience stronger climate change impacts, increasing flood areas in both the Delta freshwater and saline zones due to the sea level rise. Combined these would further reduce agriculture production in Vietnam’s Mekong Delta.

The effect of herbicides and pesticides on Mekong aquatic ecosystems have not yet been analyzed. Irrigated rice culture tends to lead to increased needs for pesticides and herbicides.

The comparison of the 2007 baseline and the 2020 and 2040 development scenarios shows that hydropower development provides positive and negative impacts. It can reduce extreme flood events as the reservoirs store peak flood water, reducing rice production losses. Indirectly, reduced electricity prices (assuming rural grid expansion) are relevant for agricultural enterprises.

The increase of agricultural area for rice and cash crops (e.g. maize and cassava) in Cambodia and Lao PDR would support food security of their growing populations as well as enhance exports. The improvement comes at the cost of losing forests and wetlands, accelerated soil erosion and reductions in natural capital. This is critical because all Member Countries have committed to sustainable development and to promote the conservation and restoration of forests and natural land.

An important concern is the competition (from the secondary and service sectors) for labour necessary for agricultural expansion. Potential mitigation includes investing in modern agricultural machinery, developing higher yielding crop varieties, food processing, improved irrigation efficiency, and precision farming.

7.5. Domestic and Industrial water use

Rapid industrialization and urbanization tends to result in the pollution of water bodies adjacent to development areas, where untreated wastewater is discharged into natural water systems or leached into soils. Environmentally sound technologies to treat urban and industrial wastewater are available and need to be considered. The total domestic water consumption of the LMB is approximately 2.02 billion m^3 in 2007, 2.74 billion m^3 in 2020, and 3.82 billion m^3 in 2040. High population growth increases the volume of domestic wastewater as well as the discharge of nitrogen, phosphorus and other pollutants into the river.

The concentrations of total nitrogen do not exceed the value adopted by the International Finance Corporation (IFC) as permissible (treated) from industrial facilities (10 mg/l). However, the levels do exceed the MRC threshold of 5 mg/l. Total nitrogen levels would be acceptable if the Mekong flow and dissolved oxygen levels remain at present levels. The concentrations of total phosphorus exceed the IFC threshold for discharge from industrial facilities of 2 mg/l. The current MRC Water Quality Guidelines do not include thresholds for total phosphorus. To protect human health and aquatic life, improvements and monitoring of domestic and industrial wastewater treatment to reduce nutrient levels will be necessary.

There may be transboundary water quality issues associated with the two parameters (nitrogen and phosphorus) between Vientiane and Nakhon Phanom which is located downstream. The study detected no significant transboundary impacts between Lao PDR and Cambodia, or between Cambodia and Vietnam related to water quality in terms of total nitrogen and phosphorus.

The volumes of domestic wastewater discharging from Vientiane and Phnom Penh are higher than the volumes released from other cities along the Mekong mainstream. Peak wastewater releases correlate with total nitrogen loads. Increased volumes of untreated wastewater from domestic and industrial sectors will exacerbate ecological impacts, including on fish biomass, biodiversity, and other aquatic organisms.

The concentrations of total nitrogen in most cities along the Mekong mainstream and tributaries range from 7.41 to 13.33 mg/l and partly exceed the IFC threshold treated value of 10 mg/l of total nitrogen as discharged from domestic and industrial facilities. These concentrations also exceed the 5 mg/l required by the MRC Water Quality Guidelines to protect human health.

Similarly, concentrations of total phosphorus from all cities along the Mekong mainstream and tributaries ranged from 10.37 mg/l to 18.67 mg/l, exceeding the IFC limit of 2 mg/l. The effects of these concentrations are amplified where low flow occurs, in particular during the dry season.

Enhanced awareness and strong political will could mitigate threats to transboundary water quality of the Mekong River resulting from industrial development.

7.6. Flood Protection

Effect of Mainstream Dams

The storage within mainstream dams is small compared to the high flood volumes and thus the marginal impact of a mainstream dam on flooding downstream is very small. However, the cumulative impact can be significant. The possible local impacts upstream in the backwater areas need to be considered on a case-by-case basis. A more significant effect may occur due to releases of flow at critical times; this has not been assessed but could be studied further in the available models. The impact of

mainstream dams on sediment regime and hence potential bank erosion downstream is more significant. Ultimately, the expected reductions in sediment load due to upper basin and tributaries dams will necessitate significant expenditure on bank protection in Cambodia and the Vietnam Delta in particular.

Development on the Floodplain

Loss of floodplain has been shown to raise peak flood levels and many urban and rural assets are already exposed to the comparatively high risk of increasing damage. Combined with climate change, it is timely that the requirements for flood defenses of certain areas are considered strategically and steps to manage the essential functioning of the floodplain are set into land use planning and development control. The rising sea level will impact flooding in the Vietnam Delta. The study considers only a short horizon to 2040 and without doubt, sea level rise and climate change will continue to build progressively higher impacts after this time.

Flood damage will increase substantially as countries develop and more assets are at risk; flood protection development can reduce this impact except for extreme flood events

Future flood damage will rise rapidly due to climate change and development putting more assets at risk. This can be offset substantially through sensitive flood protection works in the areas of most risk. At present, much of the impacted corridor is dominated by the potential risk of agricultural losses due to flooding. These risks will rise in time with increased agricultural productivity but with developing economies there will be a larger increase in assets at risk especially in urban areas. Increased risk and thus potential losses may be a factor 5 to 10 higher than current day. Mapping and prioritization of a reduction in flood risk are needed. Measures and policies for urban areas and crops, in particular, are needed as is clear planning guidance for flood risk when developing infrastructure.

Transboundary erosion issues will increase rapidly with completion of dams in the LMB

An erosion problem along the whole of the lower Mekong is steadily developing and will accelerate quickly once the planned dams are put in place. It was estimated that there is around 3,450 km of the river bank at risk along the mainstream channels, nearly 1,400 km within the Mekong Delta. It can be envisaged that bank protection works will be needed along the alluvial reaches of the main river. Further modelling work is needed to define how quickly the erosion will occur, but it is likely to be progressive as dams are developed and be realized within decades after completion. As the banks are developed the erosion will move downstream more quickly due to the ‘hungry river’ effect of rapid bed erosion, causing degradation then erosion of banks and lateral instability. With major infrastructure along the river, as well as areas of the international border between Lao PDR and Thailand, there is already a significant length of bank protective work in place on the Thai side of the river and increasingly on the Lao side, as well as local protection work in Cambodia and Vietnam. The substantial investment to contain the problem is estimated to be up to $6 billion.

Biological Resources and Flood

The positive impacts of inundation of the floodplain must be incorporated into cost-benefit assessments of flood defense and bank protection development, as well as flood damage. As areas are cut off from the river by gates and flood protection banks, a barrier is formed for organisms and floodwater and sediment/nutrients and a deterioration is predicted. Floodplain developments thus need to allow maximum connectivity, especially at the trans-border areas.