MEKONG RIVER COMMISSION

THE COUNCIL STUDY

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

SUMMARY OF COUNCIL STUDY REPORTS AND CONCLUSION

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Disclaimer

The Council Study reports are considered final drafts prepared by specialists of the Mekong River Commission and international experts through an extensive process of consultation with representatives of the Member Countries and interested stakeholders. The contents or findings of the reports are not necessarily the views of the MRC Member Countries but serve as knowledge base and reference in the work of the MRC and its Member Countries in their ongoing technical and policy dialogues to ensure sustainable development of the Mekong River Basin.

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Contents

1. Significance and Scope of the Study 1

2. Overall Costs and Benefits of Development 2

3. Hydrology and Environment 3

4. Climate Change 5

5. Socio-economics 6

6. Macro-economics 7

7. Specific Sectors 10

7.1. Hydropower 10

7.2. Navigation 10

7.3. Irrigation 11

7.4. Agricultural Land Use 12

7.5. Water Use 13

7.6. Flood Protection 14

8. Conclusion 16

1. Significance and Scope of the Study

In November 2011, Prime Ministers of the Member Countries of the Mekong River Commission (MRC) agreed to conduct a study on the sustainable management and development of the Mekong River. The study was commissioned the following month by the MRC Council – comprising Water and Environment ministers from Cambodia, Lao PDR, Thailand and Viet Nam – and undertaken by the MRC Secretariat 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-resource developments;
- integrate the results into the MRC knowledge base to enhance basin development planning and;
- promote capacity within, and ensure technology transfer to, the National Mekong Committees.

In what came to be known as the Council Study, researchers highlighted positive and negative impacts of planned water-resource projects in the Lower Mekong Basin (LMB) across environmental, social and economic indicators chosen by Member Countries. Developments included existing and planned mainstream and tributary hydropower projects, expanded agriculture and irrigation schemes, domestic and industrial water-use projects, waterway navigation and flood protection. The framework allowed for systematic evaluation of positive and negative impacts associated with planned water developments, assisting Member Countries in their deliberations and policy decisions about the future of the LMB. The study involved:

- six teams in six sectors, namely hydropower, navigation, irrigation, agricultural land use, water use and flood protection;
- five cross-cutting discipline teams covering climate change, modelling, biological resources, socio-economics and macro-economics; and
- a cumulative impact assessment team.

The first step was to integrate biogeophysical characteristics of the LMB through qualitative and quantitative models, which were then used to develop water-resource development scenarios. Modelling outputs were used to assess environmental, social and economic indicators. These, in turn, were used for social and economic analyses in the six sectors related to water resources.

The strength and importance of the framework was that it provided a coherent and robust scientific basis to assess outcomes of water-resource development, combined with accessible and practical methods along with a knowledge base to support further studies, deliberations and processes. The framework is flexible, transparent and replicable to accommodate improved data management and refinements of tools.

The Council Study considered three main water-resource development scenarios over a 24-year horizon: (i) a 2007 "early development" scenario, (ii) a 2020 "definite future" scenario and (iii) a 2040 "planned development" scenario. These main scenarios aggregated combinations of water-resource developments to allow cumulative effects on the environment, social issues and economies to be assessed. The 2007 scenario represents baseline conditions and is the one against which the others were compared. The 2020 scenario includes all existing, under-construction, and firmly-committed developments in the six sectors (including the Xayaburi and Don Sahong hydropower projects in Lao PDR). The

2040 scenario includes 2020 developments plus developments in the six sectors planned for implementation by 2040.

Assessing cumulative effects of a combination of investments tends to mask the impacts of individual developments or those in specific sectors. The study therefore developed sub-scenarios to isolate increases or decreases in the sizes of the six sectors under the scenario for 2040. It also developed three sub-scenarios to isolate the impacts of climate change.

2. Overall Costs and Benefits of Development

The Cumulative Impact Assessment summarised costs and benefits of water-resource developments based on resilience and vulnerability, sustainability and cross-sector and trans-boundary trade-offs. The key conclusions were:

- Development plans are likely to combine a group of highly beneficial and a group of non-beneficial hydropower and agricultural projects.
- Hydropower development increases energy security and contributes to economic growth but results in substantial losses in ecosystem services, many of which are trans-boundary.
- Developments under the 2020 and 2040 scenarios are likely to reduce resilience and increase vulnerability of rural communities, 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 rise.
- Weather variability, particularly that associated with a drier climate, is likely to exacerbate impacts on poor people. Trade-offs between hydropower and fisheries are substantial and require project-by-project assessments.
- Developments will result in substantial sustainability losses, many of which could be reduced or avoided by adjusting investment in hydropower and agriculture.
- In the absence of successful cross-sector benefit sharing, the sustainability index based on the UN Sustainable Development Goals will decline if 2020 and 2040 plans are implemented. The 2040 development scenario would result in declined sustainability (minus 31 percent for Viet Nam, minus 29 percent for Cambodia, minus 27 percent for Lao PDR and minus 17 percent for Thailand). Positive and negative impacts of development will be unevenly distributed, with most benefits accruing to power companies at the expense of fishing households.
- Effective benefit sharing needs to be a cross-sector mechanism and not a compensation scheme between countries as beneficiaries (such as power companies) and disadvantaged groups (such as fishing households) are located in all four countries.
- Levies are a possible burden-sharing mechanism at about 8.6 percent of annual earnings for tributary dam operators and 18.9 percent for mainstream dam operators to avoid unfair distribution.

A key recommendation from the Cumulative Impact Assessment was to conduct project-by-project assessments as the scenarios combined both highly positive and negative hydropower and agriculture projects. Cumulative impacts need to be adequately considered in this process.

The study strongly recommended that current and future energy planning included consideration of other renewable power-generation technologies. These are increasingly being viewed as less environmentally damaging alternatives to hydropower.

3. Hydrology and Environment

The hydrological, hydraulic, water quality and ecological implications of the water-resource developments were modelled with the MRC Decision Support Framework (DSF), which was updated for the Council Study. This was augmented by an Australian water-modelling platform known as SOURCE, tools developed by the MRC's former Water Utilisation Programme funded by Finland and the Biological Resources Team's decision support system. These tools were used to model:

- Rainfall-runoff in the LMB;
- Hydrological regimes on a daily basis;
- Sediment and nutrient supply;
- Hydraulic conditions in the river such as area, depth, velocity and shear stress;
- Hydraulic conditions on the riparian floodplains in Lao PDR and Cambodia, the Tonle Sap Lake and the Mekong Delta in Viet Nam;
- Hydraulic conditions along the coast;
- Erosion and habitat quality in rivers; and
- Extent/abundance of vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals in the rivers, floodplains, the Tonle Sap Lake and the Delta in Viet Nam.

Modelling work for the Council Study was more extensive and integrated than anything done previously for the LMB. As such, it represents a significant step towards systematic and systemic assessments of the physical and biological implications of water-resource developments in the basin. The study highlighted a need for further developing and integrating models and tools, filling data gaps and building capacity for new applications.

Hydrological modelling for the main scenarios indicated that the impacts on total flow volumes would be subtle, but that predicted changes in seasonal flow patterns would be considerable, mainly because of attenuation by reservoirs. Developments under both scenarios result in higher dry-season flows and lower wet-season flows. At the same time, the reversal of the Tonle Sap River is likely to be delayed. While a reduction in the wet-season flood pulse is positive for flood damage, hydraulic modelling showed that it would seriously limit the duration and extent of the inundation of floodplain habitats, particularly on the Xe Bang Fai floodplains in Lao PDR, the floodplains and the Tonle Sap Lake in Cambodia and the Mekong Delta in Viet Nam.

Sediment and nutrient modelling forecast a substantial loss of sediments and nutrients moving through the system, mainly as a result of sediment being trapped in impoundments. Under the 2040 scenario, only three percent 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.

Ecosystem modelling forecast:

- Trapping of bed and suspended sediments in tributary and mainstream dams will increase bed and bank erosion downstream and reduce deposits of nutrient-rich sediment on the floodplains.
- Under the scenario for 2040 and the 2040 scenario with climate change, reservoirs associated with mainstream dams will convert much of the mainstream Mekong from Chiang Saen in Thailand to Kratie in Cambodia (excluding the large stretch from Vientiane to Pakse in Lao PDR that is not impounded) into a deeper, lake-like habitat that is unsuitable for many of the species that inhabit the river but beneficial for others such as bivalves, frogs and snails.
- Tributary and particularly mainstream dams will disrupt migration essential for the occurrence of 30-40 percent of Mekong fish species and 30-40 percent of the catch.
- The 2040 developments will seriously reduce indigenous riparian and wetland vegetation, mostly through inundation. They will change the composition of algal and invertebrate communities that form the base of the aquatic food chain, affecting viability for a wide range of animals and plants. The developments will also change the composition and reduce the biomass of fish assemblages, reducing white fish and promoting invasion by non-native species.
- Fisheries production is expected to decline substantially upstream because of the hydropower dams and their impacts on migration, habitats and primary production. The reduction is 35-40 percent under the 2020 scenario and 40-80 percent under the 2040 scenario. Downstream from Kratie, the Tonle Sap annual average fish production is expected to decrease from 350,000 tonnes to 260,000 tonnes by 2020 and 200,000 tonnes by 2040. Annual average floodplain production in Cambodia is expected to fall from 280,000 tonnes to 170,000 tonnes by 2020 and 80,000 tonnes by 2040 (taking into account impacts upstream from Kratie only). Annual fish production from the coastal Mekong plume is expected to drop from 240,000 tonnes to 60,000 tonnes by 2020 and 10,000 tonnes by 2040 (taking into account the Mekong nutrient load contribution only). The Biological Resources Team estimated the impact on Delta fish production to be less pronounced, with nutrient reductions partly compensated by locally sustained and often substantial nutrient sources (from urban and agriculture run-off, for example). Fish biomass in the Mekong Delta in Viet Nam is forecast to fall 30 percent by 2040.

These changes are likely to extend across the basin but are expected to be mainly felt in upper reaches. The Tonle Sap Lake is partly 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, however, be affected by the reduction in sediments supplied by the Mekong and the blocking of migration by white fish. Similarly, the Mekong Delta in Viet Nam would be cushioned from future changes as it is already highly modified and controlled. Higher flows in the dry season could aid fish recruitment. Changes affecting the Mekong Delta include alterations in sediment supply as well as composition and dynamics of fish populations.

The evaluation of the sub-scenarios showed that:

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

- Incremental hydrological, hydraulic and sediment-related impacts associated with agricultural land use, irrigation and floodplain infrastructure development are masked by much greater impacts associated with developments in other sectors under the 2040 climate change scenario.
- Connectivity-related impacts of mainstream hydropower dams – such as trapping of sediment, disruption of migration paths and alteration of flow regimes – are substantial and far-reaching, overshadowing those of all other planned water-resource developments in the LMB.

4. Climate Change

Three climate sub-scenarios were tested, each of which has increased ambient temperatures relative to the 2007 baseline. The three sub-scenarios covered the possible range of likely change, assuming a medium level of greenhouse gas emissions. The expected sea-level rise was also included and was similar for each sub-scenario. Changes in average 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.

Various social impacts were apparent, including the number of people affected by flood or drought. The indicator that best summarises social impacts is food security, which takes into account the differing response of crops and fisheries to changes in the river. Food surpluses approximate the capacity to manage and adapt to acute food shortages. Increased surpluses correspond with greater capacity. Impacts from climate change are generally negative with those on fish in the Tonle Sap Lake under the dry scenario being the most harmful. Crop modelling assumed a positive impact from increased atmospheric carbon dioxide. However, translation to field conditions is uncertain. In general, food sufficiency is adequate in average years but any significant reduction with climate change effects could cause significant problems for the poorest households in critically dry years. An additional strategy to alleviate this will be needed.

Maximising agricultural production is not necessarily the best cross-sectoral strategy. In all climate change scenarios, higher GDP can be generated if labour is used more effectively in other industries.

Knowledge gaps remain. For example, the combined effect of sediment being trapped 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 that will increase bank erosion and land loss. Sea-level rise combined with sediment reductions will affect coastal flooding – including reduced protection of coastal embankments by natural defences such as mangrove forests.

Even to 2040 (a modest planning horizon for climate change) significant impacts from climate change are likely. Some are due to the trans-boundary impacts of water-resource

development coupled with the changing climate. The cumulative impacts of this change need further consideration and quantification.

5. Socio-economics

The socio-economic part of the Council Study addressed food, water, health, energy, income security, employment and gender equality. Substantial changes, both positive and negative, are anticipated for the 2040 scenario. The changes are not uniformly distributed across a corridor 15 km either side of the Mekong River and they affect Member Countries unevenly, in different ways and at different times.

The corridor has enough rice and fish production to sustain 100 percent food security. However, maintaining this will require effective and willing distribution networks and cooperation among Member Countries to avoid significant increases in undernourishment in parts of the corridor.

Managing fish declines is central to improving food security. Throughout the corridor, a reduction of 3,800 tonnes of fish corresponds to an increase of 1,000 undernourished households under the 2007 scenario. Sensitivity to reductions in fish availability increases in the 2040 scenario where 3,300 tonnes of fish are equivalent to an additional 1,000 undernourished households. An increase of 12,500 tonnes of rice reduces the number of undernourished households by 1,000.

Fish catches decline by 43 percent under the scenario for 2040 and 40 percent under the 2040 with climate change scenario. Rice production increases by 16 percent under the first scenario and 13 percent under the second. The number of undernourished people in Cambodia and Lao PDR increases under both scenarios but remains relatively stable in Thailand and the Mekong Delta in Viet Nam.

Fish surpluses decline to almost zero in Lao PDR and Cambodian zones away from the Tonle Sap but remain positive in Thailand and Viet Nam under the 2040 scenarios. Smaller surpluses reduce resilience and capacity to manage acute food shortfalls. Increased prices are likely to affect poor households. It is unclear whether the current pace of wage and income increases is sufficient to compensate for rising prices.

Increased fish prices are an incentive to convert land to aquaculture. Widespread use of antibiotics, deterioration of water quality and possible 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 to 11 percent decrease in rice production due to extreme flood affects 4.5 to 5.0 percent of the corridor population. An 11 percent decrease in rice production due to extreme drought affects 3.1 to 3.3 percent. In extreme floods and drought (the 1995-96 El Niño and 2000-01 floods, for example), Cambodian riparian communities seem to be the most affected. Years where drought or floods coincide with large fish declines are forecast, potentially leading to acute undernourishment. The effects are likely to be more severe in Cambodia under the 2040 scenario with climate change, requiring careful trans-boundary planning.

The 2007 baseline represents the lowest poverty levels for all zones except those around the Songkhram River Basin in Thailand, the Tonle Sap in Cambodia and saline

areas of the Mekong Delta in Viet Nam. Under the 2040 scenario, poverty increases were estimated at 1.7 to 3.7 percent in Lao PDR and 0.01 to 2.0 percent in Cambodia. Increases in Thailand and Viet Nam were estimated at less than 1 percent.

The value of fish catches across the corridor will decline by $1.57 billion under the 2040 scenario, offset by an increase in rice production worth $0.95 billion over the same period. The biggest decline in fish values is between 2007 and 2020, suggesting a need for both individual and cumulative project assessments.

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

Strategies to expand agriculture and manufacturing raise the prospect of conflicting labour demands under the 2020 and 2040 scenarios as well as the potential for abandoned or underused agricultural infrastructure. Developing a dynamic modelling approach with key influencing factors – including migration patterns within and outside the corridor – is recommended as a central feature of trans-boundary planning.

National aspirations for gender equality are generally not reflected in the study but indicate a need for sustained efforts to correct imbalances. 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.

Rural electrification (energy security) and access to safe water and sanitation are expected to continue along historical trends. These are independent of investment.

6. Macro-economics

The development scenarios for 2020 and 2040 are likely to combine positive and negative outcomes. At the narrow sectoral level, much of the hydropower and agricultural expansion seems very positive. But hydropower is likely to trigger substantial losses in the fisheries sector. Labour-intensive agriculture is likely to receive too much investment which will reduce growth. Some hydropower and a few agricultural projects appear highly beneficial. This requires project-by-project impact assessments. Substantial risks are linked to climate change as a drier climate would trigger substantial losses. Cross-sector trade-offs include large losses in natural capital. Small and more focused agricultural extension combined with improved productivity in existing areas would be more sustainable. Similarly, important growth in the manufacturing and service sectors could be achieved without large cross-sector losses if certain hydropower projects could be replaced by more sustainable forms of power generation.

Cambodia shows substantial growth potential and could increase GDP from around $21 billion in 2017 to more than $60 billion in 2040. Under the 2040 plans for developing water resources, however, growth is likely to be lower with GDP of around $38.5 billion in 2040. This slowdown largely reflects excessive investment in labour-intensive agriculture and declines in fisheries caused by hydropower. Cambodia is likely to experience the highest trade-off – for every dollar gained from hydropower, about 62 cents would be lost in

fisheries. Drier-than-expected climate change would affect GDP substantially and cause a further decline in fisheries of nearly 15 percent. The scenario for 2020 with selected, highly beneficial agricultural projects is likely to have the greatest macro-economic benefits.

Lao PDR shows immense growth potential and could boost GDP from about $17 billion in 2017 to more than $42 billion in 2040. However, negative trade-offs arising from water-related developments are likely to slow growth, with GDP of about $30 billion in 2040. Some investments are likely to fuel growth while others would counter the trajectory. Many hydropower projects are likely to be very beneficial to the economy. However, about 14 percent of the benefits would be lost in fisheries, triggering major food-security issues. Seventy to eighty percent of hydropower benefits would go to investors from Thailand, China, Malaysia or South Korea. Drier-than-expected climate change would reduce hydropower benefits by as much as $2.1 billion in net present value. Agricultural expansion is likely to be too ambitious as labour demand at current productivity would slow growth in manufacturing and services.

Thailand has the potential to increase GDP of its Mekong Basin areas from about $50 billion in 2017 to about $90 billion in 2040. Investment in water resources under the 2040 scenario, however, is likely to lead to lower GDP of $71 billion, mainly due to lower fish catches. The benefits for Thailand or Thai companies from mainstream hydropower in Lao PDR are substantial – as much as $82 billion in net present value for the 24-year time period. But these would be offset by income losses for small households along the Mekong of almost $7 billion in net present value as fish stocks decline. Investment in manufacturing and services is seen as the most critical pillar for successful economic development.

Viet Nam could double the GDP from the Mekong Delta from about $50 billion in 2017 to more than $100 billion in 2040. Proposed water development plans for 2040 are, however, likely to result in lower GDP of $81 billion due to several negative factors. Strategies to prioritise investment in food processing instead of food production and to stimulate additional growth in manufacturing and services (such as navigation and education) are very promising. But strong economic growth in the past has been inflationary. There is a risk that this will be repeated as fish and other food prices are likely to rise sharply if hydropower investments are made under the 2040 scenario. The trade-offs that hydropower is likely to cause for fisheries would be substantial at $1.7 billion in net present value under the 2020 scenario and $3.2 billion under the 2040 scenario. Effective mitigation could involve sustainable expansion of aquaculture and substantial investments in manufacturing and services to reduce vulnerabilities.

Future growth potential depends on the availability of input factors, notably natural capital – especially if growth in manufacturing and services such as tourism is targeted. Agricultural and hydropower development would erode natural capital. The 2020 development plans cause a loss in natural capital of $51 billion in net present value of which two-thirds would be caused by deforestation to expand agricultural areas (actual loss until 2015). The remaining third would be from fisheries losses. The 2040 development plans would reverse the trend due to reforestation plans, which would increase natural capital by about $53 billion in net present value despite large losses in fisheries. Thailand would suffer the largest fisheries losses related to natural capital ($6.4 billion under the 2020 scenario and $8.2 billion under the 2040 scenario) followed by Cambodia ($4.7 billion under the 2020 scenario and $6.3 billion under the 2040 scenario).

The loss in natural capital ($51 billion) equals about one-third of the combined effect of 2020 development plans across four target sectors ($148 billion). For 2040 plans, the combined effect ($302 billion) would be supported by increases in natural capital ($53 billion). However, the combination of substantial agricultural expansion and extensive reforestation is highly challenging, particularly as urbanisation continues to rise. This could be addressed 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 project-by-project impact assessments of hydropower projects. Realising only the most beneficial projects with effective mitigation would significantly improve sustainability.

7. Specific Sectors

7.1. Hydropower

Hydropower emerges as the water-related sector with a share of up to almost half of the growth potential of the four sectors (hydropower, fisheries, agriculture and navigation) combined. However, it is also linked to controversial trade-offs – about 26 percent of the hydropower gains would be lost in the fisheries sector under the 2020 scenario and 15 percent under the scenario for 2040. Under this scenario, mitigation could reduce fish losses by an estimated 11 percent.

Mainstream schemes do not require active reservoir storage. Analysis of peaking options indicates that storage provides very limited commercial benefit. Reservoirs envisaged for mainstream schemes are to generate head not storage. Reservoirs obstruct fish migration, trap sediment, affect water quality and increase environmental footprints. Reductions in size would, therefore, be beneficial.

The LMB would lose about 60.3 percent of economic benefits in the hydropower sector if mainstream dam projects were not realised including those already under construction. Non-realisation of these dams would reduce hydropower incomes by 37.1 percent in Cambodia, 45.1 percent in Lao PDR, 75.8 percent in Thailand and 47.7 percent in Viet Nam.

The main challenge is to have an effective dialogue with other countries that share the Mekong Basin – including China – to minimise the trans-boundary impacts of hydropower development. Governments of Member Countries should develop an appropriate sustainable hydropower strategy as foreshadowed in the MRC Strategic Plan 2016-2020 to overcome these challenges and achieve sustainable development. The Governments may strengthen the implementation of such a strategy through prioritisation, inter-ministerial coordination, and monitoring and evaluation involving the private sector, civil society and development partners. Governments might also want to consider plausible, implementable and effective trans-boundary actions such as benefit-sharing, joint projects or other mechanisms to manage trade-offs between sectors and countries.

7.2. Navigation

In upstream reservoirs created by hydropower dams, sufficient water depth will allow bigger vessels to navigate year-round along these stretches of the river. Moreover, studies predict that dams with reservoirs in the Lancang cascade in China and LMB tributaries will reduce wet-season flows and increase dry-season flows substantially. Without the reservoirs, the cost-benefit ratio of river works – dredging, and removal of rapids and reefs – to allow bigger ships to navigate all-year round would be negative.

The Navigation Development Plan to 2020 and 2040 for the Mekong Basin envisages 500-tonne vessels travelling throughout the year between the Green Triangle (Cambodia, Lao PDR and Viet Nam) to Kratie in Cambodia, requiring a bypass canal with three locks at Khone Falls. Stretches should be navigable year-round for 2,000-tonne vessels between Kratie and Kampong Cham, 3,000-tonne vessels between Kampong Cham and Phnom Penh, 7,000-tonne vessels between Phnom Penh and Can Tho and 10,000-tonne vessels between Can Tho and the sea. The Tonle Sap river and lake between Phnom

Penh and Chhong Kneas in Siem Reap should be navigable all year round for vessels of 500 tonnes.

To achieve this goal, investments of $560 million ($23.4 million per year) are envisaged (excluding the bypass canal at the Khone Falls which is estimated to cost $525 million). With these investments, river cargo transport would increase from 22.9 million tonnes in 2017 to 167.9 million tonnes in 2040. Similarly, passenger transport would increase from 70.2 million people (including 0.8 million tourists) in 2017 to 318.9 million people (including 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 by which time an estimated $121.6 million income could be generated from tourism, up from $16.3 million today. Employment in navigation would rise from the current level of about 750,000 people to an estimated 1,875,000 people by 2040.

In the absence of investment, inland waterway transport growth would be very low. Some stretches of the river would see no growth at all or even a decline due to competition with faster road transport which is more expensive and polluting. The sustainability of navigation development under the 2040 scenario depends on the implementation and enforcement of safety measures for vessels, ports and waterways as well as rigorous environmental and social safeguarding for all development projects.

7.3. **Irrigation**

While irrigation development increases agricultural production and reduces food security risks, efficiency improvements are of paramount importance. As the amount of water is limited, it is necessary to enlarge storage capacity, rehabilitate facilities such as dams, headworks and canals, and improve operation and maintenance.

Irrigation development in Cambodia will help increase rice production. However, there is low resilience to drought. The study highlighted a significant decline of soil water in the Tonle Sap watershed and a large decline in irrigated agricultural yields under the dry climate scenario. Improving storage and delivery efficiency at the farm level may involve increasing reservoir storage.

Developing irrigation in Cambodia may increase salinity intrusion, lower water levels and reduce water quality in the Mekong Delta in Viet Nam. Future irrigation planning could be improved by jointly examining the water balance between Cambodia and Viet Nam – including irrigation return flows – and future risks.

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

Irrigation efficiency and sustainability in Thailand need to be improved by modernising facilities and capacity building for operation and maintenance. The study recommended increasing storage capacity, reducing delivery losses, strengthening flow monitoring in canals, and promoting participatory irrigation management. Large irrigation developments may affect other parts of the basin during the dry season due to reduced downstream flows. Preventive drought measures need to be considered.

The sustainability of year-round irrigation in Viet Nam is higher than in the other Member Countries. However, salinity intrusion is expected to expand due to reduced flows

from the Mekong and higher sea levels. Trans-boundary cooperation would be necessary to mitigate the reduced flows that facilitate salinity intrusion.

Discharge from hydropower increases the flow of the Mekong during the dry season. However, increased irrigation development has the potential to further reduce instream flows. Sustainable irrigation requires reduced delivery losses and more efficient water use.

7.4. Agricultural Land Use

Development of hydropower on the Mekong mainstream has both positive and negative impacts. It is partly beneficial to agriculture as it increases dry-season flows and decreases flood peaks that can reduce the flooded area in the Mekong Delta. Increased supply of accessible electricity could benefit the agricultural sector by reducing operating costs for farm machinery such as sprinklers or pumps. By contrast, 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 dams and also during operation to reduce impacts on downstream countries.

Member Countries can mitigate food security risks and reduce labour demand in the agricultural sector by encouraging investment in modern farming technologies. Competition for labour from the expanding manufacturing and service sectors is a major concern. Modern technologies include agricultural machinery, new high-yielding crop varieties, more efficient irrigation systems and precision farming. LMB countries could also benefit from investing in the sustainable development of agro-ecotourism, agro-forestry and organic farming, with the potential to access growing demand for “clean” food and increase farm incomes.

The drier climate-change scenario highlighted falls in rice production in Cambodia, Lao PDR and Thailand. Reduced production in Viet Nam would reflect both climate factors and sea-level rise. Member Countries would benefit from climate change adaptation in the agricultural sector such as increased water storage capacity, adapted crops or crop calendars, improved soil management and seed varieties with higher flood, drought and saline resistance.

Modelling suggested that the expansion of agricultural areas focusing on rain-fed rice and decreases in forest area have a small impact of 0.5 percent or less 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. Long-term monoculture is degrading soils in all countries.

Expanding agricultural areas and increasing irrigation capacity would increase rice production and reduce production variability. Across all development scenarios, aggregate food production is sufficient to meet current and future food security needs of each Member Country, although this depends on the purchasing capacity of poor households and efficient distribution networks.

Climate change is likely to reduce rice production due to non-optimal temperatures, higher evaporation and lower precipitation. Production declines are predicted for Cambodia, Lao PDR and Thailand under the climate change scenario that assumes drier conditions. Viet Nam is likely to experience stronger climate-change impacts, increasing flood areas in both the Delta freshwater and saline zones due to sea-level rise. This would further reduce agricultural production in the Delta.

The effect of herbicides and pesticides on Mekong aquatic ecosystems has not yet been analysed. Irrigated rice culture tends to increase needs for pesticides and herbicides.

Hydropower development provides positive and negative impacts. Hydropower can reduce extreme floods as reservoirs store peak waters, reducing rice production losses. Reduced electricity prices – assuming rural grid expansion – are positive for agriculture.

Expanding Cambodian and Lao agricultural for rice and cash crops – such as maize and cassava – would support food security for growing populations and increase exports. But this comes at the cost of losing forests and wetlands, accelerated soil erosion and reductions in natural capital. This is critical as Member Countries have committed to promote the conservation and restoration of forests and natural land.

7.5. Water Use

Rapid industrialisation and urbanisation tends to result in pollution next 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. Total domestic water consumption of the LMB is estimated at about 2.02 billion m^3 in 2007, about 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.

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 Mekong flows and dissolved oxygen remain at present levels. The concentrations of total phosphorus exceed the IFC threshold of 2 mg/l for discharge from industrial facilities. MRC Water Quality Guidelines do not include thresholds for total phosphorus. To protect human health and aquatic life, better monitoring of domestic and industrial wastewater treatment to reduce nutrient levels will be necessary.

Trans-boundary water quality issues related to nitrogen and phosphorus may exist between Vientiane and Nakhon Phanom in Thailand, located downstream from the Lao capital. For these two parameters, the study detected no significant trans-boundary impacts between Lao PDR and Cambodia or between Cambodia and Viet Nam.

Volumes of domestic wastewater being discharged from Vientiane and Phnom Penh are higher than those 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.

Concentrations of total nitrogen in most cities along the Mekong mainstream and tributaries range from 7.41 to 13.33 mg/l which partly exceeds the IFC threshold of 10 mg/l. Such concentrations are well above the 5 mg/l requirement under 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 flows occur, particularly in the dry season. Enhanced

awareness and strong political will could mitigate threats to trans-boundary water quality resulting from industrial development.

7.6. Flood Protection

Storage in mainstream dams is small compared to high-flood volumes so the marginal impact of such dams on flooding downstream is very small. However, the cumulative impact can be significant. Possible local impacts upstream in backwater areas need to be considered on a case-by-case basis. A more significant effect may occur due to releases of flows at critical times. This has not been assessed but could be studied in 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 tributary dams will require significant spending on bank protection in Cambodia and the Mekong Delta in Viet Nam in particular.

Many urban and rural assets in floodplain areas are already exposed to the comparatively high risk of increasing damage from peak flood levels. Combined with climate change, it is timely that requirements for flood defences in certain areas are considered strategically and that steps to manage the essential functioning of the floodplain are set into land-use planning and development control. Rising sea levels will impact flooding in the Delta in Viet Nam. The study considered only a short horizon to 2040. Without doubt, sea-level rise and climate change will have progressively greater impacts.

Flood damage will increase substantially as countries develop. Flood-protection development can reduce this impact – except in cases of extreme floods. 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 areas most at risk. At present, much of the impacted corridor is dominated by the risk of agricultural losses due to flooding. In developing economies, increases in assets at risk – especially in urban areas – are large. Potential losses may be 5 to 10 times higher than today. Mapping and prioritisation of reductions in flood risk are required. Measures and policies for urban areas and crops, in particular, are needed as is clear planning guidance for flood risk when developing infrastructure.

Trans-boundary erosion will increase rapidly as dams are completed. An erosion problem along the whole of the Lower Mekong is steadily developing and will accelerate quickly once planned dams are in place. It is estimated that there is around 3,450 km of river bank at risk along mainstream channels, of which nearly 1,400 km is in the Mekong Delta in Viet Nam. Bank-protection works will be needed along the alluvial reaches of the main river. Further modelling is needed to define how quickly the erosion will occur, but it is likely to be progressive within decades of dams being completed. As banks are developed, the erosion will move downstream more quickly due to the “hungry river” effect of rapid bed erosion, causing degradation and then erosion of banks and lateral instability. With major infrastructure along the river, as well as areas of the border between Lao PDR and Thailand, there is already a significant length of bank protective works in place on the Thai side of the river and increasingly on the Lao side, as well as local protection works in Cambodia and Viet Nam. The substantial investment to contain the problem is estimated to be up to $6 billion.

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

8. Conclusion

The Council Study has met its objectives and stands as a seminal achievement with integrated processes, tools and datasets that can be used to guide future sustainable development. The main outputs are (i) an integrated and cumulative assessment of the consequences of current and planned water-resource development projects in the LMB (ii) recommendations and key messages for MRC Member Countries to inform national and collective decision-making, (iii) enhanced capacity development for technical staff in Member Countries and (iv) development of an integrated impact assessment approach and tools for the LMB. This enhanced capacity will assist the MRC Secretariat and Member Countries in their planning, joint development, management and monitoring of the water resources of the LMB.

The study framework is being fully transferred to the four countries for independent revision, iteration of the assessments and evaluation of additional scenarios with different future development policies and assumptions. Future capacity building and knowledge transfer to Member Countries is a primary focus of post-2017 planning.