MEKONG RIVER COMMISSION

THE COUNCIL STUDY

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

Thematic Report on the Positive and Negative Impact of Irrigation on the Social, Environment, and Economic Conditions of the Lower River Basin and Policy Recommendations

(Unedited Version)

12 January 2018

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

Suggested citation:

Koponen, J., Paiboonvorachat, C. and Munoz, A. (2017). The Council Study: Study on the sustainable management and development of the Mekong River, including impacts of mainstream hydropower projects. *Thematic Report on the Positive and Negative Impacts of Irrigation on the Social, Environmental, and Economic Conditions of the Lower Mekong River Basin and Policy Recommendations.* Mekong River Commission (MRC), Vientiane, Laos PDR. 119 pp.

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Abbreviations and acronyms

AIP	:	Agriculture and Irrigation Programme (of the MRC)
AquaCrop	:	FAO state-of-the-art physiological crop model
BDP	:	Basin Development Plan
BDP2	:	BDP Programme, phase 2 (2006 –10)
BDS	:	(IWRM-based) Basin Development Strategy
BioRA	:	Biological resource assessment team (under Council Study)
CCAI	:	Climate Change and Adaptation Initiative (of the MRC)
CIA	:	Cumulative Impact Assessment
CNMC	:	Cambodia National Mekong Committee
CS	:	Council Study
DMP	:	Drought Management Programme (of the MRC)
DSF	:	MRC Decision Support Framework based on hydrological, water resources and hydrodynamic models
EP	:	Environment Programme (of the MRC)
FAO	:	Food and Agriculture Organisation
FMMP	:	Flood Mitigation and Management Programme (of the MRC)
FP	:	Fisheries Programme (of the MRC)
HH	:	Household
IQQM	:	Integrated Quantity and Quality Model
IBFM	:	Integrated Basin Flow Management (MRC study)
IFAD	:	International Fund for Agricultural Development
IKMP	:	Information and Knowledge Management Programme (of the MRC)
ILO	:	International Labour Organisation
IWRM	:	Integrated Water Resources Management
IWRM-model	:	Modelling framework integrating DSF, SOURCE and WUP-FIN for socio-economic and environmental indicators
ISH	:	Initiative for Sustainable Hydropower (of the MRC)
JC	:	Joint Committee (of the MRC)
LMB	:	Lower Mekong Basin
LNMC	:	Lao National Mekong Committee
M&E	:	Monitoring and evaluation
MRC	:	Mekong River Commission
MRCS	:	Mekong River Commission Secretariat
MRC-SP	:	MRC Strategic Plan
NMC	:	National Mekong Committee
NMCS	:	National Mekong Committee Secretariat
NAP	:	Navigation Programme (of the MRC)
PMFM	:	Procedures for Maintenance of Flow on the Mainstream
PWUM	:	Procedures for Water Use Monitoring
SEDB	:	Socio-economic database (of the MRC)
SIMVA	:	Social impact Monitoring and Vulnerability Assessment (conducted by MRCS)
SoB	:	State of Basin report (of the MRC)
SocEc	:	Social Assessment team (of the Council Study)
SWAT	:	Soil and Water Assessment Tool, hydrological and water quality model
TCU	:	Technical Coordination Unit (of the MRCS)
TNMC	:	Thai National Mekong Committee
UMB	:	Upper Mekong Basin
UN	:	United Nations
UNDP	:	United Nations Development Programme
VNMC	:	Viet Nam National Mekong Committee
WUP-FIN	:	MRC Water Utilization Program Finnish component

Document History

Version	Revision	Description	Issue date	Issued by
1	**0**	**Irrigation Interim Report**	**Nov 2016**	**CS**
2	0	In addition to Interim Report, the team added the scope of assessment and assessment outline, explained data quality and availability, summarized main scenario data for LMB, defined assessment indicators and methodology, improved the report outline.	15. Mar 2017	Jorma
2	1	Added sub-scenario description and summarized of irrigated areas used for sub-scenario	27 Apr. 17	Chamaporn
3	0	Added initial scenario impact analysis	29 May. 17	Jorma
4	0	Added irrigation time series and irrigation water demand, return flow, and sustainable area, hydrological modelling assessment, and impact assessment on the corridors	20 Jun 17	Chamaporn, Jorma
4	1	Major additions for the main and sub-scenario results as well as expanded modelling results analysis.	15 Aug 17	Chamaporn, Anders, Jorma
5	0	Additions for the main and sub-scenario results, more clear impact analysis, addition of main messages and addition of an executive summary.	6 Nov 17	Chamaporn, Anders, Jorma
6	0	Report revision based on the Member Country and MRCS Planning Division questions and suggestions.	8 Jan 18	Chamaporn, Jorma

1 Executive Summary

Council Study Irrigation Thematic Area has made substantial strides forward in terms of implementing an integrated methodology connecting the thematic work to the triple bottom line assessment and modelling. What remains is to bring the methodology to the general use, evaluation and update of the MRCS and the Member Countries as well as expanding the study and making it more applicable and reliable.

Irrigation expansion promises major economic and food security gains. However, the gains need to be qualified with economic and labor constraints. For Vietnam irrigation expansion to the proposed M3 level is likely to cost $3.1 billion more than what can be gained from the expansion in net present value. The other countries would gain net benefits from expansion until M3 development level but only Thailand has potential for further gains beyond that. Even for Thailand costs may be more than estimated because expansion to new areas costs more than previous ones.

Food security will decrease in the future scenarios for some Lao PDR areas and for Cambodia. This is mostly because of population growth and can become acute for specific flood and drought events. Driest climate change scenario C3 needs to be highlighted here.

Irrigation impacts are focused mostly on dry season flows. M3 level or irrigation will decrease mainstream flow up to 11% and I2 intensive irrigation further 3%. At the same time mainstream dry season flows will increase up to 28% in M3 compared to the baseline M1 scenario. Irrigation sustainability is good for Lao PDR and Vietnam but further analysis is needed for the latter in terms of irrigation expansion upstream, dry climate scenarios and increased salinity intrusion due to river channel erosion, lowering of water table and sea level rise. Thailand sustainability decreases in the future scenarios for the driest months. It has not been possible to model Cambodian sustainability.

Hydropower development has both negative and positive impacts on rice production. Gains through flood mitigation and decreased salinity can be locally up to 1 – 3 t/ha. On the other hand fertile sediment inputs decrease and yields decrease up to 20% in the most affected areas without mitigation measures.

Climate change has obvious risks involved especially if drier climate projections are realized. Modelling indicates that in the assessment corridor Tonle Sap surroundings are quite sensitive to drier climate.

2 Background

Overview of the Irrigation Sector in the LMB

Irrigation is the largest water user in the Lower Mekong Basin (LMB) using 12% of the average annual flow. All the countries of the Basin have policies and plans to expand irrigation areas to increase rice production and exports, diversify food production, respond to food security needs and address rural poverty. Various scenarios of current and planned developments suggest that future flows in the mainstream will accommodate the expansions of irrigation areas planned by all countries.

Differences are characterizing this expansion among the regions of the basin. First, some countries have seen a low development of the irrigation sector in the past 30 years with respect to others that have developed rapidly their irrigation infrastructures up to the 2000's: this is the case for Laos and Cambodia that have had a limited development compared to Thailand and Viet Nam. The total developed irrigated area within the LMB is estimated between 4.0 and 5.0 million hectares in the present state[1] . The share of each country is presented in the figure below:

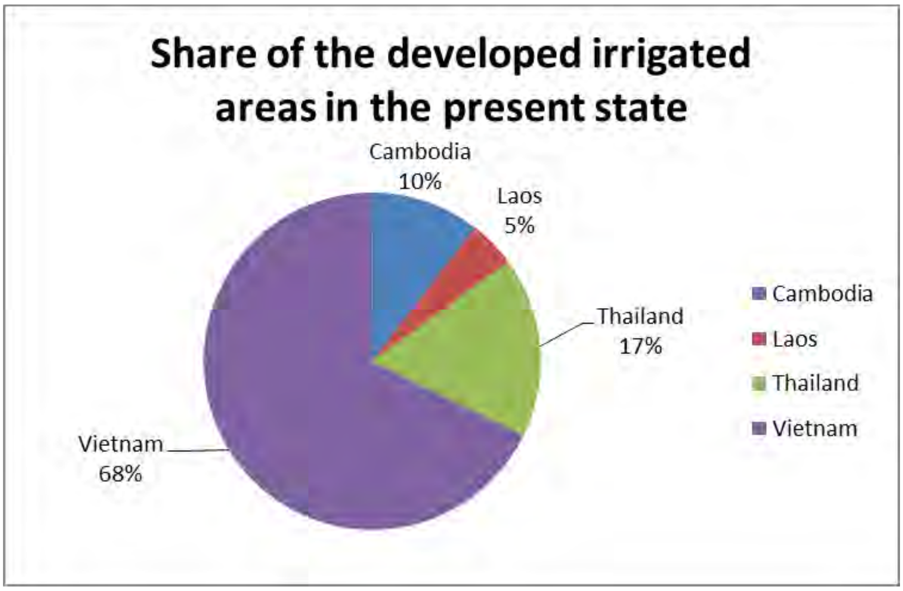


Figure 1: Share of the developed irrigation areas in the present state

According to the information collected, the total irrigation area could nearly double in the far future, reaching up to 7 million hectares. In these hypothetical plans, Laos, Cambodia and Thailand would increase dramatically their area development, whereas Viet Nam would only see a very limited one. These plans will need to be analyzed in space and time.

The central role of the irrigated agriculture in the future of the LMB, being a major water consumer and generating numerous impacts, is a key sector to be analyzed within the Council Study.

The council study will prepare a report that will analyze the positive and negative impacts of the planned irrigation development in the LMB in order to provide recommendations for impacts avoidance and mitigation measures.

[1] Figures compiled from the data collected within the council study, updated in March 2016

Among the objectives of the study for this theme, it is proposed to analyze the rate of irrigation expansion and the induced changes in flow parameters. The assessment of the Irrigation thematic area will provide key information on the resulting changes in environmental, social and economic parameters including issues of food security, employment and transboundary benefits and costs. Out of the analysis on this triple bottom-line, the study will also cover the impacts of irrigation on fisheries and of other developments on irrigation including dry season irrigation.

3 Current Status of the Irrigation Thematic area

3.1 Summary and discussion of "current" physical footprint of thematic infrastructure by selected geographic units

The vast majority of arable land in the Basin lies west of the Mekong mainstream. The Figure 2 below shows that most of the rice is cultivated around Chiang Rai in the north, northeast Thailand, Vientiane and the Seven Plains of Lao PDR, the Tonle Sap flood plains, south-eastern Cambodia and the Delta. Non-rice crops are grown in the same regions but also in the central highland of Viet Nam.

Rice dominates crop production in LMB countries, particularly in the lowland areas, with a total of over 23.1 million hectares (ha) being cultivated in 2010. Between 1990 and 2010, the overall area of rice increased by 33%. In the same period rice production has more than doubled from 40.4 million tons to 86.4 million tons.

With regard to rice yields, there was a very substantial increase in overall productivity from 2.33 tons/hectare in 1990 to 3.74 tons/hectare in 2010 (i.e. 60% increase). In 2010, rice yields ranged from 2.94 tons/hectare in Thailand to 5.34 tons/hectare in Viet Nam.

For the rice cultivation in the LMB, a variety of irrigation systems are employed and a number of variations exist within the region. **Gravity irrigation** with open channel networks is the typical irrigation system for most public schemes. Modernization has also transformed and upgraded some gravity schemes served by pressurized pipeline systems. Beside the large public schemes, the small scale irrigation is practiced all over the LMB. The combination of farm pond with mobile pump is widely used by those smallholders practicing subsistence agriculture.

Besides these rather formal systems, there are many variations of irrigation or partial irrigation systems that have been developed in specific natural conditions. Two examples can be reported: the "Colmatage or Prek" and "Tnup" They can be described as partial irrigation or a variation of irrigation because water supply cannot be planned or necessarily managed to meet crop water demand.

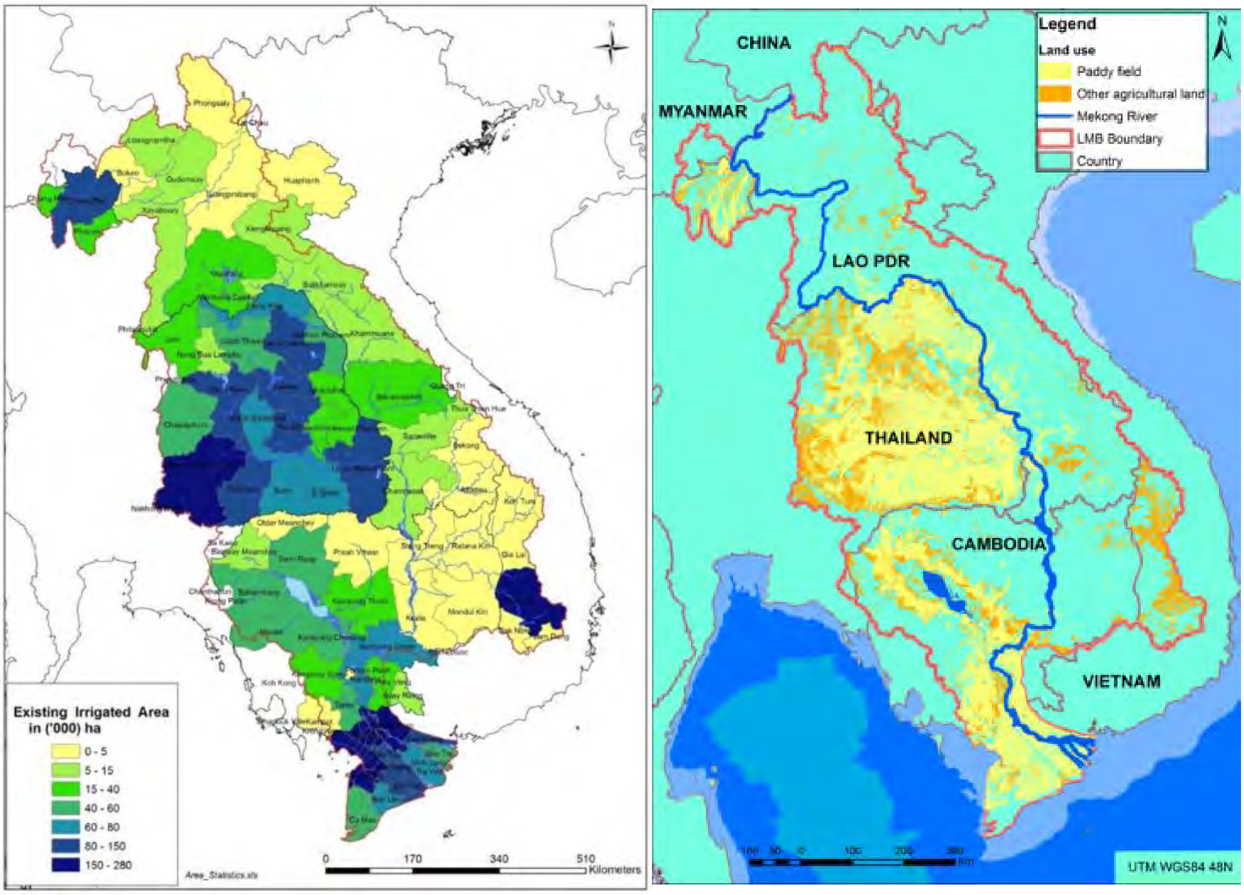


Figure 2: Percentage of Cultivable Land that is Irrigated in the Wet Season (Right) and Current situation of the Irrigation sector in 2007 (Left)

3.2 Cambodia

In Cambodia, water policy as a whole and irrigation in particular are seen as crucial elements of the development of agriculture, leading to food security and poverty alleviation, the main objectives pursued by the state in a country where agriculture amounts to half of the gross domestic product (GDP) and 90 percent of employment.

The total cultivated area of Cambodia is about 4.37million ha (24% of the land), while forests cover is about 56%. Rice is the dominant crop, which covers approximately 3.57million ha, (80% of agricultural land) including the area of receding, floating rice and paddy rice interspersed within villages. Field crops comprise of 6%, rubber 2%, garden crops 7%, orchard < 1% and others as being slash and burn 8%. Rice crop is dominating the sector mainly grown during the wet season in rain-fed lowland conditions. Wet season rain-fed lowland rice crop occupies about 84% of the total cultivated areas whereas the dry season rice crops with full and/or supplementary irrigation occupy about 11%.

Cambodia has to face the heritage the land transformation that occurred during the Khmer regime; Engineering irrigation and drainage works modelled the plains with poor planning and design criteria, affecting the development of the irrigation practice. The MOWRAM is programming since several years the development of the sector mainly through requalification and rehabilitation of those systems. (Samphear, 2016)

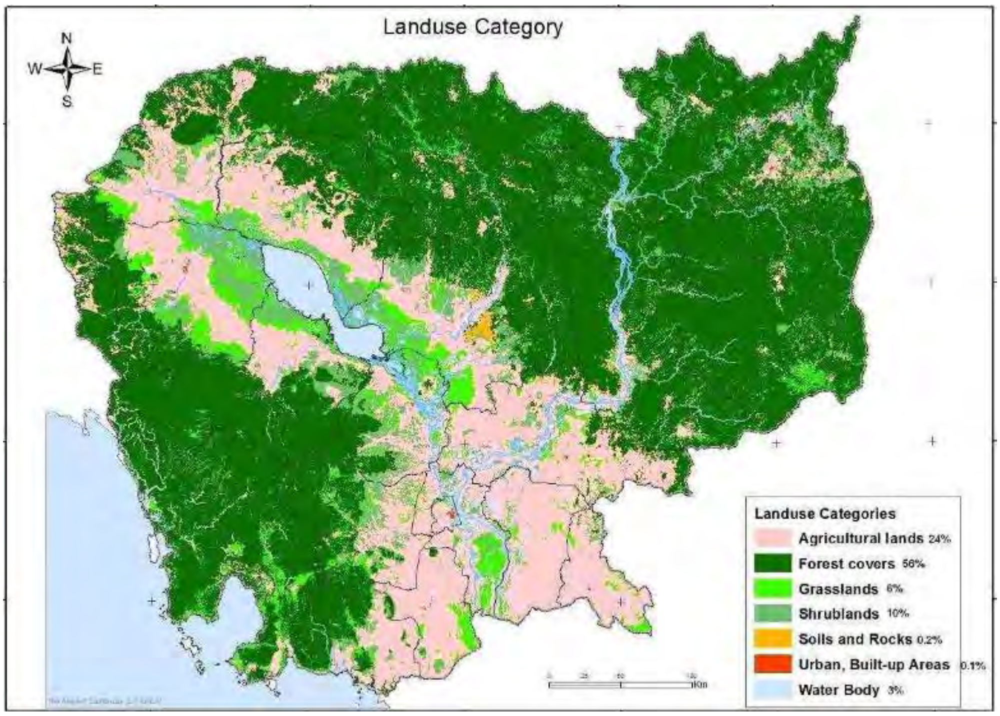


Figure 3: Land Use map of Cambodia

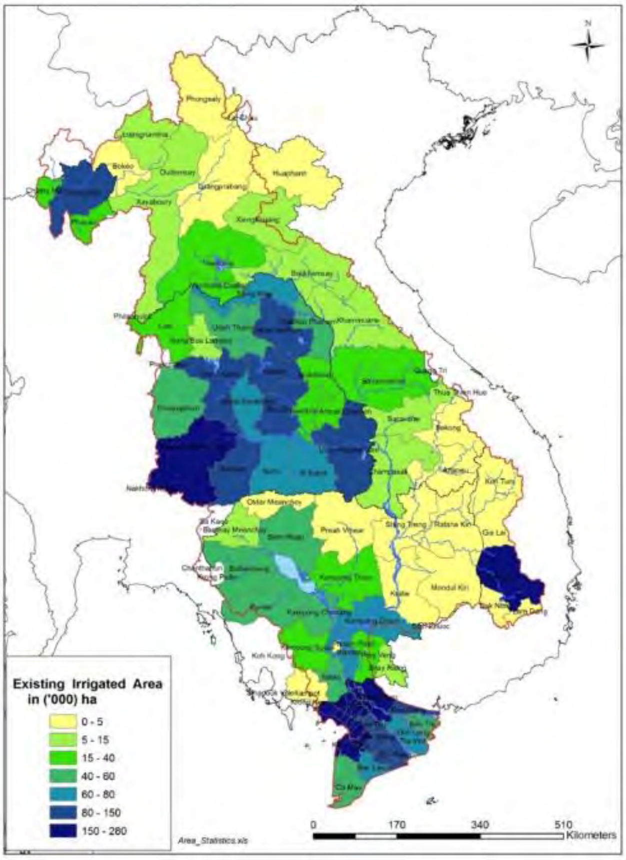


Figure 4: Current situation of the Irrigation sector (2007)

3.3 Laos

According to 2013 statistics, the Lao part of the Mekong basin (MBL) has a total area of about 264,233 km^2 and a population of about 6.3 million people. The study area has resources fertile land, water from Mekong River and rainwater can provide for agricultural production with an important contribution to the socio-economic development of a stable and sustainable MBL area.

The topography of the area is mountainous within the North and West regions and low land with flat in the Western and Southern regions. The average ground elevation range between 1000 m to 100 m above mean sea level. Flat plain is favorable for the development of irrigation systems and water control for agricultural production development. The country is located in the tropical monsoon area, with high temperatures and relatively stable with an average rainfall of about 1600mm. The rainfall regime is unevenly distributed over space about (1600-2400 mm / year), and time (the amount of rain in the rainy season, from May to October about 90%, in the dry season from November to April about 10% of the annual rainfall). (LNMC, 2016)

Agriculture is central to the Lao economy. It contributes 42 percent of GDP (2005/06); accounts for at least 15 percent of recorded exports; and accounts for 67 percent of the employed adult workforce.

The **Laos** irrigation sector was for a long time characterized by small scale irrigation systems, directly managed by farmers withdrawing water directly from the nearby river by gravity (wet season) or through the use of small diesel pumps (dry season). The development of the large scale hydropower sector has offered the possibility to use the stored water in the reservoirs and to feed large scale irrigation schemes connected with long engineered canal systems. This is the way the irrigation sector is being transformed in the future.

Currently, 3,162 irrigation projects have been censed in Lao PDR within the lower Mekong basin region. They are classified as follows:

Table 1: Irrigation Existing Project Database_2014

Existing Irrigation Project in Lao PDR by Irrigation Database statistic_2014		
No	Irrigation Type	Amount of Project
1	Weir	2,218
2	Diversion gate	69
3	Pump Station	548
4	Reservoir	267
5	Other	60
Total		3,162
6	Existing irrigation area on wet season (Ha)	261,689.00
7	Existing irrigation area on dry season (Ha)	170,539.00

For the current situation, the total irrigated agriculture during the dry season 2014 reached 170,539 ha and 261,689 ha for the wet season.

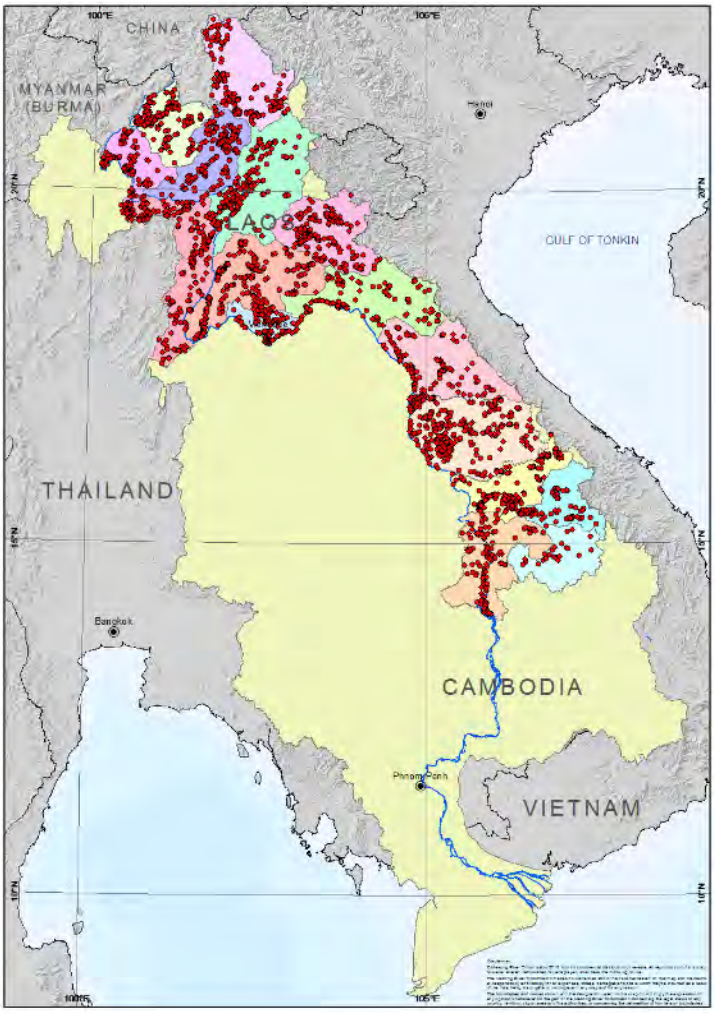


Figure 5: Location map of the irrigation projects – Lao PDR.

3.4 Thailand

Among 25 major river basins in Thailand, five river basins are flowing into Mekong River including Kok, Khong (North and Northeast), Chi, Mun, and Tonlesap River Basins. These basins covering the total area of 188,760 km^2 in 21 provinces which is 37% of the country's total area and serve 24.6 Million riparian people or approximately 38% of the country. The whole area of the Northeast of Thailand is in the Mekong River Basin in which the Chi and Mun river basins are the significant river basins having large catchment areas that constitute 23% of the total area of the country. (Chuthong, 2015)

The potential area for irrigation development within the Thai share of the Mekong basin is up to 4.6 million hectares[2].

In North east **Thailand**, the irrigation sector is characterized by large scale gravity canal systems in that often draw water from a large scale dam and reservoir or barrage type structure: large scale weirs with control gates. These irrigation schemes are highly sophisticated engineering works but they change riverine aquatic ecosystems on a large scale, too.

In the current situation, 810 thousand hectares are irrigated.

Table 2: Basic information of Kok, Khong, Chi, Mun, and Tonlesap Basins

Topic	Item	Unit	Khong (North)	Khong (Northeast)	Kok	Chi	Mun	Tonlesap	Total	Country	%
General	Catchment Area	rai	6,247,973	29,494,896	4,562,394	30,706,169	44,419,750	2,553,700	117,984,882	321,281,184	36.72
		ha	999,676	4,719,183	729,983	4,912,987	7,107,160	408,592	18,877,581	51,404,989	36.72
		km^2	9,996.8	47,191.8	7,299.8	49,129.9	71,071.6	4,085.9	188,775.8	514,049.89	36.72
	Average Annual Rainfall	mm	1,354.5	1,530.0	1,490.1	1,207.9	1,268.0	1,497.4	1,391.3	1,431.60	97.19
	Average Annual Runoff	MCM	3,480.2	20,763.0	3,192.7	11,159.4	17,117.7	1,605.9	57,318.9	199,277.40	28.76
Land Use	Agricultural Area	rai	3,037,004	17,807,421	1,823,416	20,339,177	32,403,266	1,627,796	77,038,080	169,255,098	45.52
		ha	485,921	2,849,187	291,747	3,254,268	5,184,523	260,447	12,326,093	27,080,816	45.52
		km^2	4,859.2	28,491.9	2,917.5	32,542.7	51,845.2	2,604.5	123,260.9	270,808.2	45.52
	Potential Area for Irrigation	rai	1,413,297	3,921,443	564,385	11,226,682	11,686,902	257,700	29,070,409	60,294,241	48.21
		ha	226,128	627,431	90,302	1,796,269	1,869,904	41,232	4,651,265	9,647,079	48.21
		km^2	2,261.3	6,274.3	903.0	17,962.7	18,699.0	412.3	46,512.7	96,470.8	48.21
Population, Economics	No. of Household	housing unit	343,925	1,373,961	829,855	1,616,636	1,197,024	106,213	5,467,614	20,597,664	26.54
	Population	population	962,398	5,099,756	2,201,296	6,164,100	9,853,398	323,553	24,604,501	64,397,764	38.21
	Population Density	population/km2	77	110	94	125	146	78	105	125	84.00
	GDP	Millon Baht	180,020	327,722	192,173	533,059	646,049	73,559	1,952,582	20,077,300	9.73
	Net Household Income	Baht/Household/Month	2,866	2,312	2,424	15,170	3,464	2,641	4,813	6,499	74.05
Water Demand	Irrigated Agriculture	MCM/year	82.2	295.0	80.3	4,608.1	4,261.0	42.9	9,369.5	45,053.6	20.80
	Rainfed Agriculture	MCM/year	144.2	972.0	81.9	n/a	33,892.0	344.6	-	61,115.7	-
	Domestic	MCM/year	70.3	171.8	160.7	217.7	303.4	23.6	947.5	24,177.0	3.92
	Industrial	MCM/year	13.1	11.8	11.4	33.0	44.6	6.5	120.4	2,592.4	4.64
	Livestocks	MCM/year	5.2	48.9	10.2	62.4	135.8	3.6	266.1	679.5	39.16
	Ecology	MCM/year	378.3	3,174.6	698.4	157.1	1,383.0	262.2	6,053.6	28,532.6	21.22
	Total Demands	MCM/year	693.3	4,674.1	1,042.9	-	40,019.8	683.4	47,113.5	-	-
Present Water Resources Development Project	Number	no.	626	1,789	232	2,116	2,732	145	7,640	16,126	47.38
	Capacity	MCM	210.7	1,462.1	126.1	5,356.0	4,357.9	159.4	11,672	76,370.0	15.28
	Irrigation Area	rai	378,650	1,255,739	362,902	2,635,466	2,251,276	106,250	6,990,283	28,363,084	24.65
		ha	60,584	200,918	58,064	421,675	360,204	17,000	1,118,445	4,538,093	24.65
		km^2	605.8	2,009.2	580.6	4,216.7	3,602.0	170.0	11,184.5	45,380.9	24.65
	Beneficial Area[1/]	rai	603,930	902,147	290,647	878,749	1,606,309	68,460	4,350,242.0	12,198,326	35.66
		ha	96,629	144,344	46,504	140,600	257,009	10,954	696,039	1,951,732	35.66
		km^2	966.3	1,443.4	465.0	1,406.0	2,570.1	109.5	6,960.4	19,517.3	35.66
Planned Water Resources Development Project	Number	no.	180	701	89	1,277	1,168	84	3,499	8,789	39.81
	Capacity	MCM	752.0	535.0	315.8	2,728.4	851.9	207.0	5,390	26,603.0	20.26
	Irrigation Area	rai	654,129	1,180,293	318,454	5,196,207	14,363,286	209,161	21,921,530.0	34,040,852	64.40
		ha	104,661	188,847	50,953	831,393	2,298,126	33,466	3,507,445	6,910,229	50.76
		km^2	1,046.6	1,888.5	509.5	8,313.9	22,981.3	334.7	35,074.4	69,102.3	50.76

Source: Basin-Level Irrigation Development Planning Project (60 Million Rai Framework), Royal Irrigation Department (October 2010)

[2] Report 60 Million Rai 2010

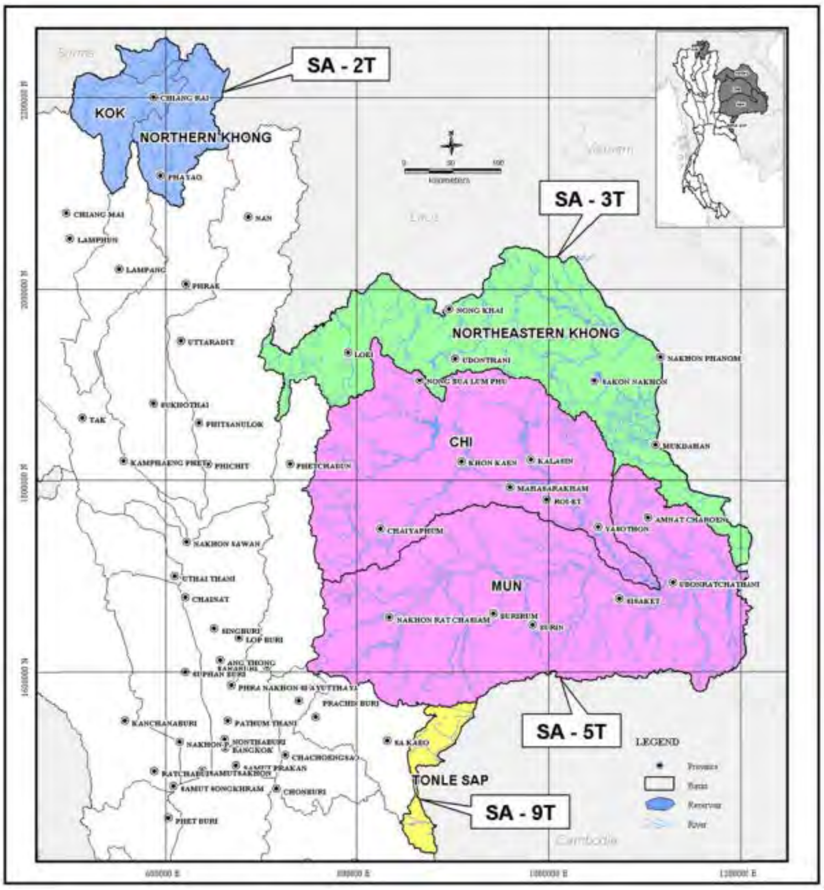


Figure 6: Overview of the Mekong river basin in Thailand

3.5 Vietnam

Vietnam is still involved in massive investments for rural and water infrastructures. The Red river and Mekong deltas require huge outlays for works on dikes (flood protection) and channels, notably the Mekong, with further reclamation of land in the Plain of Reeds and closing off of the seashore, allowing freshwater irrigation during the dry season. Significant investments are also being made in rehabilitation and modernization, since most of the schemes developed in the 60s and 70s are now in a severe state of degradation. Agriculture provides about a quarter of Vietnam's GDP and exports and employs two-thirds of the labor force, further crop diversification and increases in productivity require modern hydraulic infrastructure and more efficient delivery of irrigation and drainage services (Duc Dung, D. and Quang Tho, T., 2016).

Vietnam is characterized by two typical systems according to the area. In the Mekong Delta, intensive irrigation of rice crops is conducted. The natural and engineered network of canals feeds the paddy rice plots either by gravity or by pumping according to the tide water level. Irrigation systems in the Central Highlands (Upper Se San and Srepok Basins) of Viet Nam are typical reservoir-gravity canal systems. Active development of both surface and subsurface water resources is underway.

- *The Mekong Delta*

Figure 7: The Mekong river delta area divided into 13 districts

The **Mekong delta** is one of the most productive rice area of the globe. The gross area is 3.9 million hectares with an agriculture land of 2.7 million ha producing more than 20 million tons of rice per year.

From 1996 to present, along with the development of socio-economic in the MKD, state and people have to build more irrigation systems throughout the region. Until now, the channel system was completed building on basic level, especially the main channel, premier and secondary canals. Inland irrigation system was also noted in the areas of investment have produced a stable structure.

In the area of irrigation development projects earlier and synchronized planning has brought greater efficiency, such as salinity control, increasing the supply of fresh water during the dry season, improve flood control, drainage alum, and water supply, and land improvement, agricultural development for diversified and higher standards of living. At the same time, thanks to irrigation systems have brought many new areas open, contributing to switch production from rice cultivation to aquaculture seafood on a large coastal area.

Irrigation has been moving away from thinking to prevent saltwater salinity control, actively serving both the agriculture and fisheries. Planning work is trying to integrate and coordinate between departments, water objects, between the mining and resource use, between economic development and social and environmental protection, diversity in production between export-oriented agriculture with the construction of large-scale production of key agricultural products.

The issue of environmental protection, ecological protection of mangroves, and infrastructure development of new settlements in the flooded areas are also of interest. The State is gradually overcoming the asynchronous investment, lack of focus areas to promote efficiency projects.

Reality show for years, investment in construction is essential, but the mechanism and investment management operation is equally important; ensure economic stability, growth general social and agricultural production, fisheries in the project area in particular in accordance with set objectives. This is the main issue with the system works in the MKD.

The major infrastructure works for the irrigation sector are dedicated to flood protection, salt intrusion prevention and water supply.

In the current situation, 1.9 million ha are fully developed. The total annual water needs are up to 16.8 BCM. Three seasons of rice production are occurring in the delta area.

- ***The Central Highlands***

The area called central highlands is combining three sub basins that are tributaries of the Mekong river extending in the Vietnamese territory: the Sesan, Srepok and Ea Hleo sub basins. The total area of these subbasins is up to 29,800 km^2. The irrigation development is currently marginal in this sub basin, but plans for their development are to be implemented from here to 2020 and 2040.

The area of agricultural land amounts to 812,420 ha (accounting for 27.18% of total area). Area planted with annual crops is 321,444 ha, of which land area of 99,664 hectares of rice only, others are annual crops like cassava, coffee, rubber. A total land area of 485,355 ha for perennial crops occupy 59.74% of the land for agricultural production. This demonstrates that the perennial plants are the strength of the Central Highlands.

The current irrigation works, in the sub-basin 7V is characterized by 1396 hydraulic works of various types of works (658 reservoirs, 664 weirs, and 74 pumping stations). The irrigation designed capacity is 165,086 ha but the actual irrigated area totals 124,191 ha or equal to 75.2% of the design capacity

Figure 8: The Central Highlands part of the LMB

3.6 Estimated "current" economic value of this sector and when appropriate, specific subsectors by country

In 2013, agriculture, fisheries and forestry represented 20% (northeast Thailand) to 34% (Cambodia) of the basin's economy, with industry (26% to 33%), which includes hydropower, and services (34% to 50%) making up the balance. Although agriculture's contribution to GNI is gradually falling, agriculture and fisheries continue to be the most significant employer within the rural areas of the basin.

The basin's production contributes to the substantial agricultural exports and agricultural trade surpluses of Thailand and Viet Nam in particular. In 2011, national agriculture exports in Thailand were US$ 37 billion with a trade surplus of US$ 27 billion. In Viet Nam in 2011, these were US$ 14 billion and US$ 2 billion respectively.

Agriculture and aquaculture will continue to be a major export earner and supplier of domestic food needs across the region. Its contribution to the basin's economy will, however, continue to decline in percentage terms. The LMB's comparative advantage in food production will provide growing opportunity for commercial agricultural enterprises to benefit from rapidly rising global demand for food. Rice production is expected to rise over the long term at 1.5% per year, driven mainly by export markets. Aquaculture production is expected to continue its rapid increase in response to growing domestic and export demands, as will livestock and other crops. Agricultural processing can be expected to continue to expand.

While looking at the outlooks of the agriculture sector, it must be reported that the general improvement of the agricultural productivity is highly connected to the access to water resources. Access to a secured source of water for farmers both for the wet season to overcome rainfall variability and in the dry season to double the crop production is one of the pillars of the development potential. This is particularly true for Thailand and Cambodia that suffer from the rainfall variability.

There are no specific data that were made available to allow a clear description of the economic contribution of the irrigation sector to the national revenues.

3.7 Narrative profiles of selected major infrastructure under this thematic area

A selection of key representative irrigation projects was operated by the national consultants of each MC. These projects were described in specific reports that are annexed to this main report. They are also equally described into a datasheet filled by each consultant.

4 Development Trends

4.1 General development trends narrative

The development of reservoirs and irrigation schemes has been, and still is, prominent in the Mekong region. The situation, however, differs sharply according to the country. Thailand and Vietnam have extensively developed the irrigation infrastructure and investments have declined in the last few years but hydropower development is in full bloom in the upper Mekong providing new opportunities for the development in Laos. Laos and Cambodia still have a low degree of infrastructural development, and options for the future are still under discussion.

The next paragraphs present the development trends by countries based on the summary of strategic development plans reported for this study.

4.2 Trends based on the following situation and MC plans

4.2.1 Cambodia

Currently, Irrigation development is still an important issue. Due to the increasing price of rice and other agricultural products the government has reinforced the efforts to raise money in the last ten years from foreign donors to rehabilitate the existing and build the new irrigation schemes so that "Cambodia would become one of the world leaders in rice (white gold) export" (Chanbosak, 2016).

For the short-term, it is not scheduled to build new schemes as thousands of existing schemes can be rehabilitated with lower cost. These last have the priority. The main challenges to irrigation development for the purpose of sustainable use of water resources for agricultural purpose are how to ensure an effective capacity building and technical assistance for the farmer to develop and manage the irrigation schemes and the financial resources to invest in irrigation construction and rehabilitation.

In order to utilize the existing potential effectively, the government mobilized irrigation funds to invest in irrigation development as well as in the set up the irrigation services centers to provide capacity and management support to the FWUC throughout Cambodia.

The national network of FWUC for the purpose of learning and policy dialogue should be also established and supported.

Thus, National Strategy lays particular emphasis on increasing the area of irrigated land, with the expectation that irrigation will make farmers less reliant on rainfall and allow them to cultivate more crops with more certainty and predictability, resulting in higher productivity and improved livelihoods

Raising the productivity of lowland agriculture remains a significant component of the overall sector objectives, and substantial hope is invested in full and/or supplementary irrigation as the catalyst for intensification and diversification of lowland cropping systems.

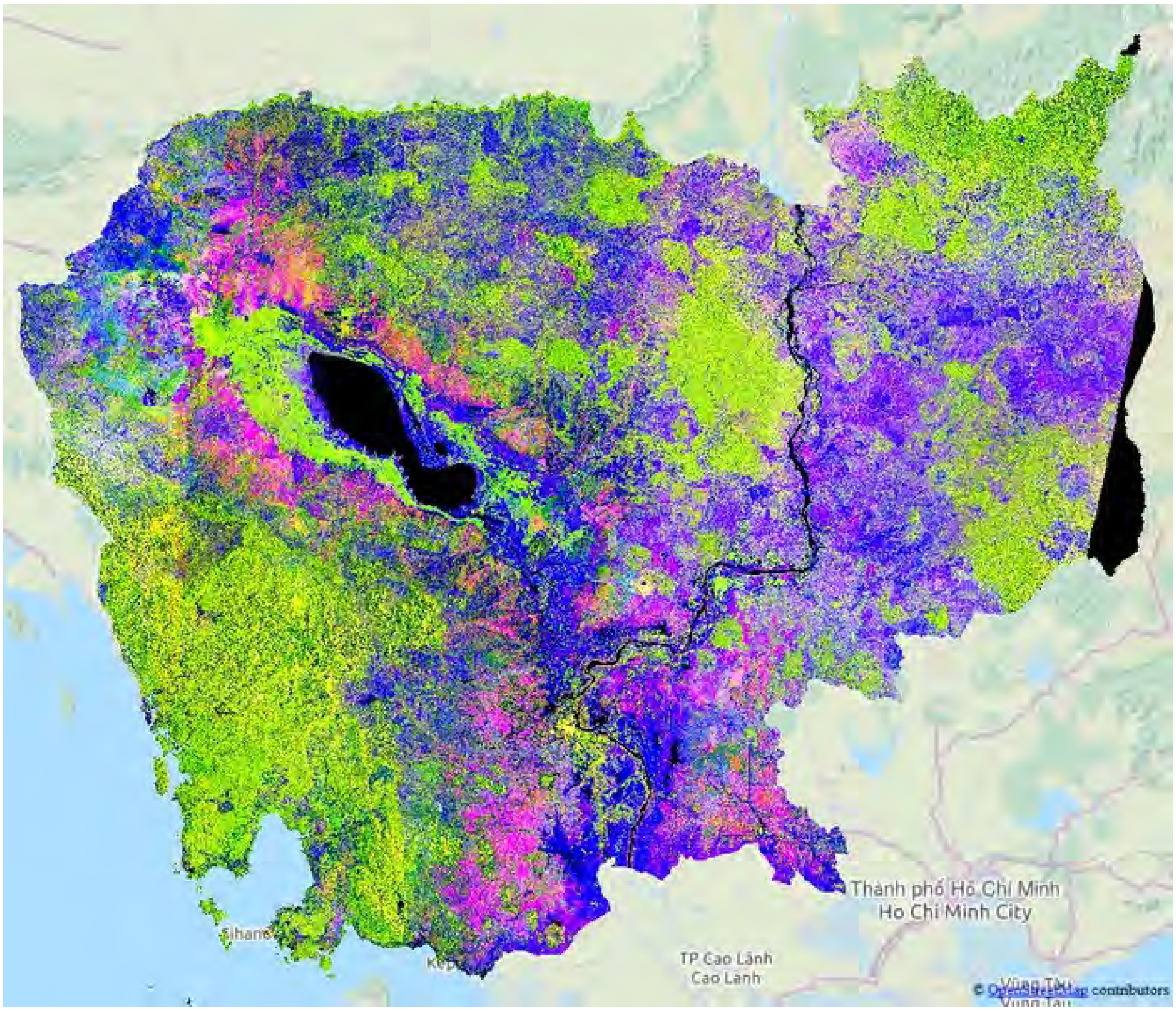


Figure 9: Rice cropped areas in Cambodia[3] - ESA

4.2.2 Laos

The Lao Department of Planning issued instructions for preparing 7th Five Year Agriculture and Forestry Sector Plan as 2010-2015, 2015-2020 and for future plan 2020-2030 and 2030-2040). MAF recommended the Department of Irrigation to develop integrated irrigated agriculture project profiles for those year sector plan (LNMC, 2016).

The objective of the National Irrigation Development strategy is to create a more conducive environment for irrigated agriculture development. The strategy covers the period of 2011-2020. It foresees a re-modeling and re-orienting of the mechanisms of the various areas of public management that relate to the Irrigation Agriculture Subsector.

[3] Changes in Cambodia from Sentinel-1A readings at 20 m resolution, acquired every 12 days from March 2015 to March 2016. Dark blue represents water surfaces, light blue to magenta represents agriculture (bare soil and cultivated fields), light to dark green represents forests, and white indicates settlements. In particular, the varying shades of magenta indicate rice sowing and transplanting between mid-September and the end of October.

The new model for public management will need to be shaped around a holistic perception of irrigation, namely as "irrigation agriculture", a business activity undertaken by farming households and the private sector, and governed by economic incentives

The strategy 2011-2020 needs to provide direction and guidance to:

i. Improve livelihood and the nutritional well-being of smallholder farmers based on increased productivity of rice and diversified farming systems that are adapted to climate;

ii. Raise commodity production through partnership investment aiming to develop value chains to domestic, regional and global market; and

iii. Align public management of the irrigated agriculture sub-sector to the requirements of an open and market-oriented economy.

The implementation of those plans could see the new development of 101,700 Ha in the period 2015-2020 and 329,425 Ha in the period 2020-2040 reaching a total irrigated area of 446,125 Ha for the large projects.

Irrigation agriculture development will have a different approach between regions that have different geographic, demographic, economic and social conditions. The agro-ecosystem in Lao PDR is composed of three major type; the uplands mountainous, the lowlands/flatland flood plains of the Mekong River, and the elevated plateau of the Boloven. A fourth ecosystem is the sub-urban areas of Vientiane Capital and major cities.

The four areas will need different development approaches for irrigated agriculture. The focus for irrigated agriculture development in those regions is described in the annexed Laos report.

The plan specifies the action to be made in irrigated agriculture focus areas and in areas located outside those focus areas.

The irrigated agriculture focus areas shall be located in the 7 major and 14 minor plains. The target is to use the potential water resource by developing gravity irrigation systems in order to reduce the cost of irrigation service and production that will enhance the price competitiveness of agriculture products.

Within the non-focus areas, which have less water resource and land potential other means and irrigation technology shall be developed such as: the use of ground water, pressurized irrigation and other. The funding of integrated irrigated agriculture project shall not only be from public investment (or public investment will be only used for funding basic infrastructure).

As the projects will be the base for new rural and urban development, there is possibility to promote investment by private sector. The first priority will be to select on gravity irrigation project.

53 large irrigation projects have been identified by the department of irrigation.

According to an estimation based on designed and feasibility study, the command area the 53 projects will be able to supply irrigation water to 446,125.00 ha. The first 27 projects plan to be implemented over 101,700 Ha during 2010-2020. The remaining 26 projects will be implemented over 329,425 Ha during 2020 -2040.

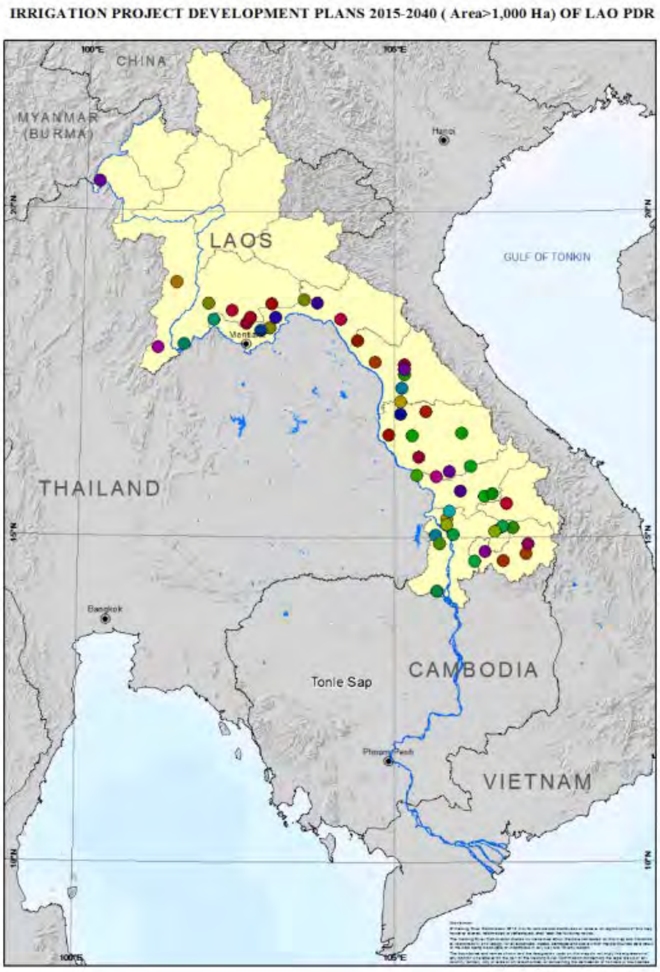


Figure 10: Location of the large irrigation projects of the Lao plan

4.2.3 Thailand

The approach strategy of Thailand for the irrigation sector is depicted in the Royal Irrigation Department (RID) plans for the development and water management.

The RID's Strategic Plan was formulated to be in accordance with the changes of economic, social, technology, country's direction, the government's policy, the State Administration Plan, The Eleventh National Economic and Social Development Plan (2012-2016), and The Agricultural Development Plan during the 11th National Economic and Social Development Plan (2012-2016). (Chuthong, Report on Selected Irrigation Projects in Mekong River Basin of Thailand, 2015)

It can be substantially performed by applying structural measures and non-structural measures.

The structural measures mainly emphasize the use of water inside the basins especially in the areas suffering from both flood and drought. The water diversion between the basins will then be considered secondly. The plans/projects can be divided according to the types of irrigation structures such as:

1. Reservoir development projects i.e. the constructions of all sizes reservoirs to be storage to retain water in the wet season that will be utilized in the dry season or during the events of delayed rainfall.
2. Weir development projects i.e. the constructions of weirs across the rivers to raise up the water levels.
3. Regulator/Barrage development projects i.e. the constructions of regulators/barrages in the rivers to raise up and control the water levels upstream which can be supplied to irrigation area.
4. Electric pumping system development projects i.e. the constructions of electric pumping stations in the areas those are not much remote to the water sources. The water distribution systems will also be developed which may include canals or piping systems.
5. Detention ponds (monkey-cheeks) development projects i.e. the developments of low-lying lands adjacent to the rivers or located in the inundation alignments by the constructions of discharge or water level control structures to retard or slow down the flow or to decrease the flood in the adjacent basins. The detention ponds can also be used as water storages.
6. Water grid or water network development projects i.e. the constructions of network systems those connect storages in different basins which can be done by constructions the control structures those can control the flow directions and the flow discharges from one basin to another basin to increase the potentials and securities of the existing storages.
7. On-farm irrigation development project i.e. the projects are to increase the efficiencies of on-farm water distributions i.e. the construction of canals/ditches system projects and land reform works inside the irrigation areas having perfect water sources.
8. Water conveyance system development projects i.e. the constructions of canals or pipes connected from the storages to agricultural lands.
9. Drainage system/flood mitigation development projects i.e. the constructions of dikes, drainage canals to prevent flooding in the protection areas, or the increments of drainage efficiencies.
10. Rehabilitation projects i.e. the improvements of the management capabilities of existing projects (Irrigation Modernization) both large-scale projects and medium-scale projects having the useful lives over 20 years to increase the capabilities to store water and reduce the irrigation losses.

The non-structural measures are the applications of technologies, coordination with other sectors and participations in managements of storages and irrigation projects in the basins and among the basins.

1. The projects to alter the reservoir management pattern by risk management.
2. The projects on monitoring and forecasting the water situations by telemetering systems.
3. The projects to promote the participations of irrigation water users groups on water management to jointly plan for cropping manage water in the dry season with users from other activities.
4. Dam safety projects
5. Water use reduction projects by changing the agricultural patterns.

6. Integration of planning and project information among agencies.

4.2.4 Vietnam

The overall objective of the Agriculture sector is to develop a comprehensive and sustainable system and to optimally utilize the potential advantages to generate a greater production characterized by a high productivity, quality, efficiency and competitiveness. (Duc Dung, D. and Quang Tho, T., 2016)

Agricultural development will meet the sustainable growth, simultaneously with the construction of new countryside and promote and encourage the role of the peasantry. This has been identified as a strategic task to contribute to economic growth and to conserve political stability, security and defense, while protecting the ecological environment.

According to forecasts by 2020 the structure of agriculture will only accounts for 30.9% of GDP. The general trend of the agricultural, forestry and fishery development is to strive to a value growth in agricultural production from 5.2% / year for the period 2011-2015 to reach an average of 4.9% for the period 2016-2020.

This will correspond to a reduction of the share of agriculture in the overall of agriculture, forestry and fisheries sector from 65.4% in 2010 to 58.4% in 2020. It will correspond to the increased proportion of seafood from 33.4% in 2010 to 40.5% in 2020.

The development plans presented for this study were compiled based on the following documents:

- Mekong Delta Master Plan in NBD and climate conditions
- Strategic development of irrigation till 2020 (2009)
- Water Resources Planning Highland 2020 (not yet approved)
- Construction Planning Highland 2030
- Mekong Delta Plan (2013-Version 2 - Netherlands)
- Basin Development Plan BDP2 (2009)
- Report profile update vung10V, 7V (BDP2 -2011).
- Development planning Socioeconomic MD 2020
- Documentation of climate change scenarios and NBD MONRE.

The summary of the plans are reported distinctively for the Mekong delta area and the central highlands area.

- ***The Mekong Delta***

The climate change effects will tend to change the soil conditions for the rice cultivation in the delta area with sea level rise and salinization. Adaptation to the new conditions will be necessary to maintain the productions. Farmers will also diversify their activities switching to aquaculture or trying to combine both rice and shrimp cultivation. In addition, the urban growth will decrease the land available to rice cultivation. As a result of these factors, the future plans only foresee a slight decrease of the irrigation development that would reach 2.384 million Ha in 2020 (DFS scenario) and would decrease to 2.323 million Ha in 2040 (PDS scenario).

The estimated population forecast in the Mekong Delta region in 2020 is to about 20-21 million people, including urban population of about 7.0 to 7.5 million people, with an urbanization rate of about 33-35%

The forecast of urban construction land and industrial is expected to turn to about 100,000-110,000 hectares in 2020, with a corresponding water demand as follows:

- Urban areas: water supply norm of 120 liters / person / day. The rate reached 100% clean water by 2020.
- Rural areas: water standards of 80 -100 liters / person / day. The rate reached 100% clean water by 2020.
- Industrial Park: standards of water supply 40m3 / day / ha with 80% scale industrial park.

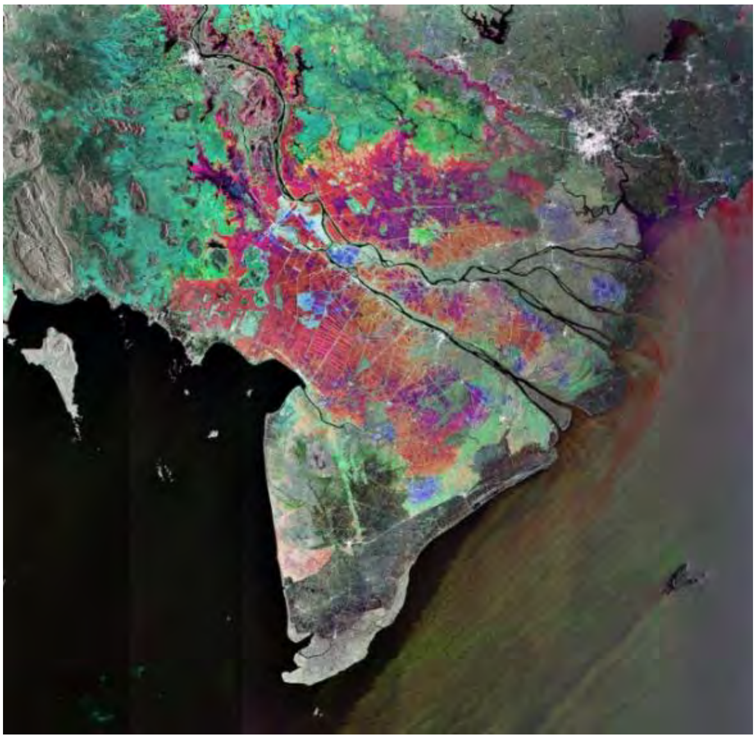


Figure 11: Satellite view of the cultivated areas in the Vietnam Delta – Photo:ESA

Total demand for water is expected by 2020 to reach 2.5-3 million m^3/ day. Demand for industrial water supply around 600,000-1 million m^3/ day.

Several major infrastructural projects are scheduled to meet the objectives of the water resources planning. It consists of canal works (dredging, linking) to link the major rivers in the area, dikes improvement to prevent floods, drainage water management, regulation structures and pumping stations development. The details are given in the annexed plan for Vietnam.

- ***The Central Highlands***

The main objective for the development of the central highlands area is to minimize the transfer of agricultural land into unsustainable land cultivation systems. In addition, it is foreseen to prioritize the expansion of rubber and coffee plantations and the development of land with annual crops in upland fields.

The priority areas for expansion are the border regions in order to combine economic development with national security and significant greening barren land just for the latex, wood.

The development of irrigation is targeted to improve rice cultivation areas and address the transfer of water service. Irrigation development will be prioritized to the precarious areas and turn them to cropland and other crops with a high economic efficiency.

In compliance with the master planning of water resources in Sub-basin 7V up to year 2020, the irrigation works foreseen for the central highlands area are the following:

Sre Pok Basin

According to agricultural planning, the cultivation area by 2020 includes: paddy area (winter-spring: 46,660 ha, traditional paddy: 59,710 ha), upland crops: 199,125 ha, annual industrial crops: 27,463 ha, and perennial industrial crops: 232,567 ha.

The government has planned the following measures for water supply:

- Upgrading 220 existing hydraulic works: 177 reservoirs, 42 dams, and 1 pumping stations to extend 13,829 ha of rice and coffee.
- Constructing 413 new hydraulic works: 301 reservoirs, 36 dams, and 49 pumping stations and 27 small hydraulic systems to irrigate 100,981 ha of cultivation area.

As the results, the irrigated area reaches 214,301 ha, in which 69,051 ha of rice, 110,205 ha of coffee; remaining is upland crops and others.

Se San basin

According to agricultural planning by 2020, expected cultivation area in the Se San basin includes: paddy area (in which 15,710 ha of winter-spring rice, 27,920 ha of traditional rice); 13,977 ha of upland crop; 3,001 ha of annual industrial crops; 49,859 ha of perennial industrial crops.

To supply water for these agricultural areas, water resources measures by 2020 and vision to 2030 are proposed as follow:

- In general, water supply measure for Se San basin and its vicinity needs to upgrade, maintain, and construct 421 hydraulic works. By which, the irrigated area of entire basin is about 40,788 ha including 20,472 ha of winter-spring rice, 18,001 ha traditional rice, 2,249 ha of upland crops, 17,708 ha coffee, and 360 ha of other crops.
- Upgrading and improving existing 205 hydraulic works: 54 reservoirs, 145 dams, and 6 pumping stations to ensure irrigation of 2,923 ha increased cultivation area (1,225 ha of winter-spring rice, 1,568 ha of coffee, and 131 ha of upland crops).
- Construction of 216 new hydraulic works: 72 reservoirs, 137 dams, 2 pumping stations, and 5 small hydraulic systems to ensure irrigation 13,075 ha cultivation area (6,450 ha of rice, 4,697 ha of coffee, and 1,928 ha of upland crops).

The full potential of the irrigation development in the area is up to 1.1 million hectares for the Sesan basin and 1.8 million hectares for the Sre Pok basin (including Ea Hleao). However only a short part of this potential is planned for development by the Vietnamese authorities:

In the Sesan basin, 2,156 ha will be upgraded by 2020 whereas 39,806 ha will be newly developed. In the srepok basin, 16,998 ha will be upgraded whereas 131,242 Ha will be newly developed. Finally, the Ea Hleo basin will see the upgrade of 4,820 Ha and the new design of 65,169 ha.

4.3 Discussion of national, regional, and local plans

The paragraphs below present the summary of the development scenarios formulated for each country. The analysis at the Lower Mekong Basin level was made based on the information collected for the council study[4].

Thus, to allow a global view of the extension of the infrastructure development that might be foreseen at the LMB level for the irrigation thematic area and for the different scenarios proposed within the council study, a primary gap filling strategy was conducted. This strategy that is depicted in the *working paper*[5] was based on scientific assumptions based on best professional judgement together with the help of the BDP2 dataset in order to fill the gaps. This strategy was used for the redaction of the interim report, while hoping that efforts will be developed by the national consultants of the member countries and arbitration of the RTWG to obtain a full representative dataset covering the LMB for the final version of the report.

The discussion of the plans concentrates on the irrigation area development which represents the first element of comparison of the development.

4.3.1 2007 development situation

Cambodia

The data collection of the national consultant was completed in March 2016. The figures proposed by the National Consultant were based on a revision of the BDP2 database. The figure proposed to characterize the Early Development situation: 488,433 Ha

Laos

The early development of the Irrigation sector in Laos corresponds to a developed irrigation area of 209,116 Ha. These figures are higher than the ones presented in BDP2 (165,985 Ha) but much more reliable since they were issued out of national census.

Thailand

For the scenario development, Thailand presented the figures that only relates to the riverine provinces of the Mekong River. These figures do not allow having a full representation of the development of the sector for the LMB.

However, global figures to be used to characterize the development of the Thai part of the basin were communicated on purpose after a special national meeting in January 2016.

A total of 809,671 Ha are declared to be developed in the 2007 early development scenario. In parallel, the BDP2 dataset was presenting a total of 1,412,298 Ha for the early development. Although the figures presented by Thailand are much lower, we thus retain the figure of 809,671 Ha for the LMB early development. (Chuthong, 2016)

[4] Thematic Data and Map Specifications Document – Irrigation – Interim report – Apr2016

[5] Thematic Data and Map Specifications Document – Irrigation – Interim report – Apr2016

Vietnam

The total irrigation area developed in 2007 in the Vietnamese part of the Mekong basin totals 3,162,346 Ha. The area is the sum of the Central highland area and the Mekong delta that represent 740,540 Ha and 2,421,806 Ha respectively. These figures are much higher than the figures presented in BDP2, but after discussions with the national consultants they were revised and confirmed.

Finally, the table below presents the figures characterizing the Early Development Scenario for the Lower Mekong Basin.

Table 2: Early Development Scenario – Developed Irrigation Area by Country

Irrigation Area in Ha	***Proposed Data***
Country	***ED - 2007***
Cambodia	488,433
Laos	209,116
Thailand	809,671
Vietnam	3,162,346
Total	**4,669,566**

4.3.2 2020 development scenario

As exposed in paragraph 4 – Development Trends – each of the four-member countries have on their agenda an infrastructural development of the Irrigation thematic area. The details are given below for each country.

Cambodia

Discussions were held with the officers of the MoWRAM and other donors by the international consultant in Phnom Penh. All the discussions mention that a program of development of the sector is underway in the country. The investments are concentrated on the rehabilitation of existing schemes. However, private investors are also developing the irrigated agriculture in large areas to support the industrial agriculture development. These projects are not under the control and the planning system of the Ministry. The National consultants have proposed in March 2016 a dataset based on a revision of the BDP2 data to illustrate the2020 development scenario.

Hence, the Definite Future Scenario for 2020 proposes a total of 756,008 ha of irrigated area for Cambodia, representing an increase of 55% respect to the Early Development Scenario.

Laos

The data provided by the Lao national consultants to describe the future developments that will occur in the irrigation sector were constructed based on the 2015-2040 development strategy. As mentioned in the previous section – Development Trends – Laos is planning to develop 27 large projects totaling 101,700 Ha. The rest of the development will be for the medium and small-scale irrigation.

Based on the declared figures, Laos will increase the developed area by 48% to reach a total of 309,068 Ha in 2020. In comparison BDP2 was mentioning a development that would have reached 450,000 Ha for the same period.

Thailand

For the areas riverine of the Mekong River, Thailand mentions a large development of the total irrigation area, increased by 95%, to reach a total developed area of 1,582,554 Ha. These figures are different with the BDP2 development figures that were proposing 2,358,918 Ha.

Vietnam

The figures proposed by Vietnam for the 2020 Definite future scenario will see a global decrease of the irrigation area of -1%, varying from 3,162,346 Ha for the Early Development to 3,145,432 Ha in the DFS. While looking at the differences between the Central Highland and Delta area, the first one will see an increase of the area by 3%, whereas the irrigation area in the Mekong Delta will decrease by -1%.

Based on the proposed figures, the overall LMB area will see an increase of the irrigation area by 24%.

Table 3: Definite Future Scenario – Developed Irrigation Area by Country

Irrigation Area in Ha	**Proposed Data**		
Country	***ED - 2007***	***DFS - 2020***	***Incr.***
Cambodia	488,433	756,008	55%
Laos	209,116	309,068	48%
Thailand	809,671	1,582,554	95%
Vietnam	3,162,346	3,145,432	-1%
Total	4,669,566	5,793,062	24%

4.3.3 2040 development scenario

From the information mentioned in the development plans of the four member countries, each country have formulated global figures for the development of the sector up to the 2040 horizon. The information only partially applies to the basin area:

- In *Vietnam* the development forecasted for the Central Highlands area in 2020 will remain unchanged in 2040. Only the Mekong delta will see a decrease, following the trends of the diminution of the irrigated land due to the population growth and the connected urbanization growth rate. We retain the proposed figures for the scenario development.
- In *Cambodia,* the figures communicated were only listing the projects that were supposed to be developed. An interpolation was thus made out of the BDP2 dataset to present a target development horizon for Cambodia in 2040.
- In *Thailand*, the consultant proposed a global figure representing the Thai part of the basin for 2040, but the detailed data only focus on the corridor.
- In Laos, the consultant proposed a dataset detailed by province for 2040, that was fully used.

The following figures, issued from the National Consultants characterize the 2040 Planned Development Scenario.

Country	***ED - 2007***	***DFS - 2020***	***PDS - 2040***	***Incr.***
Cambodia	*488,433*	*756,008*	*1,155,815*	*53%*
Laos	*209,116*	*309,068*	*597,893*	*48%*
Thailand	*809,671*	*1,582,554*	*1,854,763*	*15%*
Vietnam	*3,162,346*	*3,145,432*	*3,084,459*	*-2%*
Total	***4,669,566***	***5,793,062***	***6,692,930***	***13%***

Based on the proposed figures, the overall LMB area will see an increase of the irrigation area by 13% increase between the 2020 and the 2040 horizons. The development would lead to a total irrigation area of 6.7 million hectares over the basin. The largest development would occur in Cambodia with an increase of 48% occurring between 2020 and 2040.

4.3.4 Uncertainties and plausible changes in the plans/trends

The information collected in the first months of the project did not allow a satisfactory development of the scenarios. Only global figures characterizing the expansion of the irrigation area at the province level were made available. This is not enough to serve the purpose of the connected modelling activities that are planned to be developed in phase 2:

- Details should be made available at the district or sub basin level to allow a fine analysis of the hydrologic impacts
- No information was made available in the changes that would potentially occur in the crop mixes
- No information is available for characterizing the development of the storage capacities linked to the potential development of irrigation in the dry season
- Very little economic information is also available for these development plans.

In addition, the narrative of each country's strategy did not highlight clearly the priorities that would be given for the development. This was a prerequisite to allow formulating the sub scenarios for the planned development with low medium and high achievement potential.

Finally, a homogenous dataset for the 2020 and the 2040 horizons is only available at a country level, and in the end, the scenarios presented in the previous paragraph are to be retained as very uncertain.

Cambodia has no development horizon that goes further than the current five year plan that will end in 2019. The country will remain dependent of the funding capacities of international donors and financial organizations to implement its development. This will give the path of the development dynamics. For sure, the funds will concentrate on the existing scheme's rehabilitation rather than in the creation of new ones. Another point of uncertainty is linked to the investment of agro-industrial enterprises that has bloomed in the past year and that is out of control of the planning strategy of the MoWRAM.

Laos has proposed a clear strategy for the development of the large irrigation projects. Their development is to be connected to the development of the large dams for hydropower purpose. The uncertainties in the development of this sector will surely impact directly the development of the irrigation projects. As it has been highlighted in the previous section, the national strategy does not mention clear objectives for the development of the small and medium scale irrigation. These will play an important role and will benefit from the development of the large-scale system.

Thailand clearly mentioned that the strategy existing a decade ago for the development of the Khong Chi and Mun watersheds is now under discussion and that the development process had been halted. This is one of the reasons that led to limit the data collection to the provinces riverine from the Mekong river. With time, these large projects linked to inter-basin water transfer may come back on the agenda of the irrigation sector development. The figures of BDP2 would be a good basis to characterize these largest development potentials.

Vietnam has depicted it roadmap for the development of the sector. The Mekong delta area will foresee a decay of its irrigated agriculture driven by the urbanization growth and the effects of the climate change (salinization and water level rise). There is no doubt that the climate change effects will bring a lot of uncertainty to the region. If the figures characterizing the extension of the irrigation area in the delta should not vary drastically, there is a large uncertainty on the cropping patterns and alternative crops that the farmers will adopt. The switch to aquaculture currently undertaken will have to be observed particularly. For the Central Highlands area, the national strategy has not yet depicted objectives that go beyond 2030. Many uncertainties will characterize this part of the country's development that is currently driven by questions of national security.

These uncertainties will need to be cleared by additional involvement by each country. They will also lead the formulation of the sub-scenarios.

Globally, in the Mekong river basin, the path of the irrigation development for the horizons foreseen by the council study (2020 and 2040) will be strongly linked to the two following issues:

1. **The need for food production** to feed a global population that shall reach 10 billion inhabitants by 2050. In this challenge that is to be addressed globally, the LMB being one of the most important areas for food production in general and rice production in particular will have to play a key role. This global question of food security will bring investments in the areas with a high production potential as the LMB is.

2. **Climate Change**, will bring uncertainties and threats to the above-mentioned production area. Droughts are predicted to increase either in frequency and intensity. The 2015-2016 El Nino episode has severely impacted the whole Asian rice cultivation. In this context irrigation infrastructure development will play a key role to secure access to water resources and limit the impacts. On the other hand these developments will be sensitive to the flooding hazards of the Mekong river.

These issues are planned to be addressed by the Council study in the second phase of the project.

4.4 Fertilizer and pesticide use

Activities were developed to document the direct impacts and to provide the information required to assess the impacts on Fertilizer and Pesticide use (F&P). The activities conducted so far were the following:

- Collection of relevant literature about the use of fertilizer and pesticides at the national level
- Collect and synthetize national; local and other plans for the use and control of (F&P)
- Collect and organize statistics on the use of (F&P)

The activity started lately and is still in progress. Different achievements were met among countries according to the availability of data and the researches of the national consultants.

Cambodia

A table was prepared, detailing the existing conditions for the 4 main regions of Cambodia. In addition, a description of the pesticides and fertilizers used in Cambodia with their origin of importation was presented.

The fertilizer use has shown to be very variable according to the region and to the type of crops for the years 2007, 2009 and 2011. In the plains, farmers generally tend to use much more fertilizer in the dry season compared to the wet season with 170 kg/ha in average compared to 120 kg/ha respectively.

Emphasis must also be given on the huge variability in the use of fertilizer according to the access farmers have to get it and the knowledge they have on their use. The fertilizer importations have increased by nearly ten times in ten years.

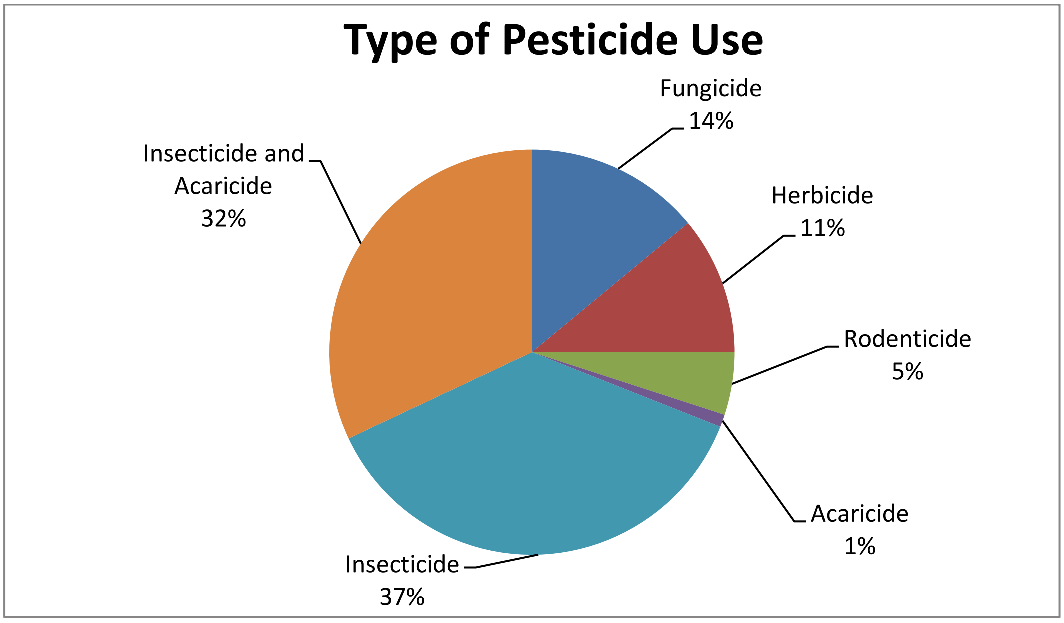
Regarding pesticides, the information details the type of pesticides used in Cambodia and the importations in the last years. Importations rose from 200 tons in 2002 up to 12,000 tons in 2012.

The awareness of Cambodian farmers on the effective use of chemical fertilizers and pesticide is limited. Most learn about the effective use through agricultural extension workers and agricultural extension programs.

This lack of awareness leads to sanitary, environmental and economic impacts for the farmers.

Table 4: Fertilizer use in Cambodia by region, in kg /ha (Source: CARDI, CSES 2007–2011)

Crops	Mekong Plain			Tonle Sap		
	2007	2009	2011	2007	2009	2011
Dry season rice	261.7	199.4	194.2	108.2	101.4	153.2
Wet season rice	127	200.1	142.8	79.4	103.5	84.4
Corn	112.6	129.9	176.8	161.1	52.3	55
Cash crops	179.7	206.9	170	46.1	50.4	67.3
Cassava	48.2	82.8	95.8	0	27.2	85.3
Vegetables	365	293.4	203.8	141.2	201.6	71.9
Others	188.2	221.4	161.5	135.6	134	158.3
Crops	**Coastal**			**Plateau/Mountain**		
	2007	**2009**	**2011**	**2007**	**2009**	**2011**
Dry season rice	0	182.2	179.4	50.4	61.3	177
Wet season rice	163.3	141	105.2	93.3	124.4	126.4
Corn	377.5	39.9	174.5	0	25.2	50.4
Cash crops	342.9	195.8	145.5	65	52.8	69.4
Cassava	0	35.5	70.9	0	90.1	30.9
Vegetables	566.1	118.2	235.7	340.1	257.4	225
Others	416.1	179.1	116.7	118.6	104	89.1



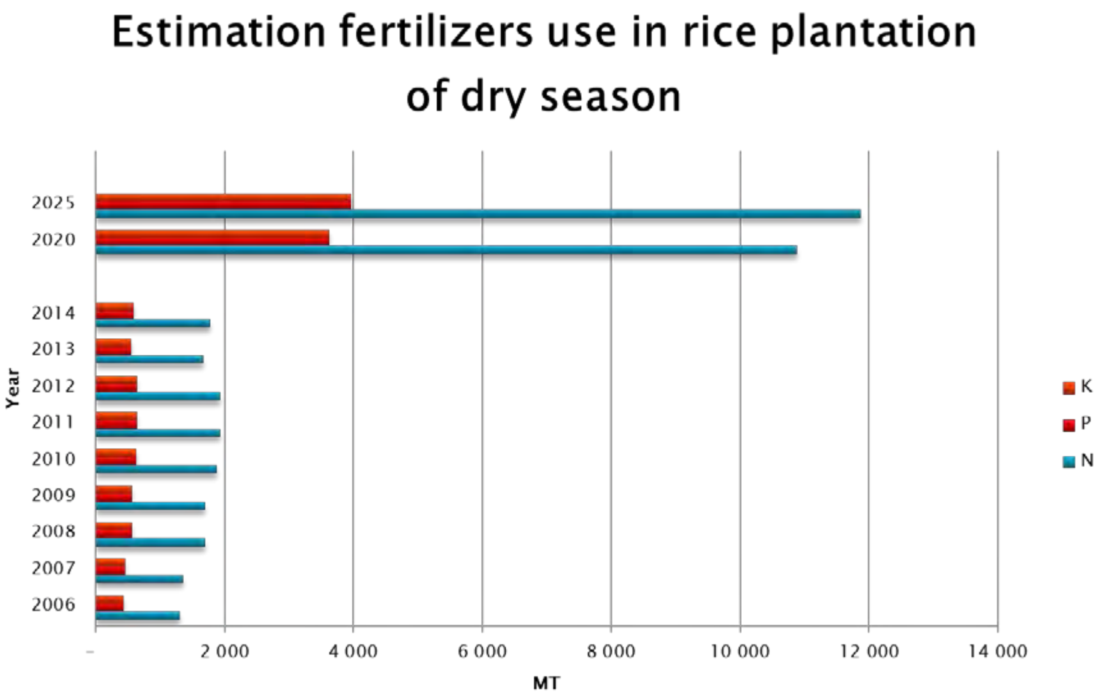
Laos

A data collection was conducted at a province level to document the present and future forecasted use of fertilizer and pesticides in the country. The dataset on the existing conditions is well described and will be useful for the model calibration. The files are annexed to the report.

Pesticides are used mainly on dry-season irrigated rice, corn, vegetables, cash crops and plantation crops, notably rubber. There still is wide-spread abuse of pesticides among farmers due to the lack of knowledge in their use that might lead to mixes without justification, use of wrong pesticides, use of wrong dosages, etc. The spread of the products is generally done without any adequate protective gear.

From 1999 to 2011 the share of households using chemical fertilizer has grown from 28% to 42% at a national level and from 33% to 40% for organic fertilizer. Similarly, in the same period, the share of households using pesticides has grown from 11% to 17% at a national level.

The analysis conducted by the consultant has prepared the Fertilizer and pesticide use rates to be used for the scenario development for the ED scenario and for the DFS scenario. This analysis details by province the average use for the rice cultivation and for the cash crops from 2006 to 2012 and gave projections for 2020 and 2040. The formulation of the fertilizer in N P and K is also detailed. In line with the planned development of the irrigated agriculture sector, the projections predict a huge development. (Louanglath, 2016)



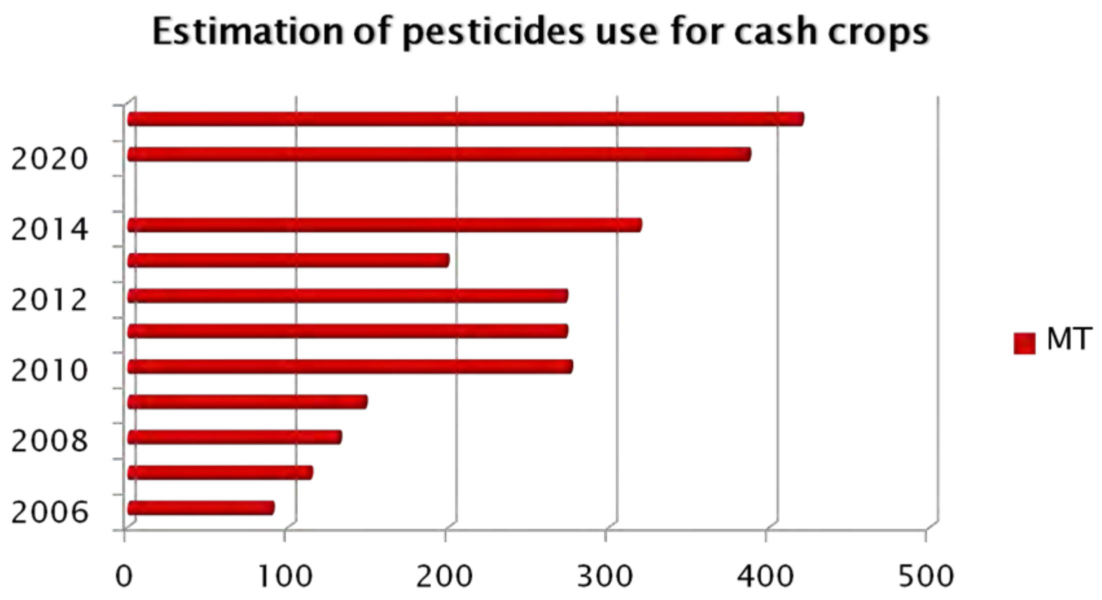


Table 5: Fertilizer and pesticide use rates to be used for the scenario development

	Early Development			*Definite future scenario*		
	Year 2007			**Year 2020**		
Chemical Fertilizers use	**N (MT)**	**P (MT)**	**K (MT)**	**N (MT)**	**P (MT)**	**K(MT)**
Irrigated rice field	1,310	437	437	10,890	3,630	3,630
Cash crops plantation	3623	1721	1657	69,040	22,321	26,767
Pesticides use						
Irrigated rice field	No data			No data		
Cash crops plantation	113			386		

Thailand

Only general statistics on the fertilizer and pesticide use at the national level were collected so far. The information underlines the linear growth of the fertilizer consumption from 1977 up to 2011 ranging from 1.0 to nearly 6.0 million tons per year.

Similarly, the importations of pesticides have ranged from 20,000 tons up to 170,000 tons between 1994 and 2013. (Chitbut, W.; Poapongsakorn, N., and Aroonkong, D., 2014)

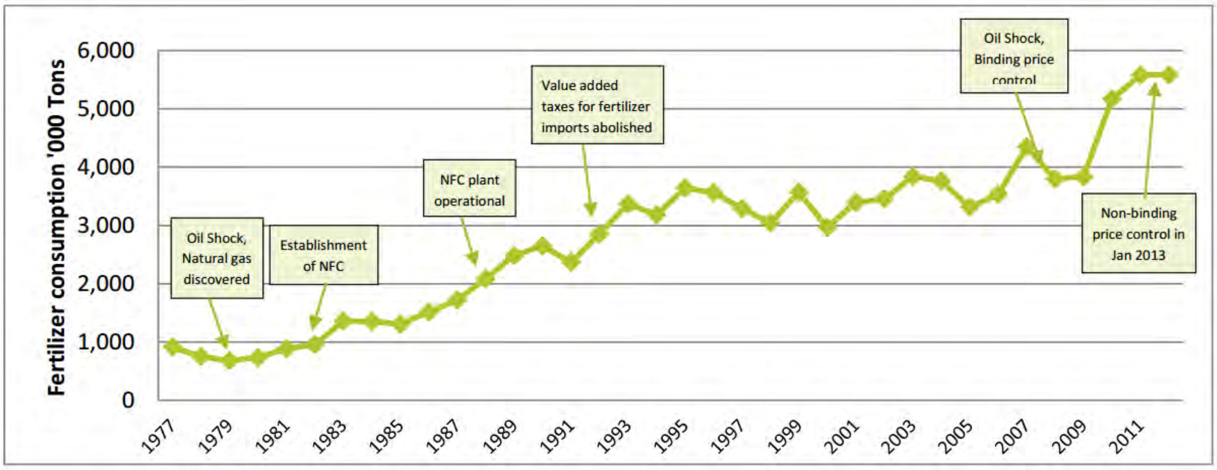


Figure 12: Timeline of Thailand's major fertilizer polices and events

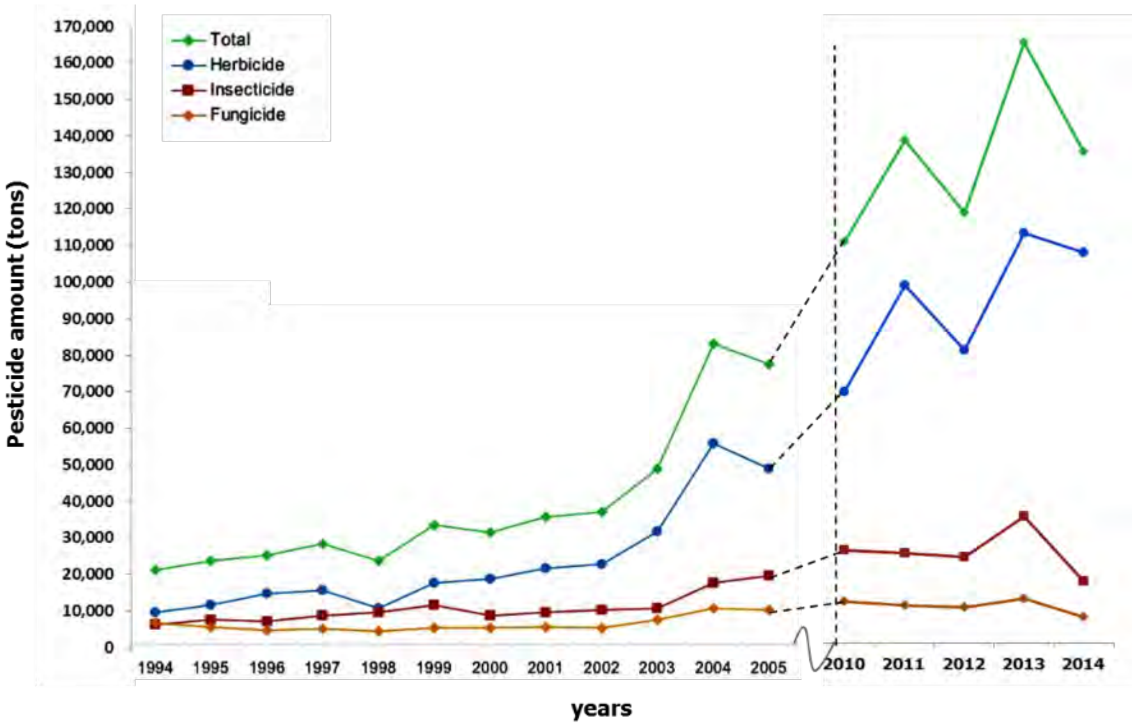


Figure 13: Tonnes of pesticide imported in Thailand between 1994 and 2014

Vietnam

A collection of national statistics issued from ministerial websites and scientific literature has been combined in a preliminary draft report to document the fertilizer and pesticide use in Vietnam.

Information is collected to describe the early development horizon with reference to the 2007 situation regarding the fertilizer consumption, formulation and importation.

From 1985 to 2007, the cultivated area in the country rose by 57.7 % and in the same time, the amount of fertilizer used increased by 517 %. According to calculations, the amount of inorganic fertilizer use increased significantly over the past 20 years: total nutrient elements N + P_2O_5 + K_2O reached 2.4 million tons in 2007, more than 5 times the amount used in 1985. In addition to the use of inorganic fertilizers, Vietnam annually still uses about 1 million tons of organic fertilizer , bio-organic , organic micro categories.

Regarding the utilization rate of fertilizer for different crop groups, rice crop is the major user with 65% followed by perennial plants with 15%. However, compared with other countries in the region and in the world, the amount of fertilizer used per unit of cultivated area in Vietnam is still low, the highest year reached only about 195 kg NPK / ha.

According to calculations by experts in the field of agro-chemicals in Vietnam, the current fertilizer use has a low efficiency: Nitrogen fertilizer use efficiency only reached 30-45%, the phosphate reached 40-45% and potassium reached 40-50%. Consequently, 60-65% nitrogen equivalent to 1.77 million tons of urea, 55-60% of the phosphorus equivalent 2 , 07 million tons of superphosphate and 55-60% potassium intake equivalent to 344 thousand tons of potassium chloride (KCl) is applied to crop land but not yet used. Part of these fertilizers that has not been used remains in the soil, partly under the water surface are washed away by rain, according to irrigation ponds, lakes, rivers pollute surface water. Finally, a portion is leached vertically down the aquifer and partially vaporized by the impact of temperature or through the process of nitrification.

Table 6: The amount of inorganic fertilizer used in Vietnam from 1985 to 2007 in th. tons of N , P2O5 , K2O (Source Vietnam Department of crop production, 2015)

Year	N	P_2O_5	K_2O	NPK	$N+P_2O_5+K_2O$
1985	342,3	91,0	35,9	54,8	469,2
1990	425,4	105,7	29,2	62,3	560,3
1995	831,7	322,0	88,0	116,6	1223,7
2000	1332,0	501,0	450,0	180,0	2283,0
2005	1155,1	554,1	354,4	115,9	2063,6
2007	1357,5	551,2	516,5	179,7	2425,2

The use for organic and inorganic fertilizer is planned to increase in the next years, following the development of agriculture. The average rate of 198 kg/ha of 2007 will increase to 230 kg/ha by 2020. The projections are not available for the horizon 2040 corresponding to the planned development scenario. (Bui The, 2016)

Table 7: Forecast of Fertilizer use in Vietnam up to 2025 (Source Vietnam Department of crop production, 2015)

Type of fertilizers	Supply and demand in th. tons	2011	2015	2020	2025
Nitrogen fertilizer	Need	**1.500**	**1.650**	**1.806**	**1.806**
	Production	482	1.660	1.806	1.806
	Import	1.018	-	-	-
	Export	-	-	-	-
Phosphorus fertilizer	Need	**732**	**805**	**885**	**885**
	Production	417	677	967	967
	Import	315	127	-	-
	Export	-	-	82	82
Potassium fertilizer	Need	**522**	**585**	**673**	**673**
	Production	-	300	720	720
	Import	522	285	-	-
	Export	-	-	-	-
Total nutrient use		**2.754**	**3.040**	**3.364**	**3.364**
In kg / ha		**200**	**220**	**230**	**230**

The unskilled and unmanaged use of fertilizers and pesticides has also been documented to cause environmental pollution impacts in Vietnam. They are often manifested in the following aspects

- Fertilizer and excessive pesticide use causing environmental pollution

Farmers often excessively use nitrogen fertilizer on bare soils, mainly manure generally spilled on the ground that is not incorporated into the soil. This technique widely used over the basin limits the fertilizer use efficiency and favors pollution through leaching by rainfall. Similarly, the use of pesticides in overestimated quantities and in a not timely manner limits the effects of the proposed use and diffuses pollutants in the environment

- Pollution from factories producing fertilizers and pesticide

In addition to the unsustainable use of fertilizer and pesticides, pollution is also caused by the factories producing them. Numerous cases of environmental pollution caused by the discharge of water hazardous substances that have not been thoroughly treated were reported over the LMB.

- Use of fertilizer and pesticides containing toxic substances

The control on the quality and the formulation of the F&P products that are found in the market is not efficient. Fertilizers containing heavy metals and harmful microorganism are commonly found since they are produced from raw materials such as municipal waste, industrial waste from agricultural processing, food or livestock waste.

5 Scope of the assessment

As defined by the Council Study Inception Report and the Implementation Plan, irrigation thematic team studies:

- Irrigation water use and return flows
- Changes in downstream flow
- Water quality
- Irrigation impacts on the other sectors
- The other sector impacts on irrigation, especially on dry season irrigation.

The Geographic scope of the irrigation impact assessment is based on the SIMVA Corridor shown in Figure 14.

Figure 14: Council Study impact assessment corridor. Same as used in the MRC Social Impact Monitoring and Vulnerability Assessment, or SIM/VA, of the Environment Programme.

The Council Study modelling is set up for the whole basin to account for its hydrology and different development interventions.

As defined by the Inception Report and the logical framework in the Implementation Plan, the irrigation study and this Irrigation Report highlight:

- rate of irrigation expansion
- induced changes in flow parameters
- resulting changes in environmental, social and economic parameters including issues of food security, employment and transboundary benefits and costs

- impacts on fisheries
- impacts of other developments on irrigation including dry season irrigation.

6 Data availability and quality

Irrigation data collected from member countries by Irrigation Thematic team are in provincial level. Cambodia, Lao PDR and Vietnam provided data for the entire watershed area for year 2007 and Thailand provided data for the Council Study assessment corridor.

In Cambodia, the irrigation data has been limited for instance for wet, dry and 3rd season rice. Therefore, database from BDP2 that AIP (Agriculture and Irrigation Program) has been used for filling the seasonal information for the council study.

In Lao PDR, missing data for dry season rice and non-rice has been gap filled using ratio of Non-Rice/Dry Season Rice in year 2014 as guidance to estimate values for the years 2020 and 2040.

In Thailand, as the Council Study modelling requires information on whole basin irrigation, the missing data of irrigation in other provinces outside the corridor has been gap filled with the BDP2 data.

In Viet Nam, the irrigation data collected by the national consultants requires no gap filling. The data provided by the country can be used for development scenario assessment. The data also includes fertilizer use for wet, dry and 3rd crop.

Description of the data collection and compiled data sets are presented in the Irrigation Team report "Thematic Report on the positive and Negative Impacts of Irrigation on the Social, Environmental and Economic Conditions of the LMB and Policy Recommendation." Data collection for the irrigation scenarios are described in the report "Development Scenarios for the Irrigation Thematic Area". Data gap filling is described in the Technical Report on "Data Analysis and GAP Filling for Model Simulation" prepared by the Modelling Team.

7 Irrigation scenarios

7.1 Baseline

Previous studies, e.g. BDP1, World Bank 2004 and Fast Track Scenarios of BDP2, have shown that the irrigated agriculture consumes the most water use in the LMB. Irrigation accounts for approximately 10% of the mean annual flow of the Mekong river basin.

The maximum irrigation area data show a wide range of concentrations of irrigation on different regions (Figure 15). The wet season irrigation area is dominated by the wet season irrigation in Mun-Chi of Thailand and in the Mekong Delta of Vietnam. There also significant irrigation areas in the northern part of Thailand, in sub-area basins along the Mekong River on the Thai side, in the central part of Laos and around the Great Lake in Cambodia. The irrigated area during the wet season in the Northern part of Laos and in sub-basins near the Vietnam border is relatively small and even very small during the dry season. The irrigated area in Cambodia upstream of Kratie to the border with Vietnam and Laos is also very small.

The distribution pattern of the dry season irrigation areas is similar, but is dominated by the dry season irrigation area of Vietnam Mekong Delta, approximately 1.5 million ha. The other areas with significant dry season irrigation are Mun-Chi, the Cambodian part of the Mekong Delta and central part of Laos.

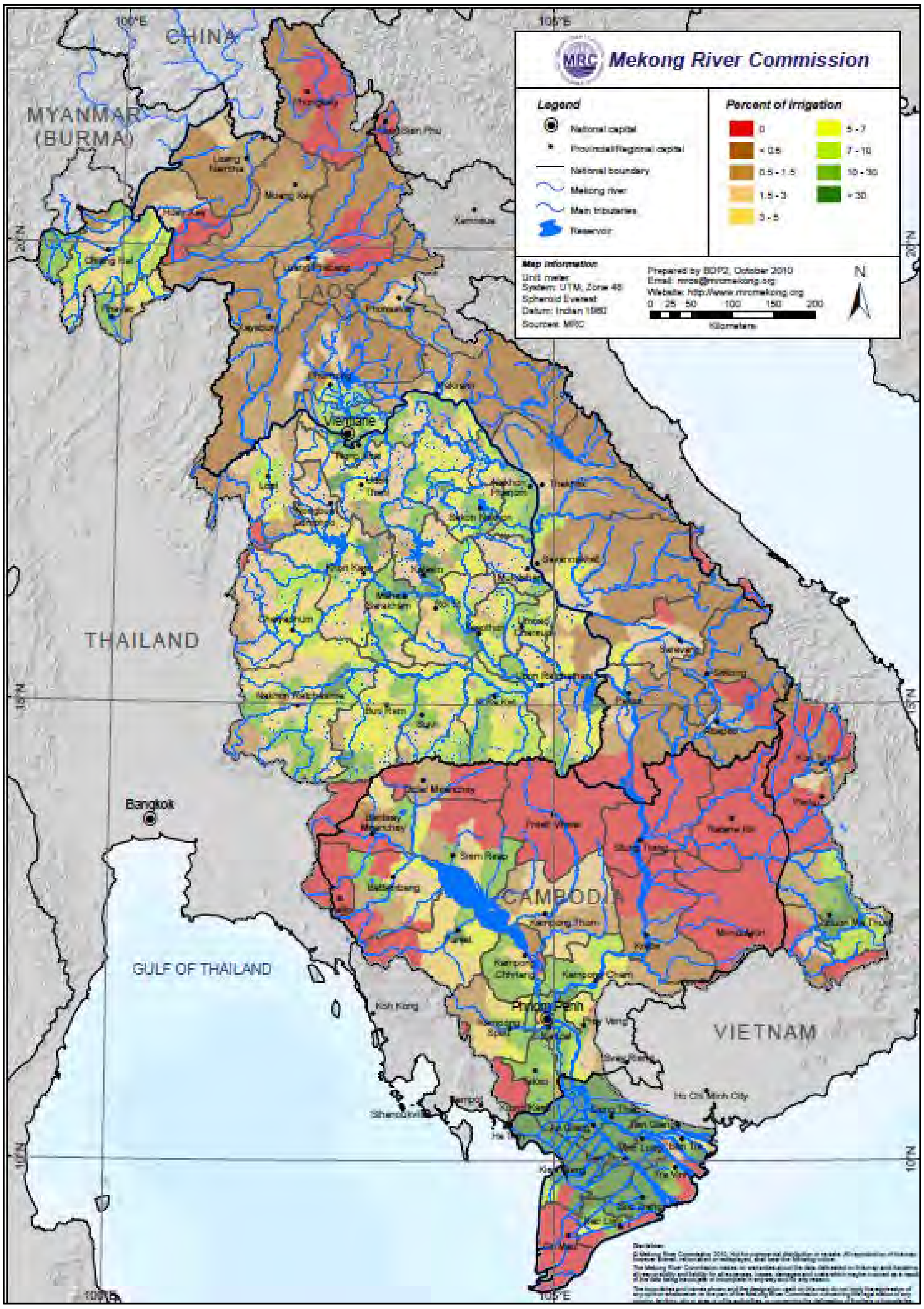


Figure 15: BDP2 baseline irrigated area percentages for each province.

7.2 Main scenarios

Based on the data collection by national consultants (National reports for irrigation thematic area of the Council Study provided each national member country) and data gap filling based on national and BDP 2 data and information as described in the Chapter 6, the main irrigation scenario data is summarized in Table 8 below. (Vonnarart, O. and Nguyen Dinh, D., 2017)

Table 8: Summary of the main cumulative scenario irrigation areas.

Country	Wet Season Rice (Ha)	Dry Season Rice (Ha)	3rd Season Rice (Ha)	Non-rice (Ha)	Annual Crops (Ha)	Irrigated in Wet Season (Ha)	Irrigated in Dry Season (Ha)	Irrigation Area	Total Area (Wet + Dry)
Early Development Scenario (Existing 2007)									
Cambodia	273,337	260,815	16,713	12,317	0	290,050	273,132	504,245	563,182
Lao PDR	209,116	70,080	0	55,884	0	209,116	125,964	209,116	335,080
Thailand	776,980	85,024	0	144,926	0	776,980	229,950	809,671	1,006,930
Viet Nam	1,719,130	1,588,923	744,308	399,317	884,960	3,348,398	1,988,240	3,348,398	5,336,638
Total LMB	2,978,563	2,004,842	761,021	612,443	884,960	4,624,544	2,617,285	4,871,430	7,241,829
Definite Future Scenario (Incl. 2020 plans)									
Cambodia	456,837	378,919	21,593	20,012	0	478,430	398,931	778,499	877,361
Lao PDR	309,068	121,172	0	75,603	0	309,068	196,775	309,068	505,843
Thailand	1,544,296	265,216	0	329,343	0	1,544,296	594,558	1,582,554	2,138,855
Viet Nam	1,701,148	1,563,330	649,142	408,423	893,727	3,244,017	1,971,753	3,244,017	5,215,770
Total LMB	4,011,349	2,328,636	670,735	833,381	893,727	5,575,811	3,162,017	5,914,138	8,737,828
Planned Development Scenario (incl. 2040 plans)									
Cambodia	678,030	746,808	387,832	20,704	0	1,065,862	767,512	1,156,025	1,833,374
Lao PDR	597,893	252,996	0	149,518	0	597,893	402,514	597,893	1,000,407
Thailand (incl Khong Chi Mun Phase 1)	2,145,161	358,986	0	399,414	0	2,145,161	758,399	2,215,274	2,903,560
Viet Nam	1,674,915	1,519,530	632,575	409,318	881,170	3,188,660	1,928,848	3,188,660	5,117,508
Total LMB	5,095,999	2,878,320	1,020,407	978,953	881,170	6,997,576	3,857,273	7,157,852	10,854,849

7.3 Sub-scenarios

The sub-scenarios are:

- I1: This sub-scenario assumes that irrigation investments are not being made and that irrigation areas remain at the state of 2007 while all other sectors change to the state of 2040.
- I2: Similar to A2, this sub-scenario assumes additional expansion of irrigation areas beyond what is assumed for M3CC, while all other sectors change to the state assumed for M3CC.

Table 9 Sub-scenarios to test the effects of water resources development in the irrigation sector.

	Scenario and sub-scenarios	Level of Development for water-related sectors						Climate	Flood-plain
		ALU	DIW	FPF	HPP	IRR	NAV		
M3	Planned Development Scenario 2040	2040	2040	2040	2040	2040	2040	Mean warmer & wetter	2040
I1	Planned Development 2040 without IRR	2040	2040	2040	2040	**2007**	2040	Mean warmer & wetter	2040
I2	Planned Development 2040 with IRR HIGH	2040	2040	2040	2040	**HIGH**	2040	Mean warmer & wetter	2040

The I2 irrigation sub-scenario is defined as highest level of the irrigated area expansion in 2040. It is assumed that all existing irrigation projects, planned projects, 100% of potential development projects will be implemented in full capacity. As the member country policies do not in general reach until 2040, the data from the Long-term Future development scenario of BDP2 for the proposed irrigation development in 2060 scenario is used to fill the gaps here. (Young, 2009)

Table 10: Summary of the sub-scenario irrigation areas.

Country	Wet Season Rice (Ha)	Dry Season Rice (Ha)	3rd Season Rice (Ha)	Non-rice (Ha)	Annual Crops (Ha)	Irrigated in Wet Season (Ha)	Irrigated in Dry Season (Ha)	Irrigation Area	Total Area (Wet + Dry)
Sub-scenario IRR 2 (High)									
Cambodia	678,030	746,808	387,832	20,704	0	1,065,862	767,512	1,156,025	1,833,374
Lao PDR	714,979	507,885	0	111,704	0	714,979	619,589	717,265	1,334,568
Thailand	2,339,708	421,784	0	592,454	0	2,339,708	1,014,238	2,396,711	3,353,946
Viet Nam	1,674,915	1,519,530	632,575	409,318	881,170	3,188,660	1,928,848	3,188,660	5,117,508
Total LMB	5,407,632	3,196,007	1,020,407	1,134,180	881,170	7,309,209	4,330,187	7,458,661	11,639,396

8 Assessment indicators

The Inception Report and Thematic Team output logical framework presented in the implementation plan define the key indicators/outputs for the irrigation as:

- Timeline of irrigated area for wet and dry season
- Changes in agricultural production
- Changes of irrigation demand and return flow
- Changes in fertilizers and nutrient loads
- Impact of irrigation on fishery within irrigated area
- Impact of other sectors' development on irrigation.

The indicators are further grouped into a) environmental, b) socio-economic and c) transboundary indicators:

a) Impacts of flow and nutrient loads on environment:
   - Water quality
   - Saline intrusion
   - Biodiversity
   - Fisheries production

b) Socio-economic indicators include:
   - Impact of flow changes on social, economic and employment indicators
   - Expected impact on food production/food security
   - Household/farm income

c) Transboundary indicators include:
   - Impact of flow changes on transboundary benefits and costs

The most important indicator is crop yield as it relates to socio-economic factors such as household income and food security. Second important indicator is irrigation demand as it relates directly to water resources management and water availability.

The different models used for the above indicators are listed in the Table 11.

Table 11: Indicators and corresponding models used in the Council Study

Indicator	Model	Justification
Timeline of irrigated area for wet and dry season	None	Model input data
Changes in agricultural production	IWRM FAO AquaCrop	IQQM and SWAT would require calibration; IWRM crop model has been applied before in the region and is state-of-the-art
Changes of irrigation demand	IQQM and IWRM FAO AquaCrop	IQQM for whole basin; IWRM for more detailed spatial impact analysis in the SIMVA corridor
Changes of return flow	Data from the countries	(Possible to compute with the IWRM model but would require validation)
Changes in fertilizers and nutrient loads	SWAT	SWAT is used for all nutrient loads
Impact of irrigation on fishery within irrigated area	None	Not in the modelling scope
Impact of other sectors' development on irrigation	SWAT; DSF (SWAT+IQQM+ISIS)	SWAT model output for sustainable irrigation area; the three models impact on mainstream flow and water availability
Water quality	DSF; IWRM	DSF required for whole watershed and river channel water quality; IWRM model for specific BioRA indicators based on the DSF results
Saline intrusion	ISIS; IWRM	ISIS required as salinity intrusion is hydrodynamically based; IWRM model for specific BioRA indicators based on the ISIS results; IWRM also for saline intrusion impacts on rice yields
Biodiversity	DSF; IWRM; DRIFT	Both DSF and IWRM provide indictors for BioRA biodiversity assessment
Fisheries production	DSF; IWRM; DRIFT	IWRM model using DSF results (water levels, sediments) for computing fish biomass; BioRA DRIFT expert assessment methodology for ecologically based fisheries assessment
Socio-economic indicators	DSF; IWRM; DRIFT	All models provide data for the socio-economic assessment; IWRM integrating DSF for socio-economic and BioRA DRIFT indicators
Transboundary indicators	DSF	DSF models compute transboundary flow changes

9 Impact assessment methodology

9.1 *Overview of the methodology used for each irrigation sector output*

Irrigation thematic outputs and corresponding methodologies are listed below. The outputs are specified in the Council Study Inception Report and the Implementation Plan logical framework (Table 1 and text).

Timeline of irrigated area for wet and dry season:

- Basic data from national consultations
- Gap filled by the modelling team
- High development irrigation sub-scenario can be estimated irrigation potential based on data available from BDP 2.

Changes in agricultural production:

- IWRM modelled irrigated yields in selected locations for generalization and socio-economic analysis
- Define separately for the different CS zones; based on demand maps sub-divide if necessary
- The assessment of crop production is focused on rice. Maize was not included in the socio-economic assessment and consequently it has not been assessed by modelling. Cassava and vegetable is not included in the assessment due to non-significant amounts of cultivation comparing to rice and maize.

Changes of irrigation demand and return flow:

- SWAT and IWRM modelled irrigation demands
- SWAT modelled sustainable areas
- Country specified return flow
- Define separately for the different CS zones; based on demand maps sub-divide if necessary.

Changes in fertilizers and nutrient loads:

- Use available thematic team data on fertilizer use, especially on irrigated area use
- Use literature data on nutrient loads from agricultural areas
- Complement data with SWAT modelling of nutrient loads.

Impact of irrigation on fishery within irrigated area:

- No data has been obtained from bio-assessment and use of agro-chemicals as well as other constraints for maintaining irrigated fisheries make this assessment less relevant.

Impact of other sectors' development on irrigation:

- Modelling team data especially on hydropower development impacts.

Impact food production/food security including agriculture and ecosystem services:

- Data from socio-economic and modelling discipline teams.

- The socio-economic analysis has detailed information on food security components as well as projected population growth. Combining these with modelling results of crop yield annual variation and yield changes in the scenarios gives detailed view on level of food security and related risks.

Impact on household/farm income:

- Data from socio-economic discipline team.
- Need to take into account inputs/costs (irrigation, agro-chemicals, labour, equipment, infrastructure etc.), crop yields as well as revenue. This information would be available from previous studies such as the World Bank Hydro-Agro-Economic Model for Climate Change Adaptation. In the Council Study the household income is assessed independently based on the DSF and IWRM modelling results such as SIMVA zones annual crop yields.

Impact of flow and water quality changes on transboundary benefits and costs:

- Data from modelling and S-E teams.

9.2 *Irrigation modelling methodology*

The hydrological indicators that affect irrigation demand include:

- rainfall
- soil water content
- evapotranspiration (potential and actual); includes impact of temperature.

Irrigation demand and sustainable potential for irrigation has been computed with the DSF IQQM model based on these hydrological factors. The model requires inputs from the hydrological model SWAT including daily rainfall, potential evapotranspiration and water yield. Based on this information and irrigation area definitions the IQQM model computes the irrigation indicators presented in ANNEX I. The computation method for crop water demand in IQQM is based on reference plant (grass surface) and crop dependent crop coefficient as implemented in the FAO-56 model (ref. Council Study IQQ modelling technical report).

In addition to the hydrological conditions irrigation demand depends on crop growth which in turn is affected by water availability, soil fertility, temperature (both daily average temperature and daily temperature fluctuation), salinity, flooding and CO_2 concentration. These factors in addition to detailed hydrological conditions are included in the FAO AquaCrop model that is integrated in the IWRM model. The IQQM computation is spatially lumped (not taking into account spatial variation in hydrological, soil, topography and river channel characteristics) for sub-areas whereas the IWRM/AquaCrop model is distributed and takes fully into account spatial variation. The land use information for the AquaCrop modelling is based on the MRC 2010 land cover map (Figure 16) supplemented with the BDP2 irrigation data. The BDP2 data is available as irrigation area map data (GIS polygons) expect in Vietnam the data is on provincial level only. This provincial information was used to derive spatial distribution through GIS programming. Different approaches for distributing the irrigation areas were trialled. The most natural results have been obtained using existing irrigation channels as basis for the distribution (Figure 17).

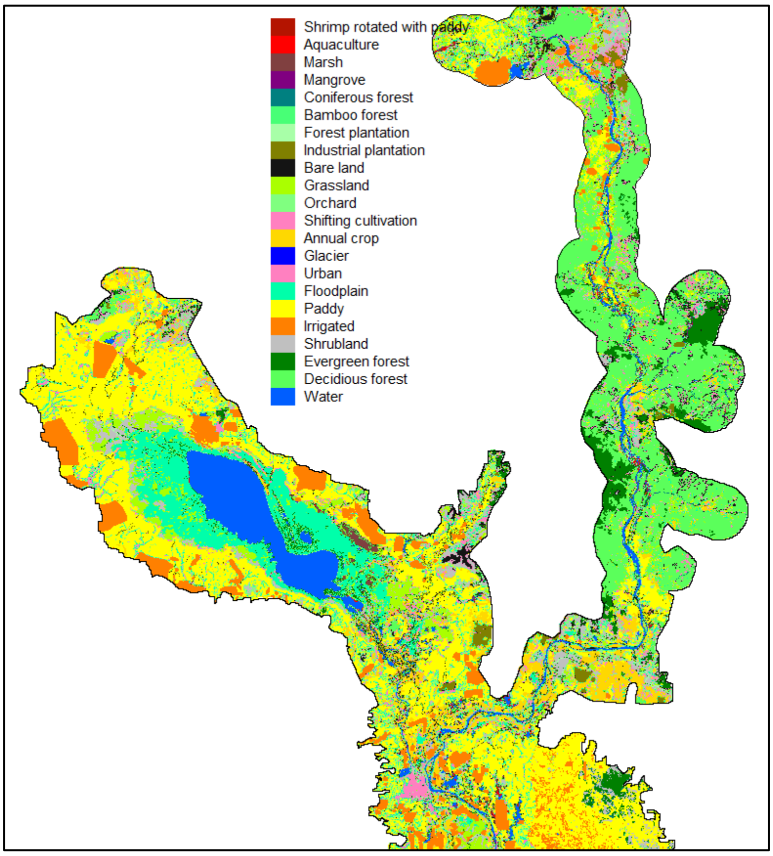


Figure 16: Sample of the land use map for irrigation assessment (MRC 2010 Land Cover combined with the MRC AIP irrigation maps). Orange colour indicates irrigated areas.

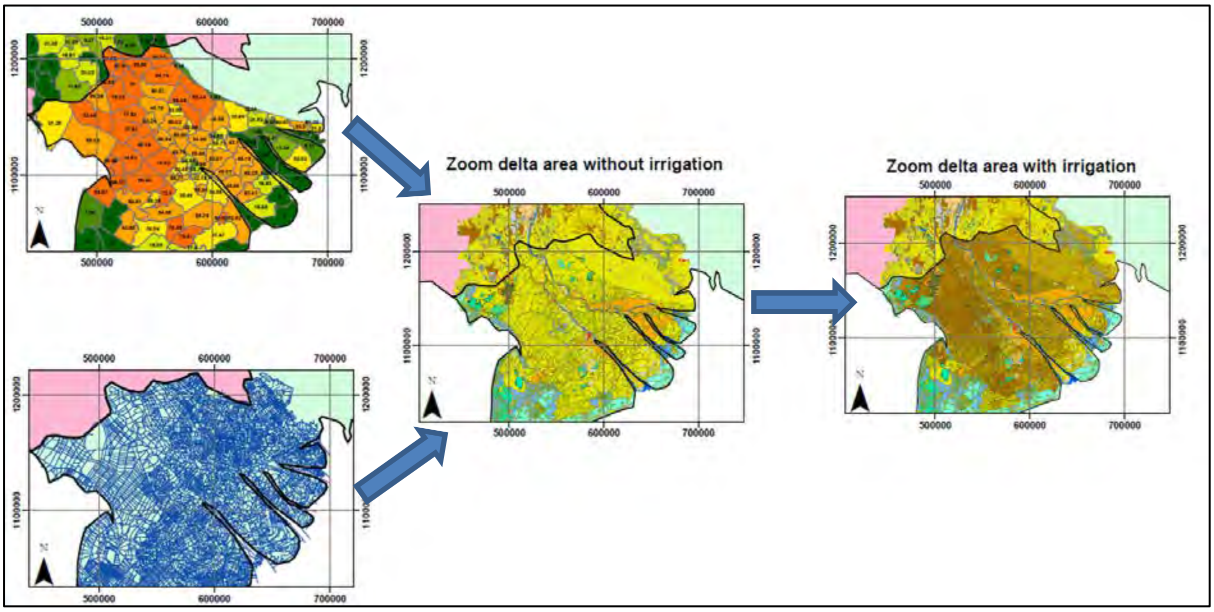


Figure 17: Generation of model irrigation areas based on the BDP2 provincial percentage data (left upper figure), river and irrigation channel network (lower left figure) and the MRC 2010 land cover data (middle figure).

9.3 *Spatial scope of the irrigation assessment*

In this report irrigation is analyzed on both whole basin/country and sub-zone impact corridor level. The country level is obvious because of national interests and because irrigation needs to be accounted for in a basin scale for flow and other impacts. Especially for transboundary impacts in the Delta and Cambodian floodplains whole upstream watershed needs to be accounted for (Figure 20 for BDP areas used for the DSF outputs). On the other hand, the Council Study social and economic analysis is done based on the SIMVA corridor (Figure 18), SIMVA sub-zones (Figure 19) and Council Study sub-zones (Figure 18). The modelling results have been processed for the SIMVA zones used in the socio-economic analysis (Figure 19 and Table 12) & two additional zones 6B and 6C (Figure 19) as requested by Vietnam. It should be noted that modelling has been set for the whole impact assessment area in Figure 18 but the *socio-economic impact assessment area in Figure 19 excludes tributary floodplains* that are important for rice and fish production. The socio-economic assessment is about 15 km on both sides of the Mekong mainstream from Chiang Saen up to the main Cambodian floodplains.

Figure 18: Council Study impact assessment area with main zone division.

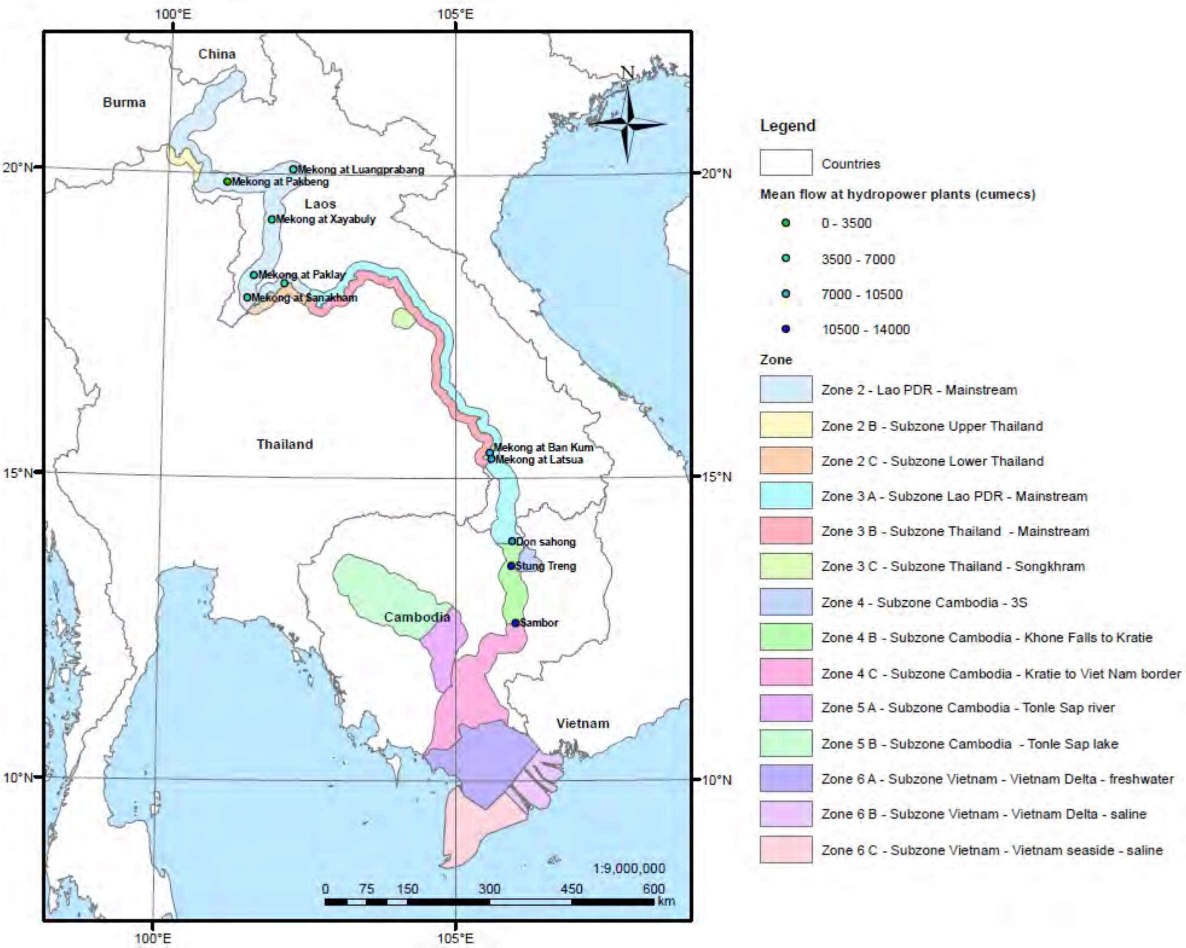


Figure 19: Model output areas for the socio-economic analysis

Table 12: Description of the SIMVA zones used in the model analysis and socio-economic study

SIMVA Hydro-ecological zone	Description: IBFM	Description: SIMVA	Social survey Sub-zones	Description
Zone 2	From Chinese border to	From Chinese border to Vientiane (Upstream)	Zone 2 - Lao - Mainstream	Lao PDR side of Zone 2
	Vientiane		Zone 2 B - Subzone Upper Thailand	Thai side of Zone 2 in 2 significantly different Sub-zones: Upper stream in Chiang Rai and Phayao Provinces and Lower stream west of Vientiane in Loei and Nong Khai provinces
	(Upstream)		Zone 2 C - Subzone Lower Thailand	
Zone 3	From Vientiane to Pakse	From Vientiane to Lao-Cambodian border	Zone 3 A - Subzone Lao - Mainstream	Lao side of zone 3 along the Mekong mainstream (incl. Vientiane)
			Zone 3 B - Subzone Thailand - Mainstream	Thai side of zone 3 along Mekong mainstream
			Zone 3 C - Subzone Thailand - Songkhram	App. 40 km upstream from confluence of Songkhram and Mekong – wetland areas and undammed river
Zone 4	From Pakse to Kratie	From Lao-Cambodian border to Cambodian Viet Namese border	Zone 4 B - Subzone Cambodia - 3S	App. 40 km from confluence of 3S and Mekong – undammed river, special eco-system
			Zone 4 A - Subzone Cambodia - Khone Falls to Kratie	Along Mekong mainstream down to start of floodplain
			Zone 4 C - Subzone Cambodia - Kratie to Viet Nam border	A 15 km zone around the maximum flooded area on the floodplain along the Mekong mainstream and Bassac east and south of Phnom Penh
Zone 5	From Kratie to Phnom Penh (upstream), incl.	From Phnom Penh up to and including Tonle Sap lake	Zone 5 A - Subzone Cambodia - Tonle Sap river	The socio-eco system of Tonle Sap river is considered different from the Lake so a special subzone has been drawn
	Tonle Sap		Zone 5 B - Subzone Cambodia - Tonle Sap lake	The area is defined as 15 km around the maximum flooded area (in year 2000)
Zone 6	From Phnom Penh to Mekong Delta.	From Cambodian-Viet Namese border to sea - the Mekong Delta	Zone 6 A - Subzone Viet Nam - Mekong Delta - freshwater	The subzone covers the area of the Mekong Delta which has freshwater
			Zone 6 B - Subzone Viet Nam - Mekong Delta - saline	The saline subzone has special characteristics such as problems with saline intrusion

10 Timeline of irrigated area for wet and dry season

Methodology for assessing irrigation development for the future scenarios as well as overview of the respective irrigation area changes for each country are presented in the Chapter 7.

10.1 Whole LMB irrigated area

Relative size of dry and wet season irrigated area in the BDP zones is shown in Figure 20. Total wet season irrigation area is similar in Vietnam, Cambodia and Thailand whereas irrigated area in Lao PDR is much smaller. Dry season irrigation is most developed in the Vietnam Delta as it has abundance of water available, branching natural river channels and well-developed irrigation channel network. Thailand has relatively small dry season irrigated area due to dryer climate and poorer water availability.

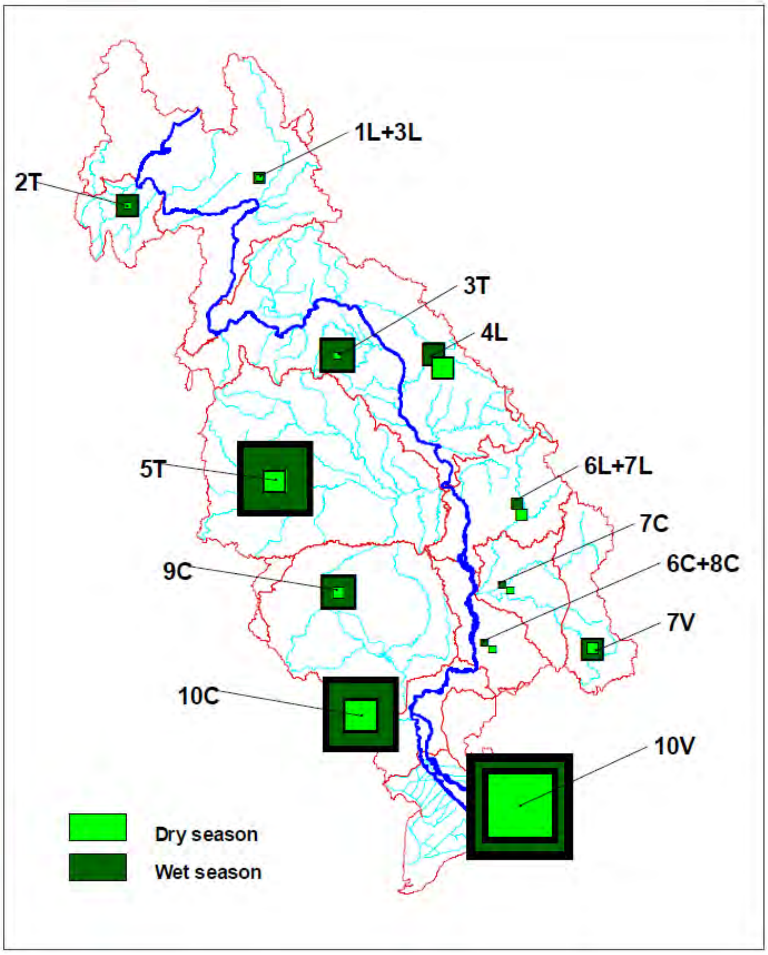


Figure 20: Distribution and relative size of baseline irrigation areas by BDP sub-areas (from BDP2 documentation).

Development of wet and dry season irrigated area in 2007, 2020 and 2040 scenarios is illustrated in the figures next page. Annex I Table 22 gives more detailed view of the irrigation areas for each country, scenario and month.

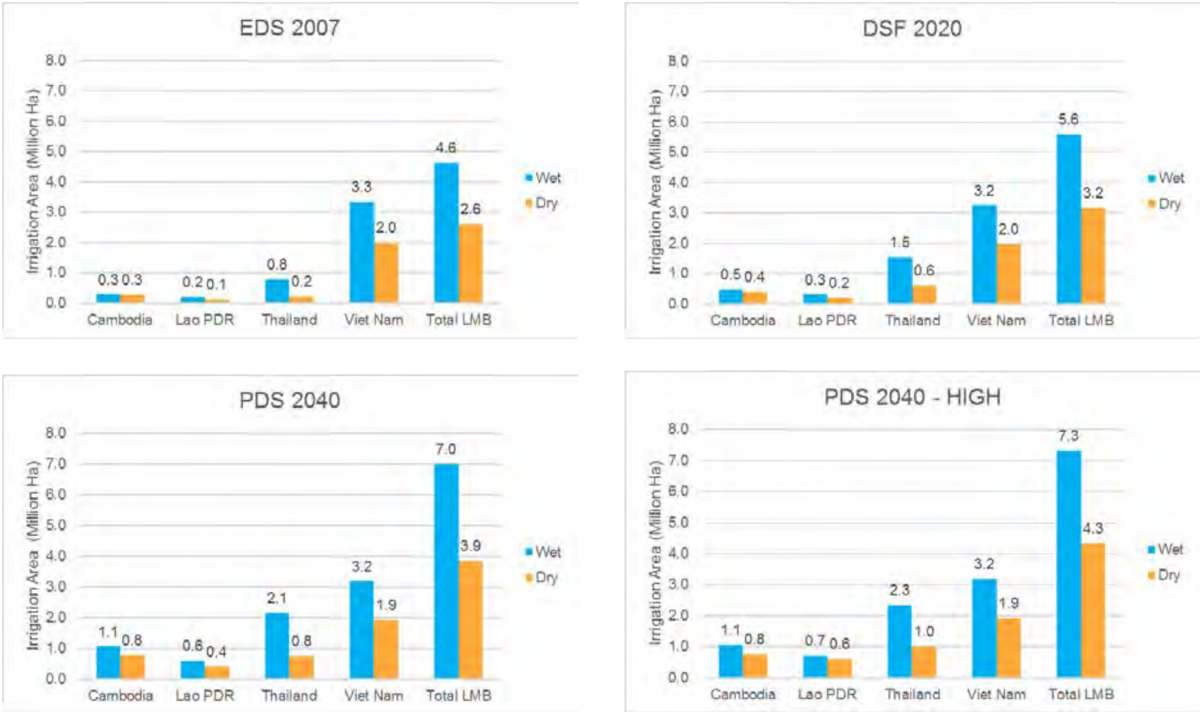


Figure 21: Wet and dry season irrigated area for 2007, 2020, 2040 and 2040 High development.

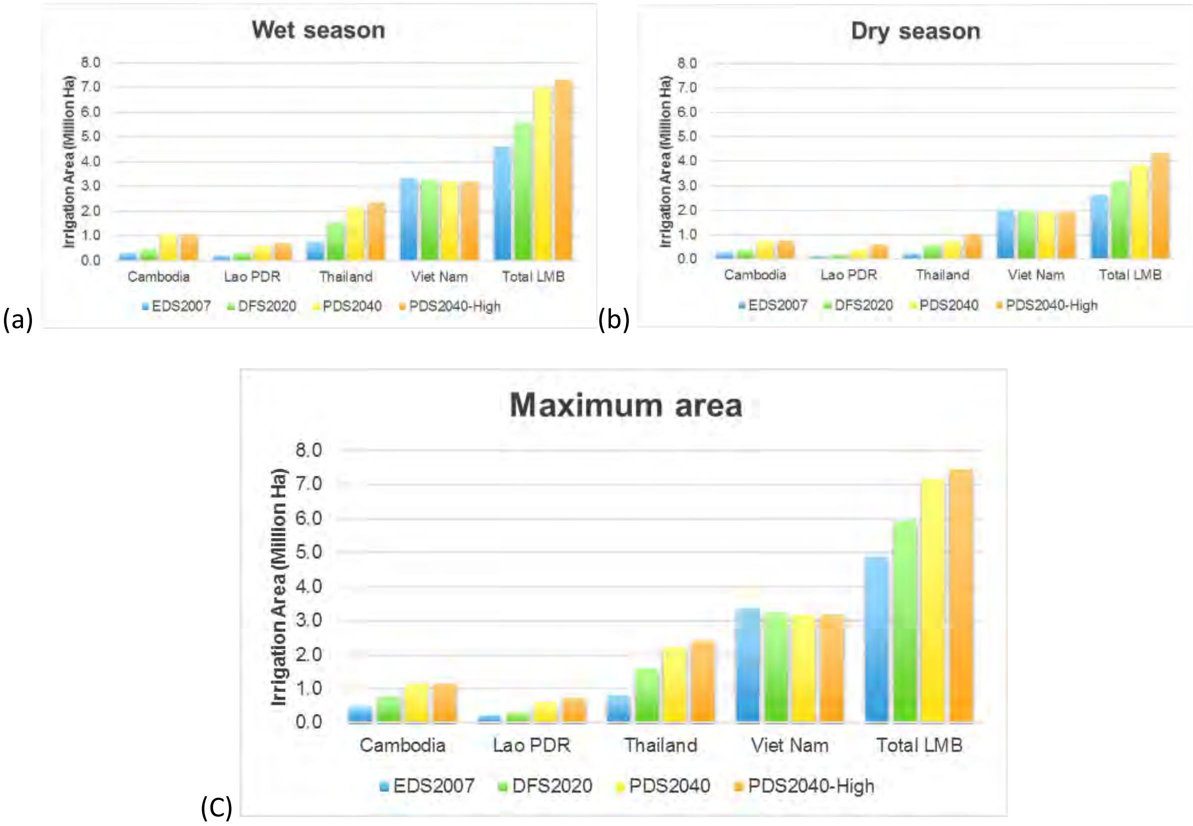


Figure 22: Irrigated area in 2007, 2020, 2040 and 2040 High development for (a) wet and (b) dry seasons and (c) maximum irrigation area.

The most significant characteristics of the irrigation development area:

- Cambodia increases irrigated area about 50% by 2020 (0.8 MHa) and roughly triples area by 2040 (1.2 MHa) compared to 2007 (0.5 Mha). The irrigated area between wet and dry seansons are not much different in 2007 but in the future, the irrigated area in wet season will be expanded around 20-40% more than those in dry season.
- Laos increases irrigation 50% in 2020 (0.3 Mha) compared to 2007 (0.2 MHa) and triples irrigation in 2040 (0.6 Mha) compared to 2007. Irrigation area in wet season is about 50% more than in dry season for all scenarios.
- Thailand doubles irrigated area in 2020 (1.6 MHa) compared to 2007 (0.8 MHa). Also 2040 (2.2 MHa) has significant increase of about 50% compared to 2020. It should be noted that the irrigation area in Thailand will reach the numbers mentioned 2040 in case that the first phase of major mainstream Mekong irrigation water diversion is fully operated. The irrigation area in wet season is triple dry season area.
- Vietnam has slightly decreasing trend for irrigation from 2007 (4.8 MHa) to 2040 (3.2 MHa). The irrigation area in wet season is around 50% higher than those in dry season.
- Irrigated area Thailand is significantly higher in the wet season than in dry season due to limited water availability and storage capacity in the dry season.
- In Cambodia and especially in Vietnam irrigated area remains similar in different seasons except in the highest flood months September to November.
- In total LMB, the irrigated area approximately increases 20% by 2020 (5.9 MHa) and 50% by 2040 (7.1 MHa) compared to 2007 (4.9 MHa).

10.2 Upstream LMB SIMVA corridor irrigated area

Figure 23 shows total paddy area in the upstream LMB from Kratie upstream for irrigated (planting date first of January) and non-irrigated (planting date mid-June) rice. The area is time averaged and depends on flooding. Irrigated rice area (dotted line) more than doubles from scenario M1 to M3 and M3CC.

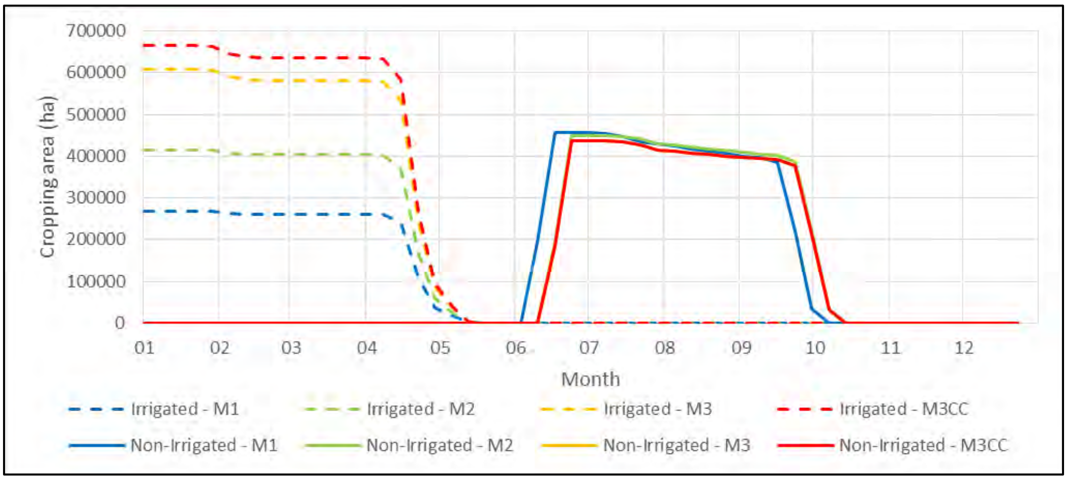


Figure 23: Upstream Kratie SIMVA corridor irrigated area in the dry season (dotted line) for M1, M2, M3 and M3CC scenarios compared to the wet season non-irrigated crop area (solid line).

11 Irrigation on country level

11.1 Irrigation demand

Based on the DSF results, total irrigation water demands by country and by each main scenario are presented in the Table 13. The irrigation demands include secondary and tertiary crops based on the crop calendars as presented in the IQQM report "IQQM Model for the Council Study, Main and Sub Scenarios" chapter (2.3.4) "Crop type and Crop Calendar for set up baseline model and Scenario Simulation." (Modelling team of the Council Study, 2017)

Table 13: Total irrigation water demand [m³/s] by country and main scenario (ref. DSF modelling reports)

	Scenario : EDS 2007_M1			Scenario : Dev 2020_M2		
Country	Wet (May -Oct)	Dry (Nov - Apr)	Annual	Wet (May -Oct)	Dry (Nov - Apr)	Annual
Cambodia	160	525	685	251	685	936
Laos	187	367	554	271	587	859
Thailand	838	369	1,208	1,383	659	2,042
Vietnam	974	6,061	7,035	922	5,957	6,879
Total	2,159	7,323	9,482	2,827	7,889	10,716

	Scenario : Dev 2040_M3			Scenario : Dev 2040_M3CC		
Country	Wet (May -Oct)	Dry (Nov - Apr)	Annual	Wet (May -Oct)	Dry (Nov - Apr)	Annual
Cambodia	638	1,104	1,742	668	1,117	1,785
Laos	511	1,211	1,721	495	1,282	1,777
Thailand	1,801	1,073	2,873	1,608	1,123	2,731
Vietnam	962	5,906	6,868	966	6,118	7,085
Total	3,912	9,294	13,205	3,737	9,641	13,378

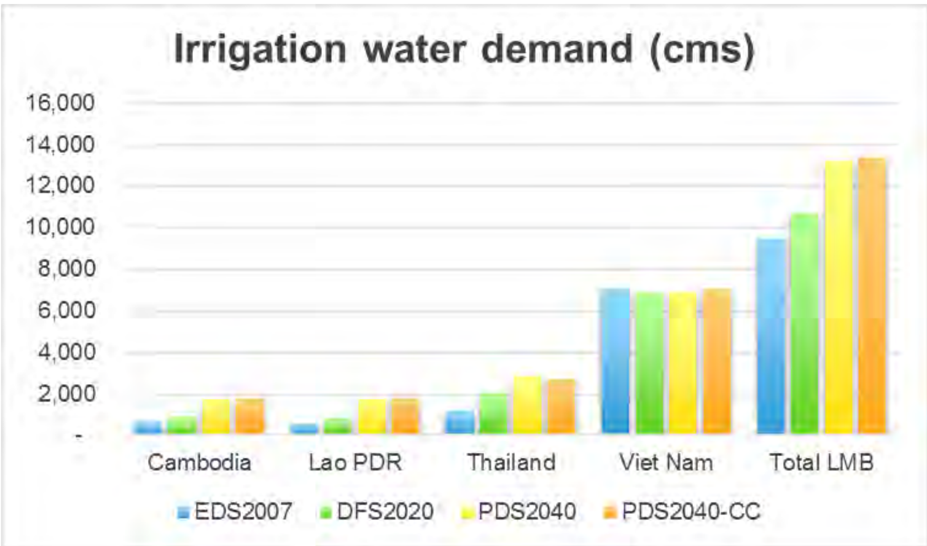


Figure 24: Total irrigation water demands [m3/s] by country and main scenario (ref. DSF modelling reports).

The changes of the national irrigation demands are caused by changes in the irrigation area. Climate change impact between M3 (2040) and M3CC (2040 CC) is small. This conforms to the AquaCrop model results that are shown in the later chapters.

The water demands can be compared with the Mekong discharges (Table 14 and Figure 25). The discharges include impact of irrigation, so they represent surplus of water in the Mekong mainstream. The future development scenarios except the climate change scenario will decrease total annual flow slightly due to increased irrigation area and consequent increased evapotranspiration. Also added number of reservoirs will increase evapotranspiration but this is insignificant compared to the impact of the irrigation increase. Seasonally discharge will decrease during the wet season and increase during the dry season due to the hydropower water storing during wet season and release during dry one (Figure 25). This is also shown by the Kratie monthly average discharge, Figure 26. The changes in the average hydrograph are small but they are much larger especially dry years.

Looking at the Figure 25 it is obvious that water security near the mainstream will be improving with the M2, M3 and M3CC scenarios despite of the increased irrigation area. However, the **analysis here doesn't include critical dry years** such as 2015 – 2016 when reservoir water levels reached critical levels in Thailand. Role of the hydropower reservoirs in mitigating droughts depends on available water and operations. For instance, the China dams start their higher release quite late in dry season so they would not alleviate early dry season droughts if operated in the current mode.

An interesting feature of the Delta dry season irrigation is that Kratie discharge is almost 2000 m3/s smaller in the baseline and about 700 m3/s in M2 and M3 than Vietnam Delta irrigation requirement. On top of this needs to be added Cambodia irrigation requirement. The balance doesn't seem to match but it must be kept in mind that:

1. Irrigation return flow is available for downstream irrigation (next chapter)
2. Delta is high precipitation area reducing irrigation demand.

Table 14: Mekong monthly, seasonal and average flows computed with the IQQM model

UNIT : cms

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

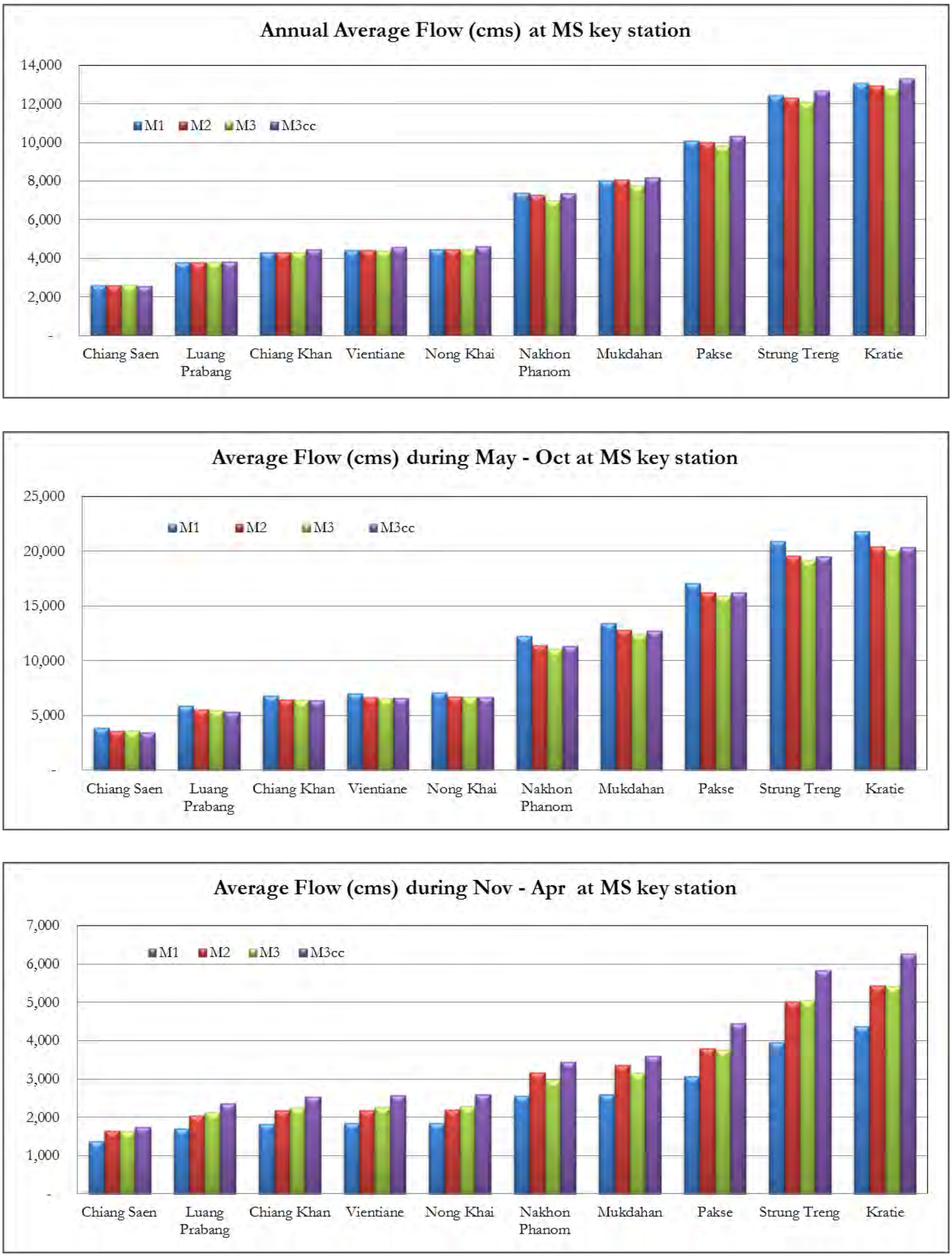


Figure 25: Average discharge [m³/s] for each country and main scenario (ref. DSF modelling reports).

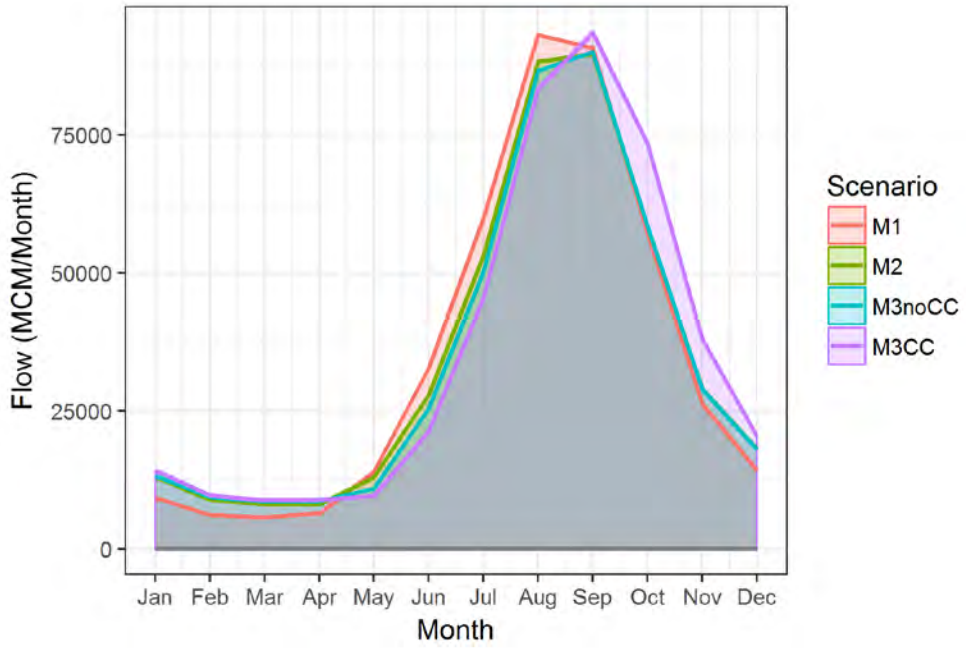


Figure 26: Average monthly flow volumes at the Kratie gauge for the four main scenarios (ref. SOURCE documentation).

Findings of irrigation water demand

- In Cambodia, the irrigation water demand increases 40% by 2020 (936 cms) and almost triple (1,742 cms) in 2040 compared to the demand in 2007 (685 cms).
- The irrigation water demand in Lao PDR, and Thailand also has increasing trend as similar as in Cambodia. Around 60-70% increase in 2020 and triples in 2040 compared to 2007.
- Viet Nam has slightly decreasing trend of the demand.
- Considering the irrigation water demand for the whole LMB, it increases around 20% by 2020 (10,716 cms) and 40% by 2040 (13,205 cms) compared to 2007 (9,482 cms).
- All countries require irrigation water in dry season 4-5 times more than those in wet season, except Thailand that has more needs of irrigation water in wet season.
- Future irrigation expansion has very small decreasing impact on annual water budgets.
- Due to the hydropower development, average dry season water availability will improve in the mainstream.
- Wet season water availability will decrease slightly in the mainstream but this has no impact on water security.
- Mekong tributaries are not included in the impact analysis and water security in them may be worse in the future due to irrigation development, climate change and reservoir operations (ref. Chapter 17 last finding).
- All aspects of the hydropower operations especially in exceptionally dry periods have not been analyzed in the study and may cause additional risks. For instance during exceptionally dry years flood is further delayed because of filling of reservoirs (ref. WUP-FIN earlier reports). This can cause serious consequences to the already stressed Mekong system.

11.2 Irrigation return flows

Irrigation return flow percentages have been defined by the member countries (Table 15). The relative return flows don't change between the scenarios but due to the changes in irrigation amounts also absolute irrigation values change in the scenarios (Table 16).

Table 15: Irrigation return flow (%) by country in each main scenario

Country	Wet (May -Oct)	Dry (Nov - Apr)	Annual
Cambodia	32	29	30
Laos	29	12	18
Thailand	29	20	26
Vietnam	13	15	15
Total	26	19	22

Table 16: Total Irrigation return flow [m³/s] by country in each main scenario

	Scenario : EDS 2007_M1			Scenario : Dev 2020_M2		
Country	Wet (May -Oct)	Dry (Nov - Apr)	Annual	Wet (May -Oct)	Dry (Nov - Apr)	Annual
Cambodia	80	259	339	125	332	458
Laos	109	83	192	158	129	287
Thailand	665	156	821	1,105	285	1,390
Vietnam	18	295	313	19	321	340
Total	872	793	1,665	1,407	1,067	2,475

	Scenario : Dev 2040_M3			Scenario : Dev 2040_M3CC		
Country	Wet (May -Oct)	Dry (Nov - Apr)	Annual	Wet (May -Oct)	Dry (Nov - Apr)	Annual
Cambodia	319	541	860	334	547	881
Laos	297	264	561	290	280	570
Thailand	1,440	459	1,899	1,282	477	1,759
Vietnam	19	320	338	19	332	351
Total	2,075	1,583	3,658	1,925	1,636	3,561

Irrigation efficiency is the proportion of irrigation that is supplied for crop growth after soil surface evaporation, return flow and on-farm and other losses have been subtracted from the total irrigation. The irrigation efficiency for the BDP sub-areas is shown in Table 17. Vietnam has the best efficiency by far followed by Lao PDR. The worst efficiency is in Cambodia and Thailand. The efficiency reflects not only irrigation losses and soil conditions but to large extent differences in climate such as rainfall, humidity and temperature.

Table 17: Irrigation efficiency for the BDP areas (ref. DSF modelling reports)

		Irrigation Efficiency - %			
Country	BDP Sub area	SCN M1	SCN M2	SCN M3	SCN M3CC
Cambodia	6C	61	61	61	61
	7C	61	61	61	61
	8C	61	61	61	61
	9C	60	60	59	60
	10C*	61	60	61	61
	11C*	61	61	61	62
Laos	1L	52	52	52	51
	3L	50	50	50	50
	4L	51	51	51	51
	6L	52	52	52	52
	7L	54	54	54	54
Thailand	2T	49	49	50	50
	3T	48	49	49	49
	5T	37	37	37	38
Vietnam	7V	76	75	75	75
	10V*	80	80	81	81
	11V*	80	80	80	80
	Country	SCN M1	SCN M2	SCN M3	SCN M3CC
	Cambodia	61	61	61	61
	Laos	52	52	52	52
	Thailand	45	45	45	46
	Vietnam	78	78	79	79
	Total	59	59	59	59

11.3 Sustainable areas

Monthly values for each country and main scenario are presented in ANNEX I. The tables in the annex show total diversions, sustainable areas and proportion of sustainable to total irrigation area. The ‘sustainable area’ is defined as irrigated area that can withstand moderate droughts through either stored water or water obtained from river flow.

The irrigation diversions don’t in general increase directly proportional to the irrigation area increase (Table 23 in ANNEX I). This is because different types of areas are hydrologically different and require different amounts of irrigation. Climate change has negligible impact on irrigation which conforms to the results of the detailed crop modelling presented in the next chapter for the Delta.

Model predicts quite significant reductions in sustainable area for irrigation in some months as compared with the total irrigation area (Table 25; more details by province are given Annex/Volume 4 in the modelling report). Laos and Vietnam have in general good water availability for irrigation as about 90% or more of the irrigated area is sustainable for all months. Thailand has good sustainability for the baseline scenario, but the sustainability decreases significantly with the development scenarios for the driest period January – April. It has not been possible to model sustainability for Cambodia.

11.4 Irrigation sub-scenario impacts

MRC DSF model has been used to analyze impacts of the irrigation sub-scenarios I1 (no irrigation) and I2 (high irrigation development). Scenarios I1 and I2 is compared with the M3CC scenarios that has year 2040 expected irrigation included but is in other ways identical to I1 and I2.

Table 18 below that is obtained from the IQQM report shows consistent changes in dry season flows connected to irrigation. The table shows that irrigation decreases especially the dry season flows up to 11% in M3CC compared to non-irrigation. Irrigation decreases flows further 3% in the I2 irrigation intensification scenario. ISIS modelling results give similar results as the IQQM ones.

Table 18 indicates that during the wet season irrigation impact on the Mekong mainstream flow is insignificant. Consequently, impacts to the other sectors are inconsequential during wet season. Based on the table it is difficult to assess how much M2 and M3 scenarios would exactly change flow compared to the M1, but the overall change compared to no irrigation is increased flow. I2, that is irrigation intensification compared to the M3, will decrease flows slightly while still maintaining overall positive impact to flow from irrigation. It can be concluded that during the dry season navigation, domestic and industrial water use and hydropower would benefit slightly from irrigation based on increased flow and water levels, less salinity intrusion and better water quality.

Table 18: Changes in discharge in scenarios I1 and I2 compared to the scenario M3CC.

UNIT : cms					
Station	Scenario Name	Average	Compare with M3 cc		
			Wet	Dry	Average
Chiang Saen	M3cc -Dev 2040	2,592			
	I1	2,593	0%	0%	0%
	I2	2,591	0%	0%	0%
Luang Prabang	M3cc -Dev 2040	3,856			
	I1	3,871	0%	1%	0%
	I2	3,846	0%	0%	0%
Chiang Khan	M3cc -Dev 2040	4,469			
	I1	4,487	0%	1%	0%
	I2	4,458	0%	0%	0%
Vientiane	M3cc -Dev 2040	4,582			
	I1	4,608	0%	1%	1%
	I2	4,566	0%	-1%	0%
Nong Khai	M3cc -Dev 2040	4,630			
	I1	4,655	0%	1%	1%
	I2	4,611	0%	-1%	0%
Nakhon Phanom	M3cc -Dev 2040	7,384			
	I1	7,694	2%	10%	4%
	I2	7,343	0%	-2%	-1%
Mukdahan	M3cc -Dev 2040	8,196			
	I1	8,543	2%	11%	4%
	I2	8,134	0%	-2%	-1%
Pakse	M3cc -Dev 2040	10,365			
	I1	10,729	2%	9%	4%
	I2	10,283	0%	-3%	-1%
Strung Treng	M3cc -Dev 2040	12,685			
	I1	13,107	2%	8%	3%
	I2	12,579	0%	-3%	-1%
Kratie	M3cc -Dev 2040	13,330			
	I1	13,752	2%	7%	3%
	I2	13,224	0%	-3%	-1%

Figure 27 shows average monthly sediment concentrations for the M3CC, I1 and I2 scenarios as obtained from the ISIS model for Kratie. Overall irrigation decreases sediment loads slightly when flow changes are accounted for.

Nutrients have not been discussed here as sediments can be taken indicative for nutrient changes. Large part of nutrients is attached to especially to the fine sediment fractions (clay). Also, nutrient simulation can't be yet considered to be reliable.

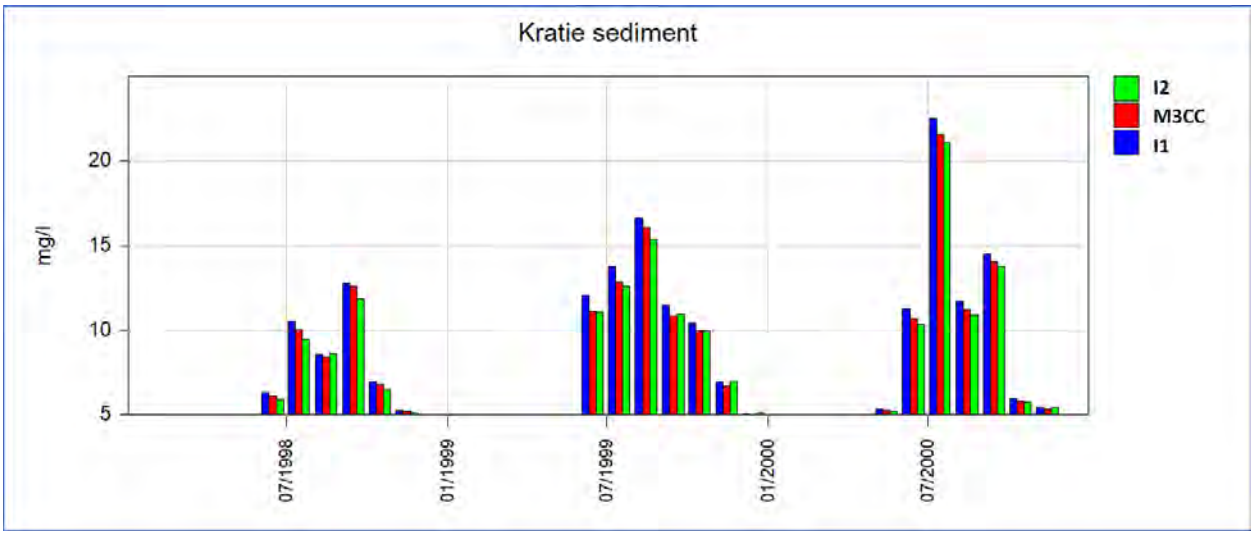


Figure 27: Kratie average TSS (Total Suspended Sediment) concentration in M3CC, I1 and I2 scenarios.

12 Upstream Kratie irrigated rice production

Variation of irrigated rice yields is partly due to variation in climatic conditions. This is because of optimized application of irrigation (see previous chapter) as well as variation in temperature. Lower average temperature – but not too low – lengthens growth period and tends to increase yields. Also difference in day and nighttime temperatures plays a role and cooler night temperatures benefit growth. Other factors creating differences in yields in the model are flooding and sediment input to the paddies which improves soil fertility.

Figure 28 shows average irrigated rice yields near Vientiane. The paddies near the river receive Mekong sediment input and are also hydrologically more favorable than upland fields. The difference between yields in the favorable locations compared to the average yields is about 0.5 t/ha.

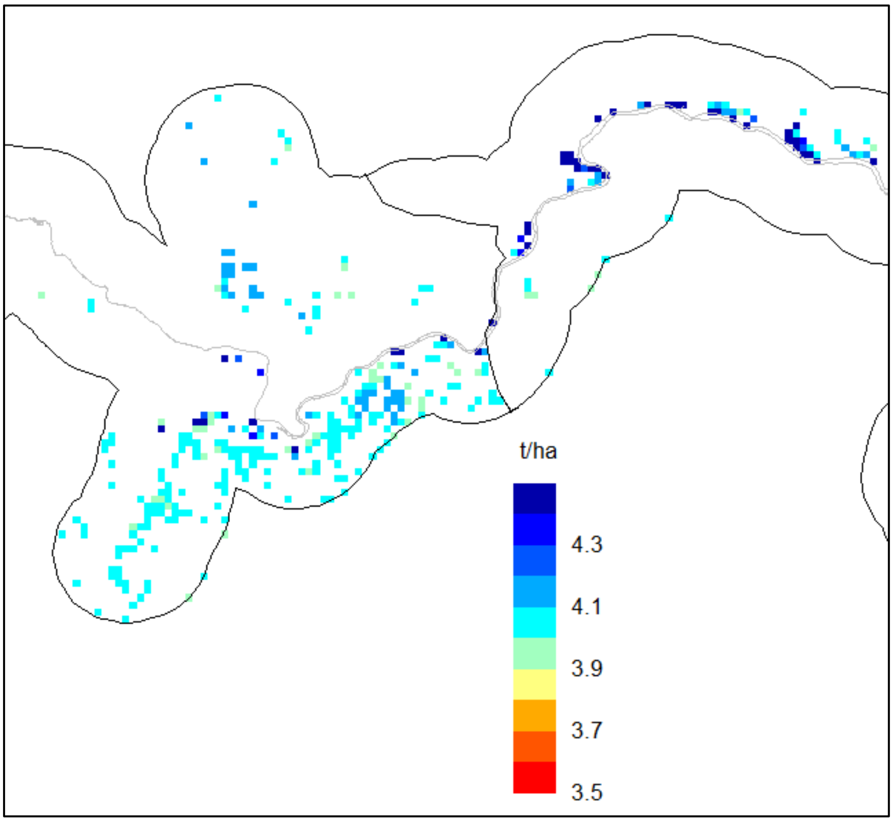
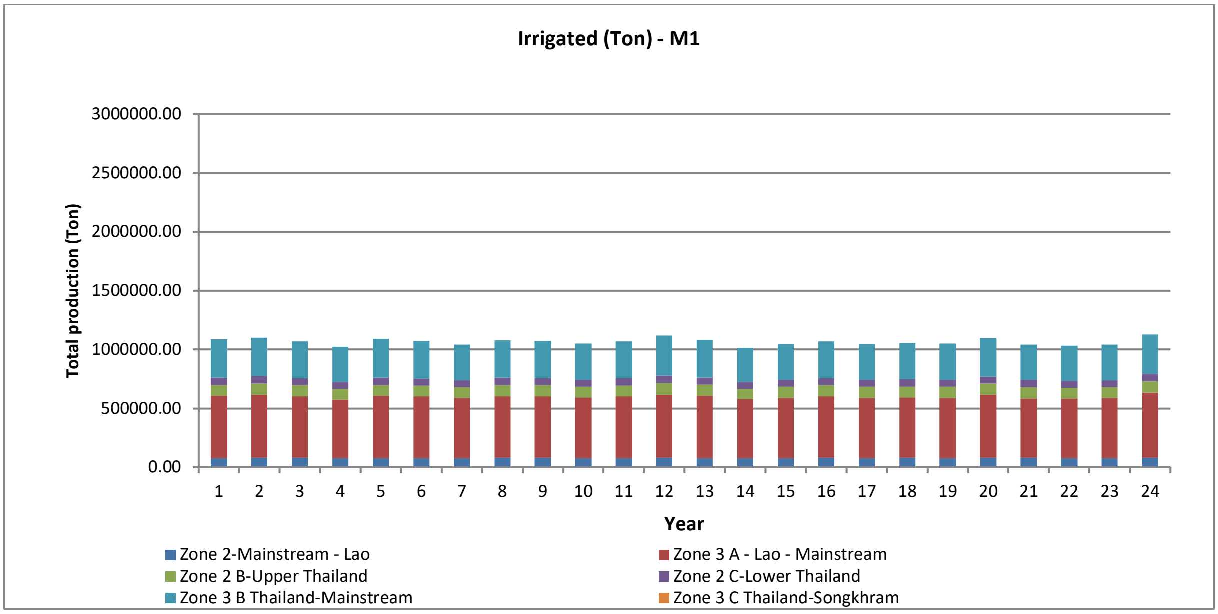
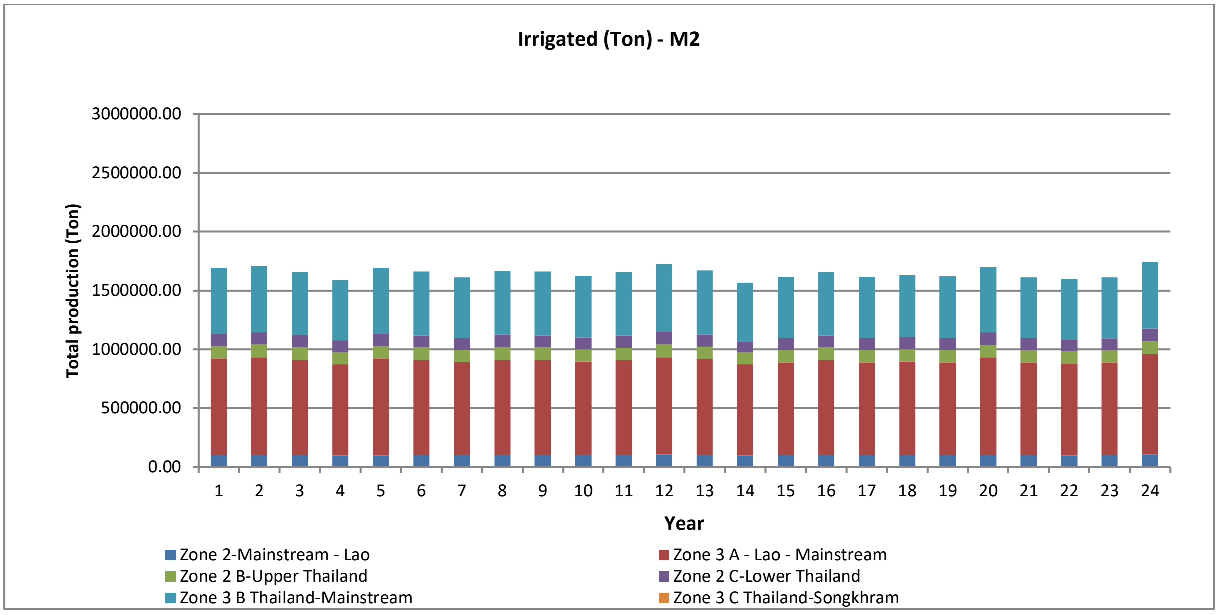


Figure 28: Average irrigated rice yields near Vientiane.

Figure 28 shows total rice production for the upper Kratie SIMVA zones for scenarios M1, M2 and M3. The differences between the scenarios are mainly due to land use changes, that is increase in irrigated area in the future scenarios.





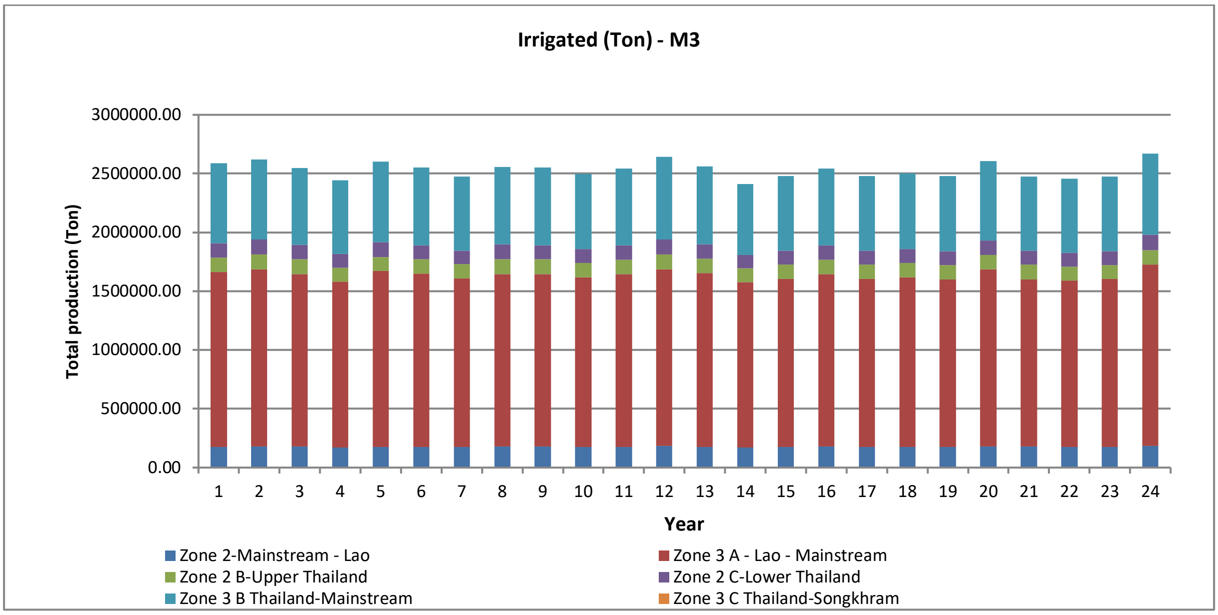


Figure 29: Upper Kratie annual total irrigated rice production for the M1, M2 and M3 scenarios.

Figure 30 shows annual total rice production for the main Lao SIMVA zone 3A for all of the scenarios. The relatively small variation (in baseline about 100’000 t) between the years is caused mostly by rainfall and temperature variation and partly also by water levels in the river enabling or disabling cultivation near river banks. Scenario H1b increases total production because it excludes mainstream dams and increases consequently cultivation area. The climate change scenarios don’t cause large changes in total rice production in this area.

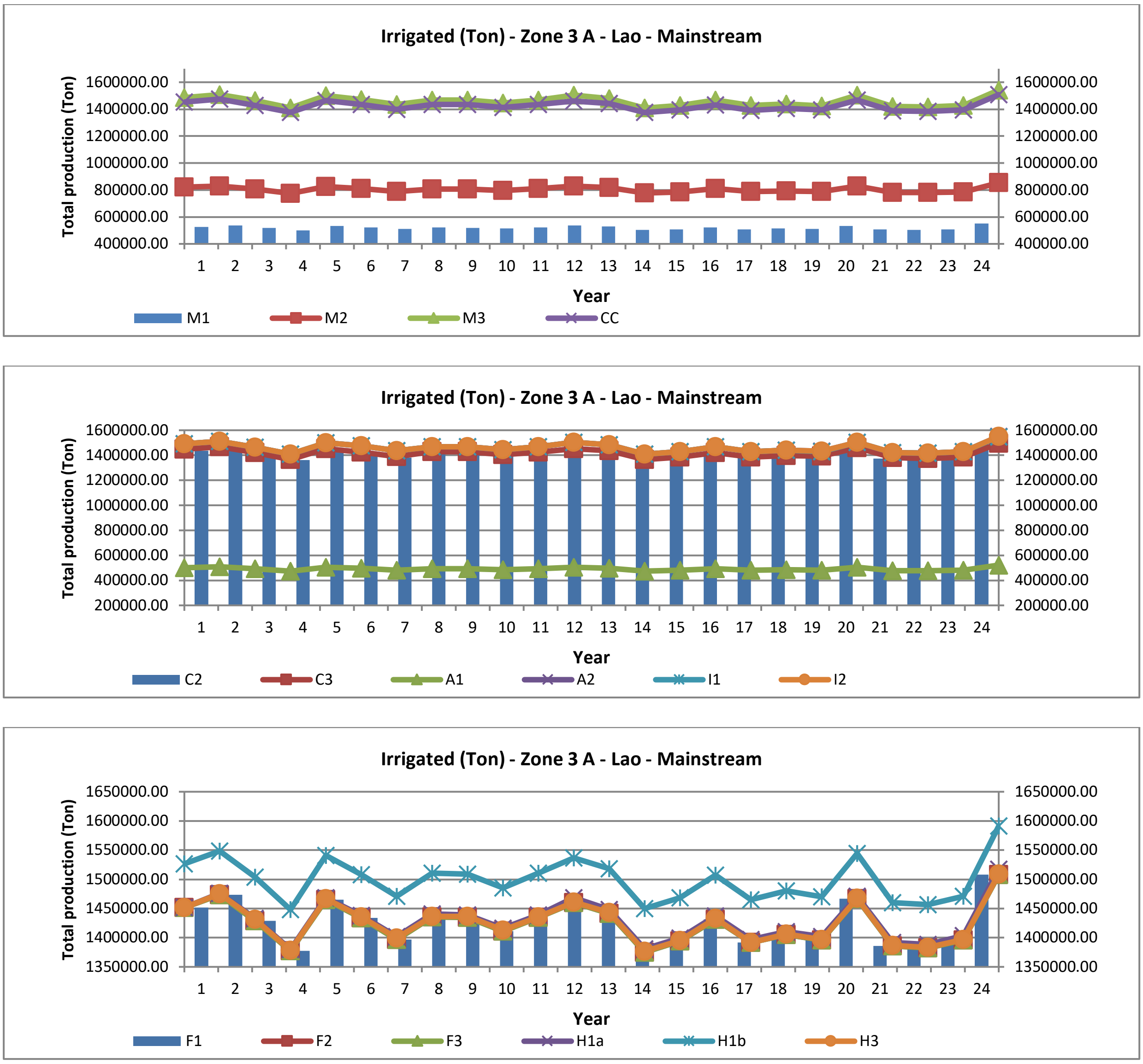
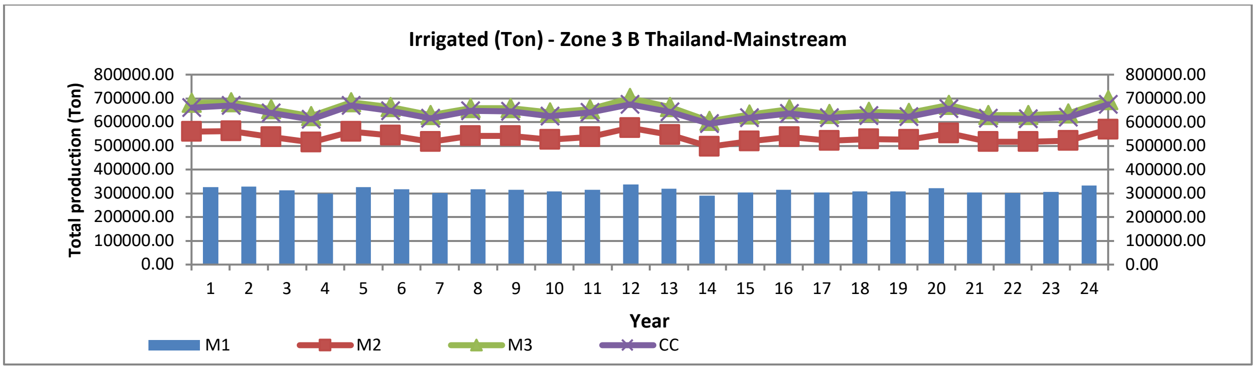
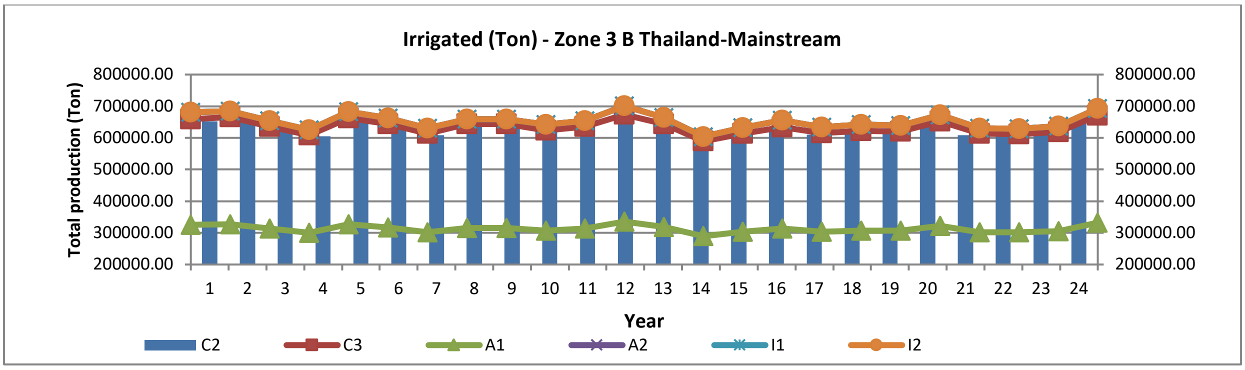


Figure 30: SIMVA zone 3A annual total irrigated rice production for all scenarios.

Figure 31 shows same scenarios for the Thai main SIMVA zone 3B. On the Thai side the mainstream reservoirs have only minor impact on total rice yields.





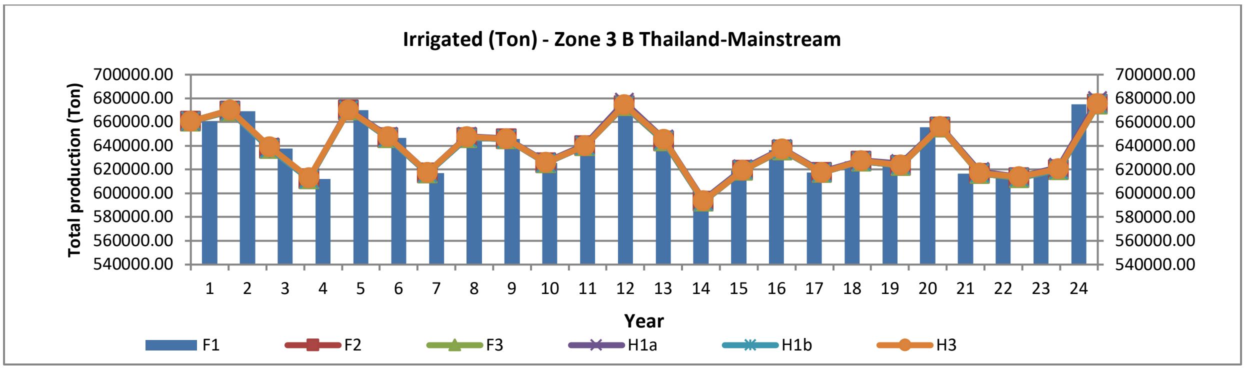
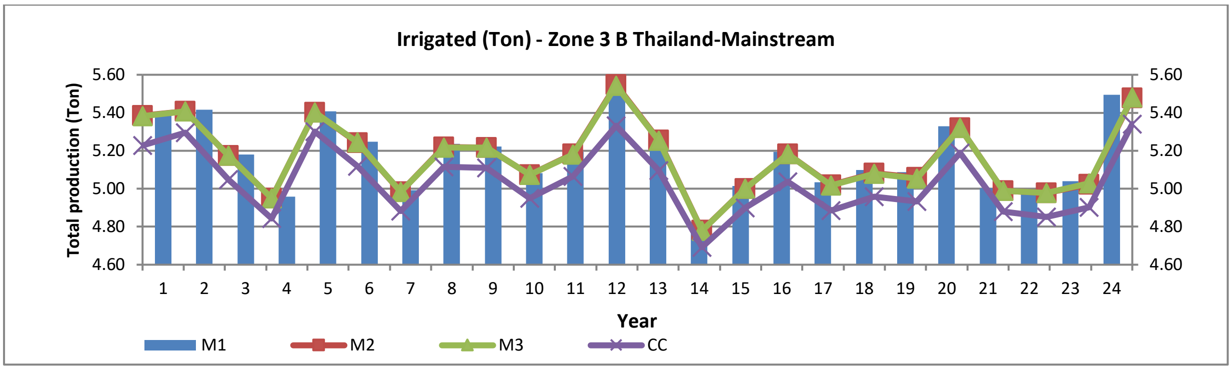
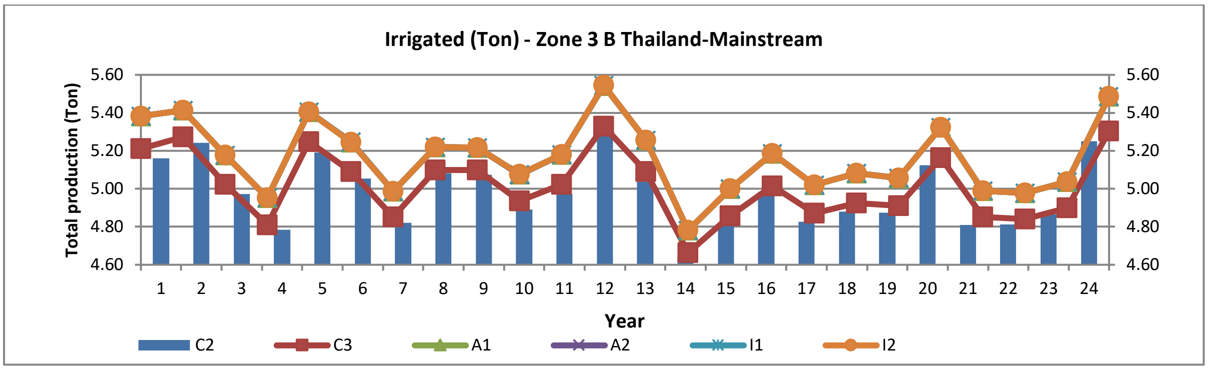


Figure 31: SIMVA zone 3B annual total irrigated rice production for all scenarios.

Figure 32 shows average irrigated rice production per hectare in the main upper Kratie Thai SIMVA zone 3B. The rice production varies up to 0.7 t/ha between the years mostly because of climatological conditions: both cooler conditions and increased rainfall increase rice yields. Cooler conditions cause rice to mature longer and produce larger yields. Increased rainfall increases soil moisture and adds to the (optimized) irrigation in the model.





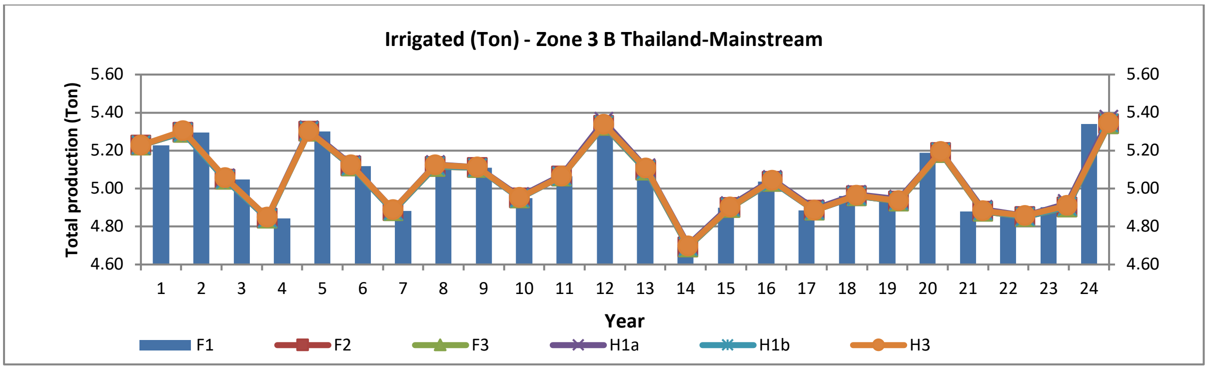
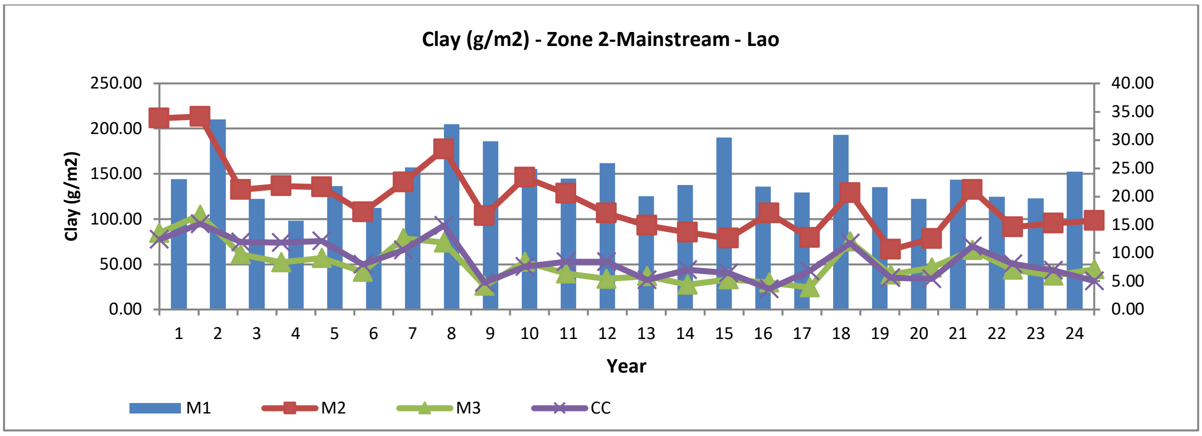


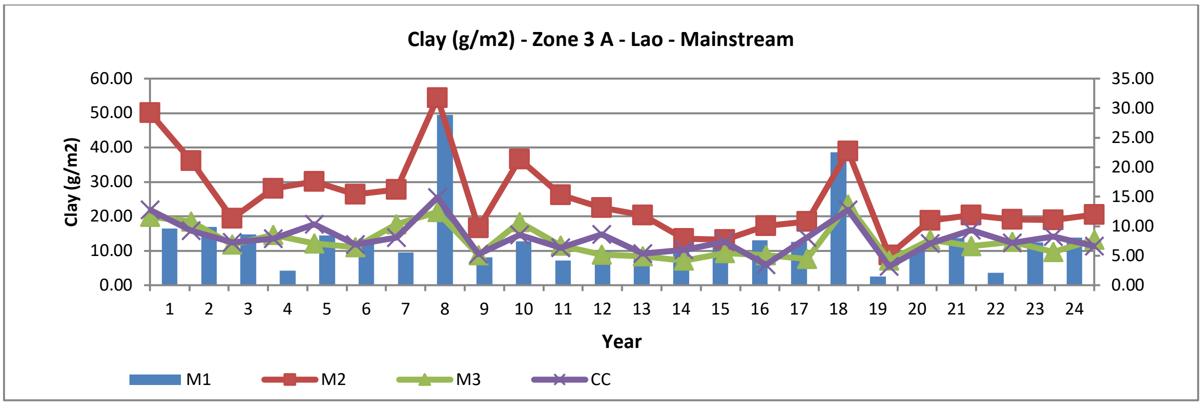
Figure 32: SIMVA zone 3B per hectare rice production for all of the scenarios.

12.1 Paddy field sedimentation

Floodplain and paddy field flood water sedimentation correlates strongly to sediment, nutrient and organic material loads; rice production; and fisheries production (see WUP-FIN modelling report (Koponen, J. and Munoz, A., 2017)). Although sedimentation doesn't have significant impact on the average production in the upstream Kratie SIMVA corridor, it can have up to 20% impact on near-Mekong paddy production where sedimentation is significant (compare results for the Delta below).

Average floodplain sedimentation in the Zones 2, 3A and 3B is shown in Figure 33. The sedimentation values vary greatly from location to location depending on the relief of the terrain as deeper river valleys, steeper river banks and limited floodplains decrease floodplain flooding and sedimentation. Flood duration plays also significant role here and especially in Zone 3A where flooded area is larger than in the Zones 2 and 3B but flood duration on the average smaller. Large sediment trapping by the reservoirs in M2, M3 and M3CC causes average sedimentation to collapse.





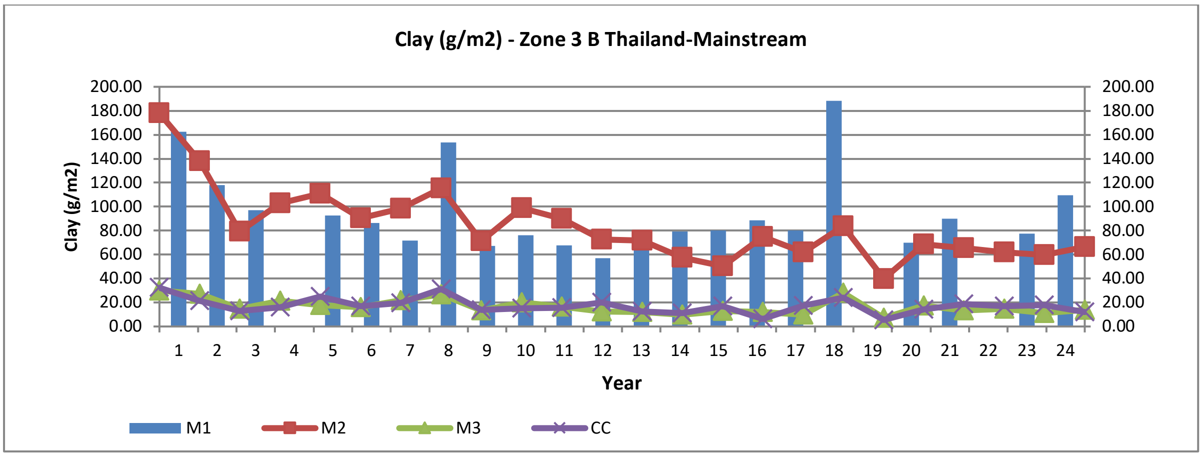
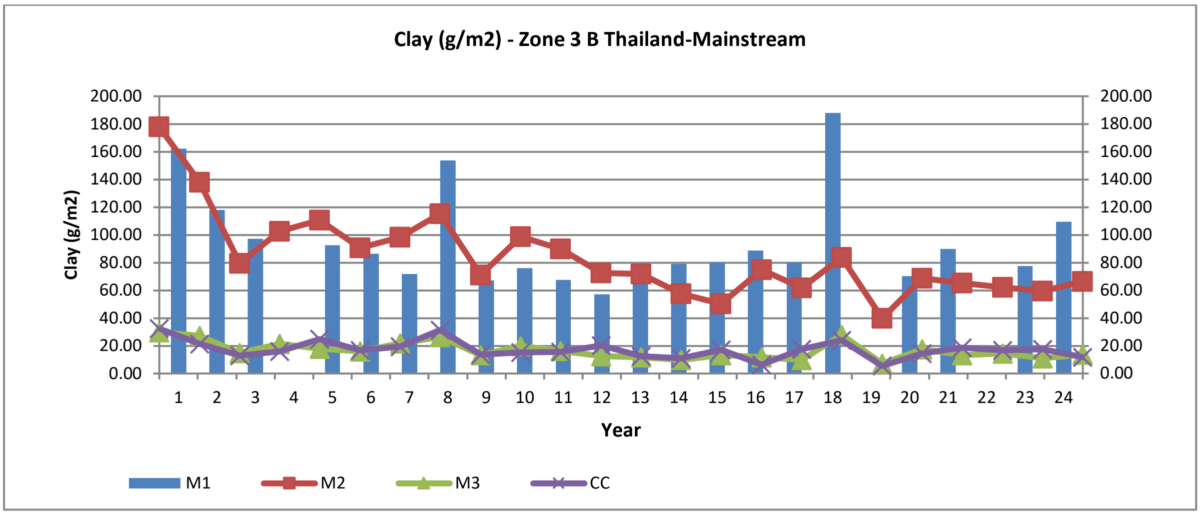
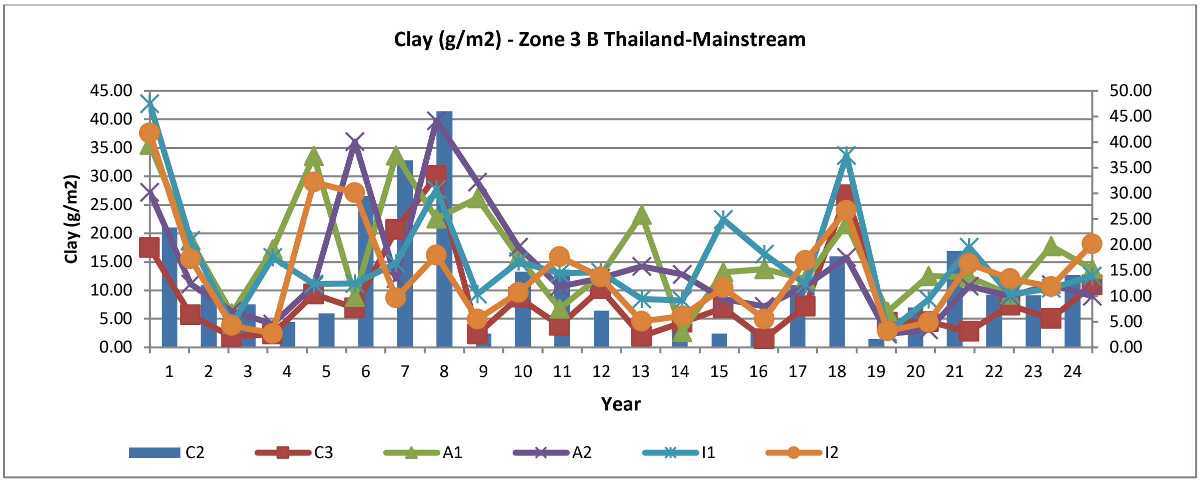


Figure 33. Annual variation of clay floodplain sedimentation for the main scenarios for Zones 2, 3A and 3B. Observe that scales are different for the bars (left scale) and for the time series (right scale).

Average annual sedimentation rates for all scenarios for the Zone 3B are shown in Figure 34. Considering the rather large uncertainties involved in sediment modelling no other conclusions can be drawn from the figure other than that the sedimentation rate is much higher for the M1, M2 and H1b compared to the other scenarios.





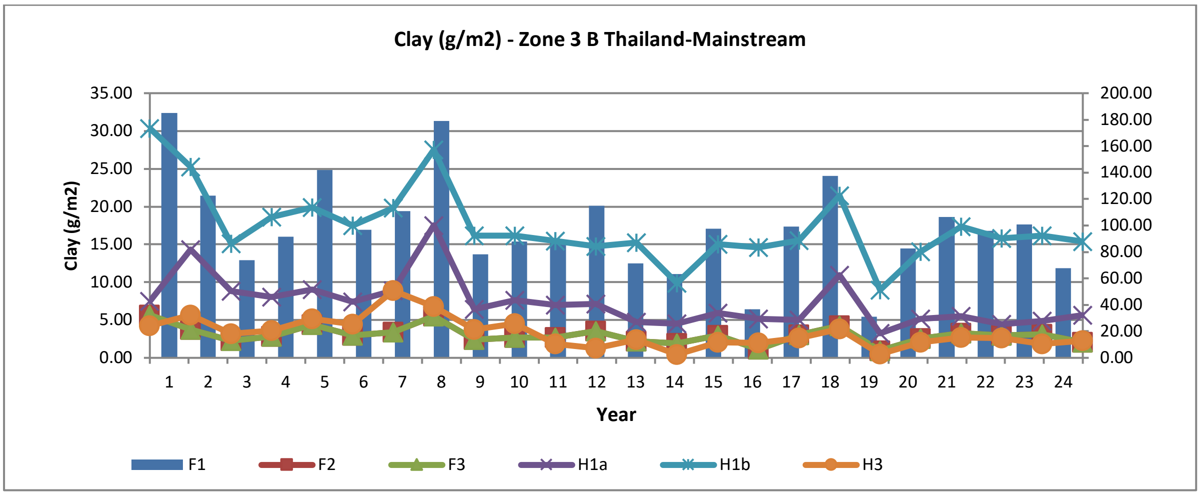


Figure 34. Annual variation of clay floodplain sedimentation for the all scenarios for Zone 3B. Observe that scales are different for the bars (left scale) and for the time series (right scale).

13 Downstream Kratie conditions affecting irrigation and rice production

This chapter analyzes factors affecting rice growth including precipitation, evapotranspiration, flooding, sediments, drought and salinity intrusion.

Precipitation

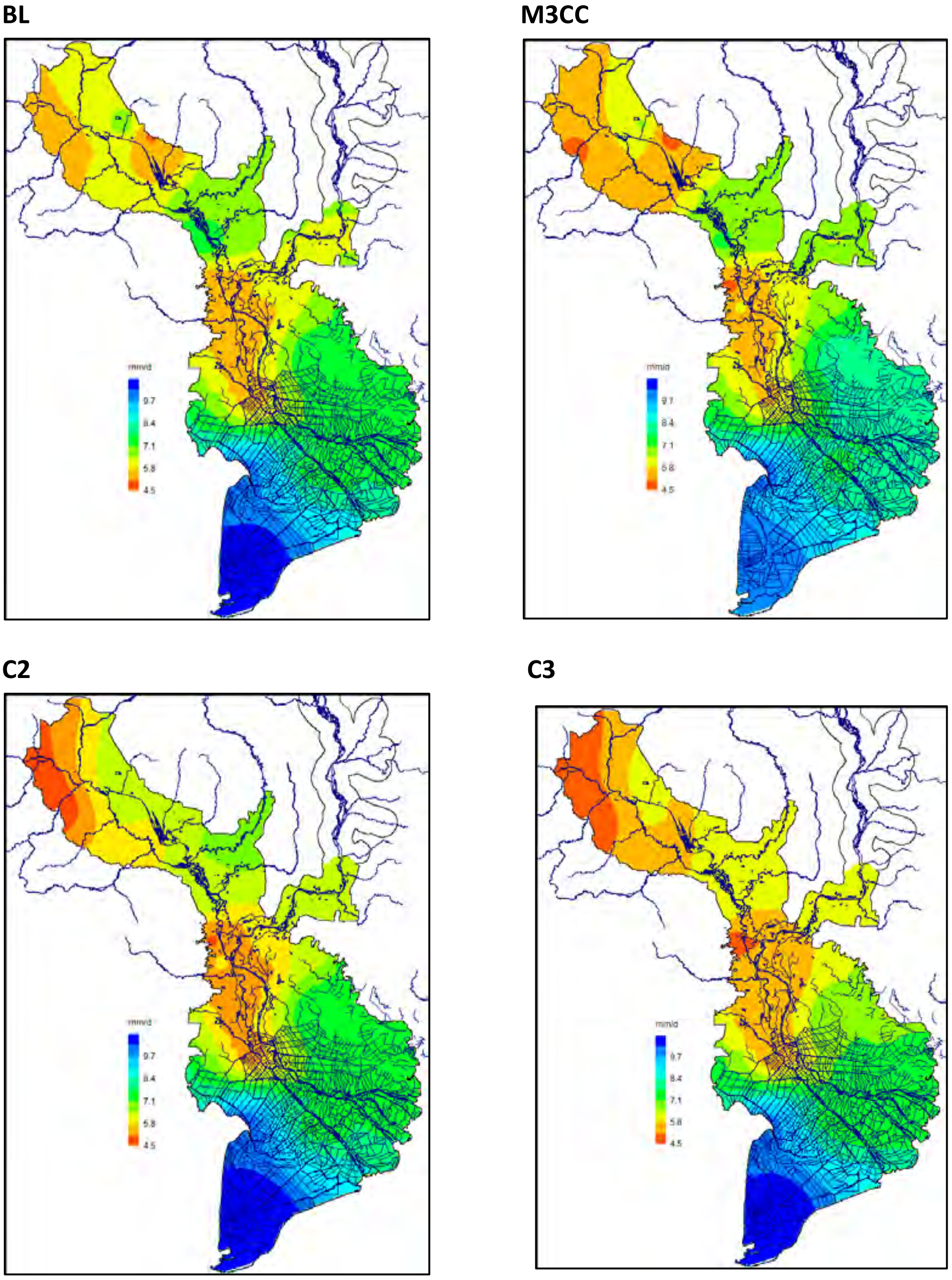


Figure 35. Wet season average rainfall for the climate changes scenarios M1 (BL), M3CC, C2 and C3.

Figure 35 shows wet season (May - October) distribution of average daily rainfall for the scenarios M1 (BL), M3CC (more seasonal), C2 (more wet) and C3 (more dry). As can be seen from the figure the characterizations of the scenarios are not necessarily accurate especially for M3CC (more seasonal = wet season wetter, dry season drier) and changes have large variation spatially.

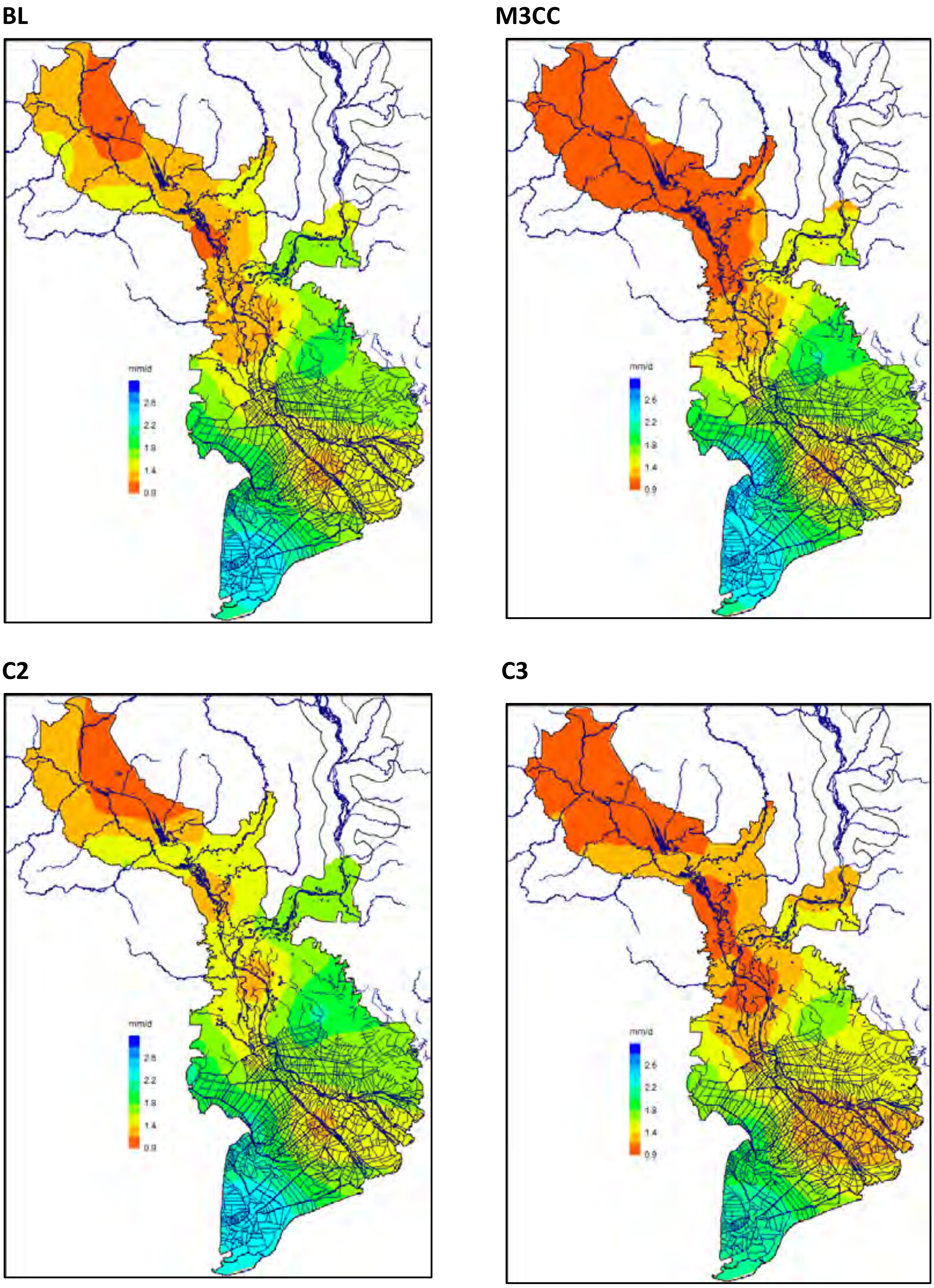


Figure 36. Dry season average rainfall for the climate changes scenarios M1 (BL), M3CC, C2 and C3.

Figure 36 shows dry season average precipitation for the climate change scenarios. Here the scenario characterizations (more seasonal, wetter and drier) are clearer.

Evapotranspiration

Evapotranspiration (ET) shows evaporation from ground and vegetation. Unlike potential evapotranspiration (PET) ET is the actual evaporation affected by soil and vegetation. Increased temperature, surface evaporation and plant transpiration increase ET but it is also dependent on available surface and soil water. Figure 37 shows how evapotranspiration is largest for the dry season in the irrigated central Delta region as well as around Tonle Sap Lake proper. This is because of water availability in these areas enables larger ET.

Climate change increases ET where water is available such as the irrigated areas. The increase is caused mainly by temperature increase. For plant growing periods also growth increases increasing ET.

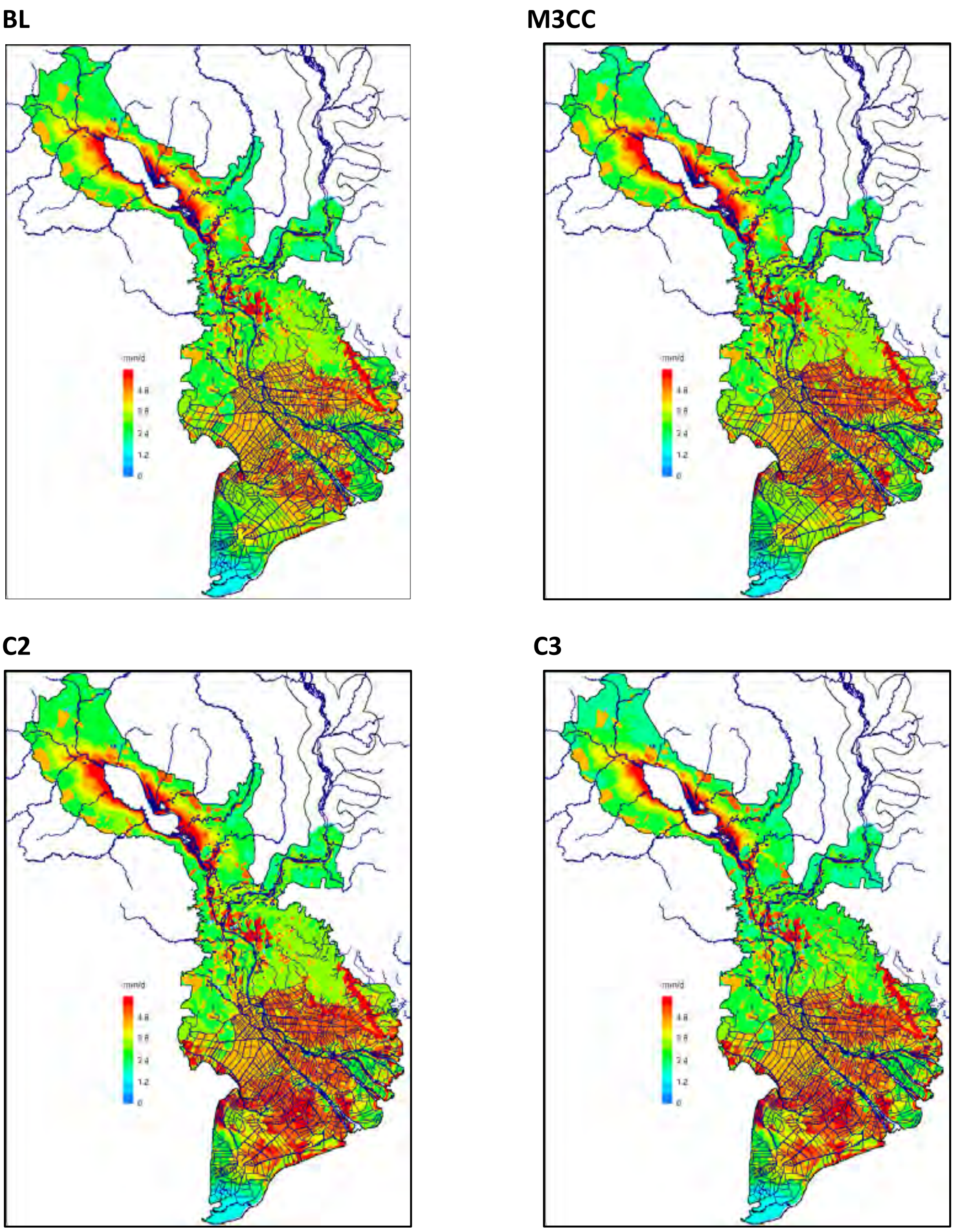


Figure 37. Computed evapotranspiration for the baseline and the climate scenarios M3CC, C2 and C3.

Drought

Member countries assess drought larger problem than flooding as the countries have adapted living with floods and floods are essential for proper functioning of the Mekong system. There are many indicators for flooding also available from modelling such as crop yield. Figure 38 shows another indicator which is number of months when precipitation is less than half of potential evapotranspiration (PET). The main climate change scenario has only marginal impact on this indicator.

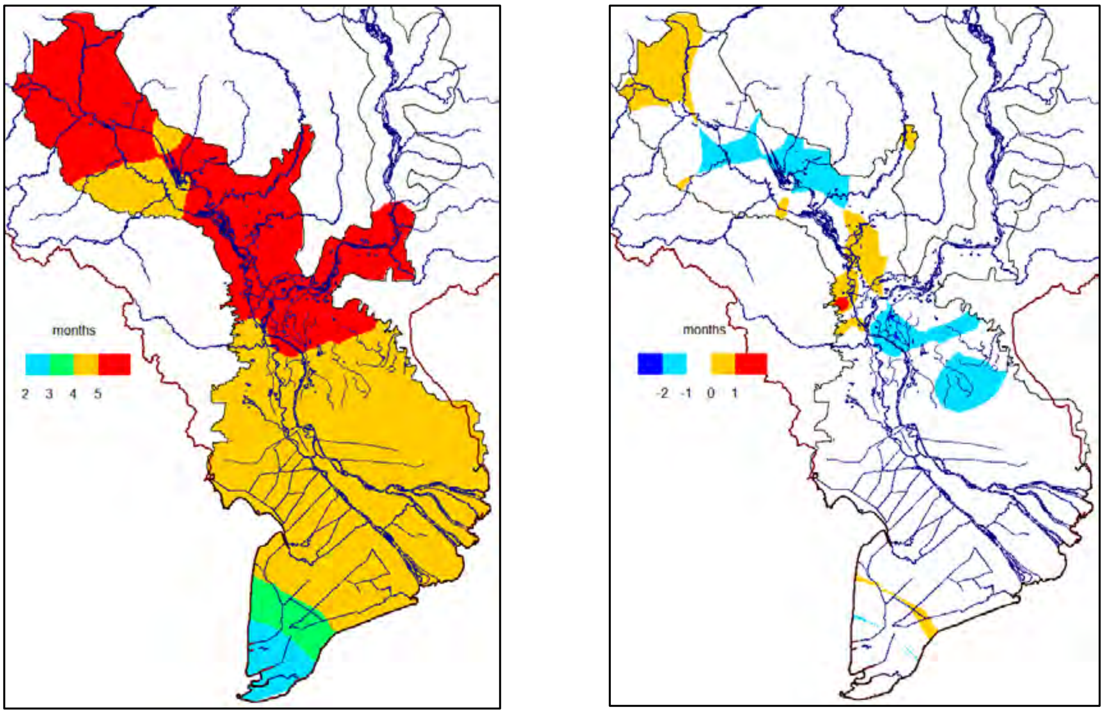


Figure 38. Average number of drought months in the baseline (left) and change in the 2040CC scenario.

Flooding

Figure 39 shows baseline flood duration and change in 2040 and 2040CC scenarios. For the most part flood duration decreases in the future development scenarios except for some areas in the flood periphery. Also, extreme flood events are reduced as the hydropower reservoirs store peak flood water (Figure 40, 2040 scenario). Climate change can on the other hand increase peak flooding even with the extensive hydropower development ((Figure 40, 2040CC scenario).

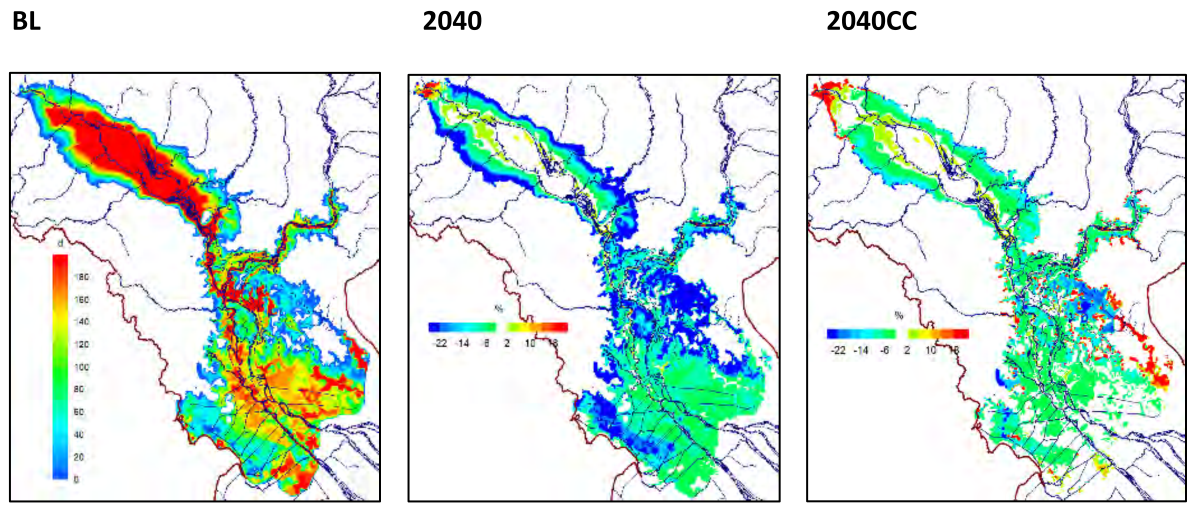


Figure 39. Average flood duration in the baseline (left), 2040 change (middle) and 2040CC change (right).

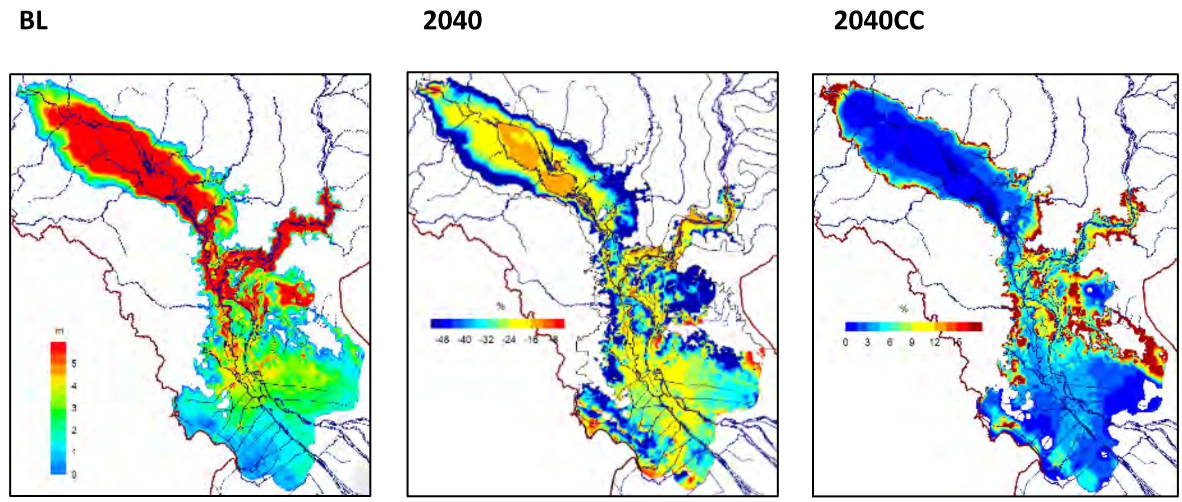


Figure 40. 100-year flood depths in the baseline (left), 2040 change (middle) and 2040CC change (right).

Flooding and rice production

Flooding is beneficial for rice production in providing fertile soil to paddies, flushing harmful substance from soils and recharging soil water. On the other hand too much flooding can slow down rice growth or damage it through long submersion. In Figure 41 shows rice yield when rice is planted mid-June and change for M3 scenario. The scenario is hypothetical in the sense that farmers would not plant rice when flood damages are expected but it illustrates clearly how hydropower development in M3 and other scenarios reduces flooding and increases yields for wet season rice not protected against flooding.

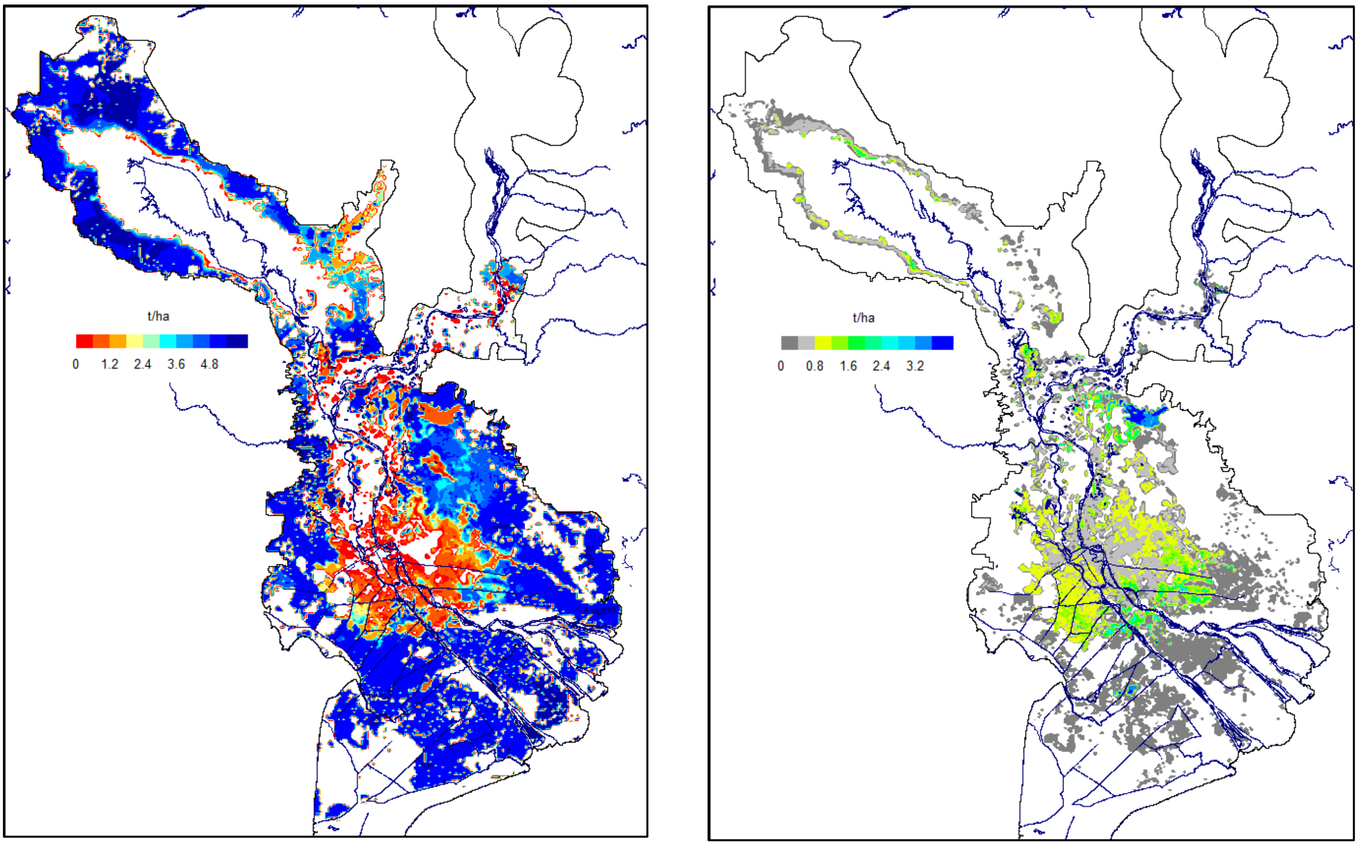


Figure 41. Flooding impact on no-flood protected rice production. Left baseline for rice planted mid-June and right yield increase in the M3 scenario.

Soil fertility and rice production

In addition to flooding rice production depends on soil fertility. Mekong alluvium (fertile sediments and organic material) improves soil quality and supplies nutrients to both natural and agricultural primary production. In agriculture lack of alluvium can be compensated through soil management and addition of fertilizers but they may be costly and time-consuming efforts. Only adding chemical fertilizers to paddies doesn't necessarily work in the long run as the soil quality tends to suffer reducing productivity.

Figure 42 shows how clay sedimentation is reduced in the M2 and M3 scenarios. In M2 sedimentation is third of the baseline and in M3 sedimentation is one tenth of that in M2. The reduction in rice production between baseline and M3 is shown in Figure 43. In the flooded areas rice reduction is between 0.1 and 1 t/ha. It should be noted that flood damages are not included in this analysis.

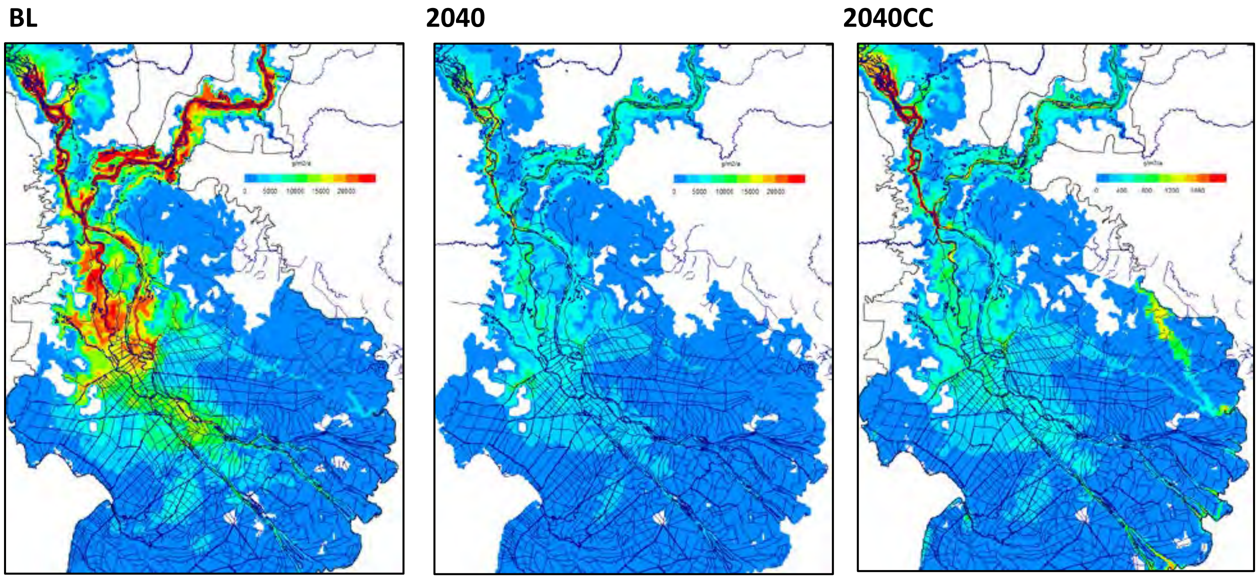


Figure 42. Sedimentation in the floodplains.

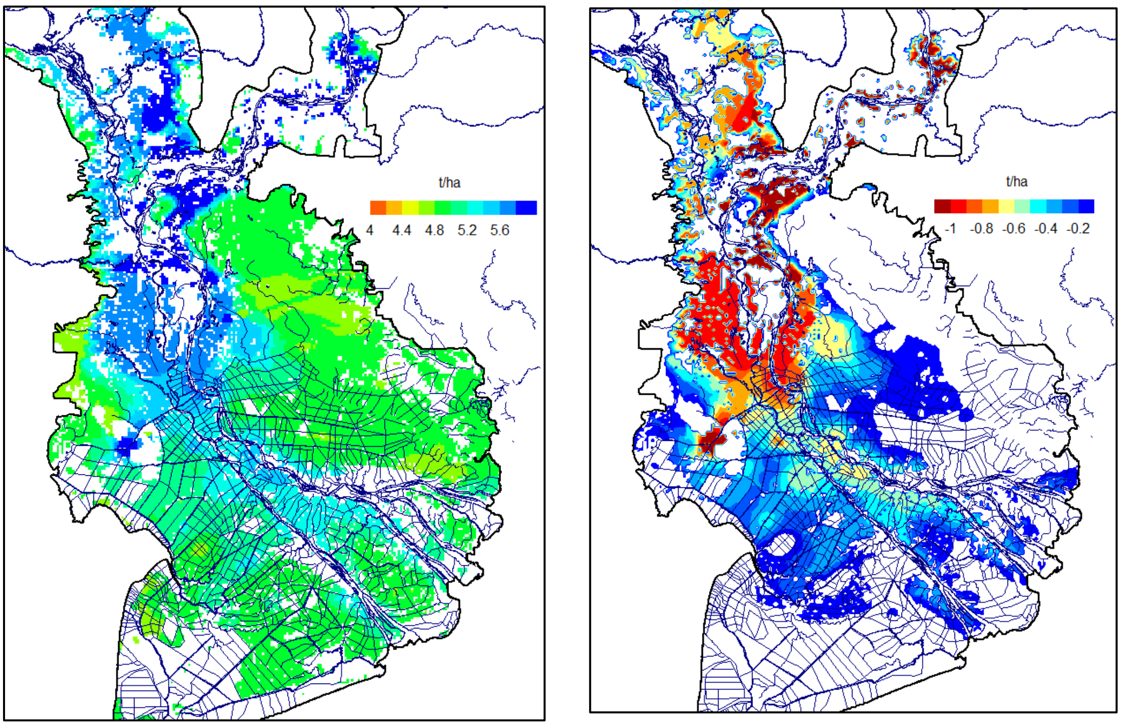


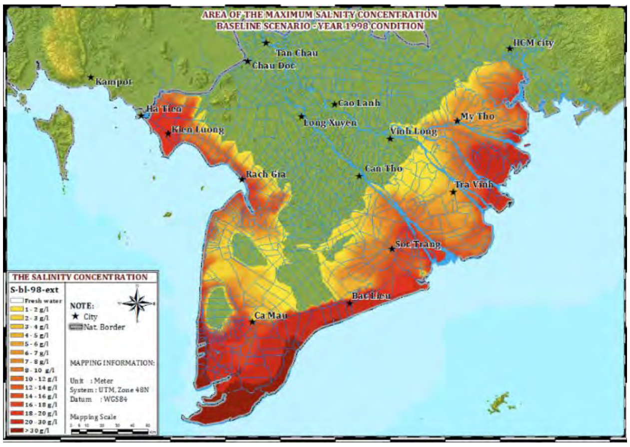
Figure 43. Sediment impact on rice production. Left baseline and right decrease of rice production in scenario M3. No flooding impact included.

The impact of sediment trapping (see ALU report) affects soil fertility and irrigated crop production. Sediments contain nutrients and organic material and maintain soil productivity. This can be at least partly be compensated with improved soil management and addition of fertilizers. Impact of non-compensated sediment trapping is shown in Figure 43. Near the Mekong mainstream where sediment loads and sedimentation are largest rice yields are decreased about 20%. Further out from the mainstream crop yield decrease is about 5% – 10%. It is difficult to verify these numbers by literature, but the Tonle Sap sediment and primary productivity model has been used as a guideline for the sediment impact and implemented in the AquaCrop model as a constraint in the soil fertility.

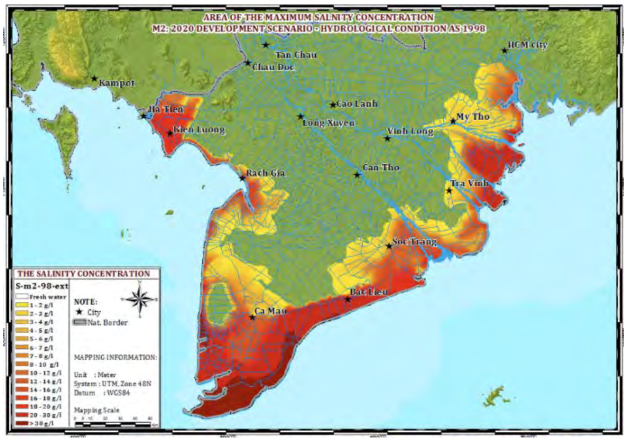
Salinity intrusion

Figure 44 shows salinity intrusion for the year 1998 hydrological conditions for M1 (baseline), M2 (2020) and M3 (2040). Salinity intrusion is affected by upstream river flow, sea level rise and flow regulation. Because of this the salinity changes between the scenarios are complex.

M1 (2007)



M2 (2020)



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M3 (2040)

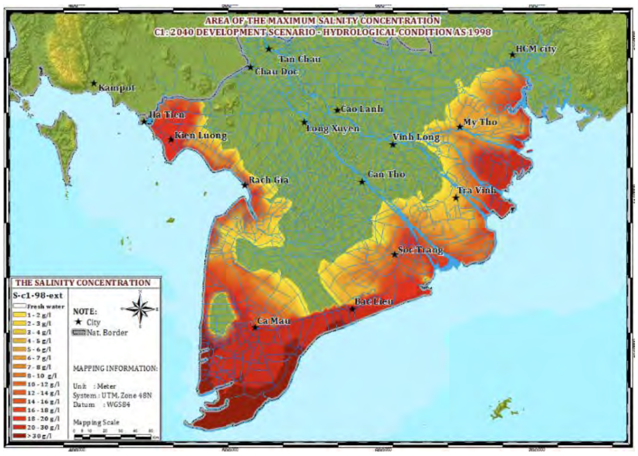


Figure 44. Salinity intrusion computed for the year 1998 for three scenarios (DSF team results)

Future scenarios change salinity intrusion through changes in river discharges and sea level rise. This is shown in Figure 46 where the hydropower development in scenario M3 increases freshwater river discharge and lowers salinity.

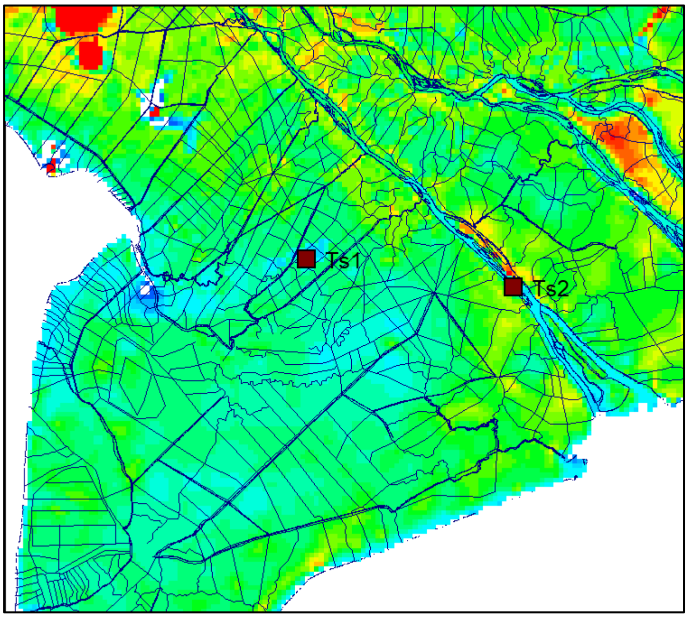


Figure 45. Salinity times series locations.

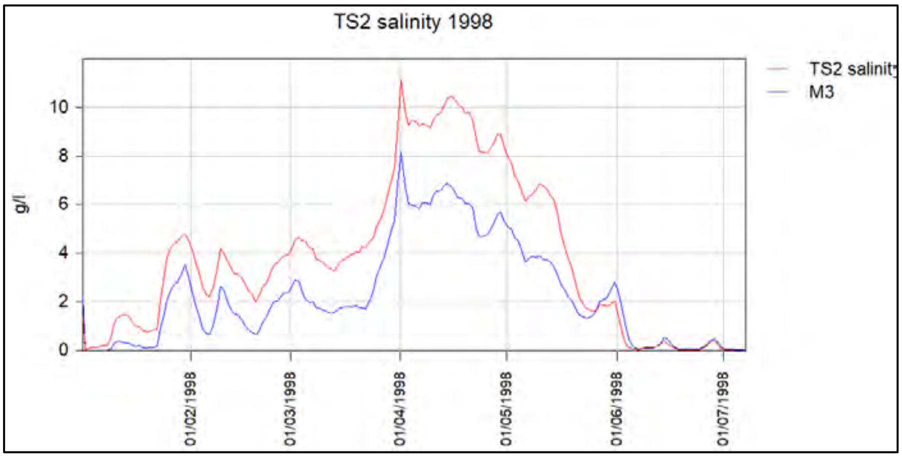


Figure 46. Salinity the Bassac River location TS2 (see Figure 45).

Figure 47 presents average salinity for irrigation water. Salinity changes are complex because of changing flood protection, water regulation, upstream flow and sea level rise.

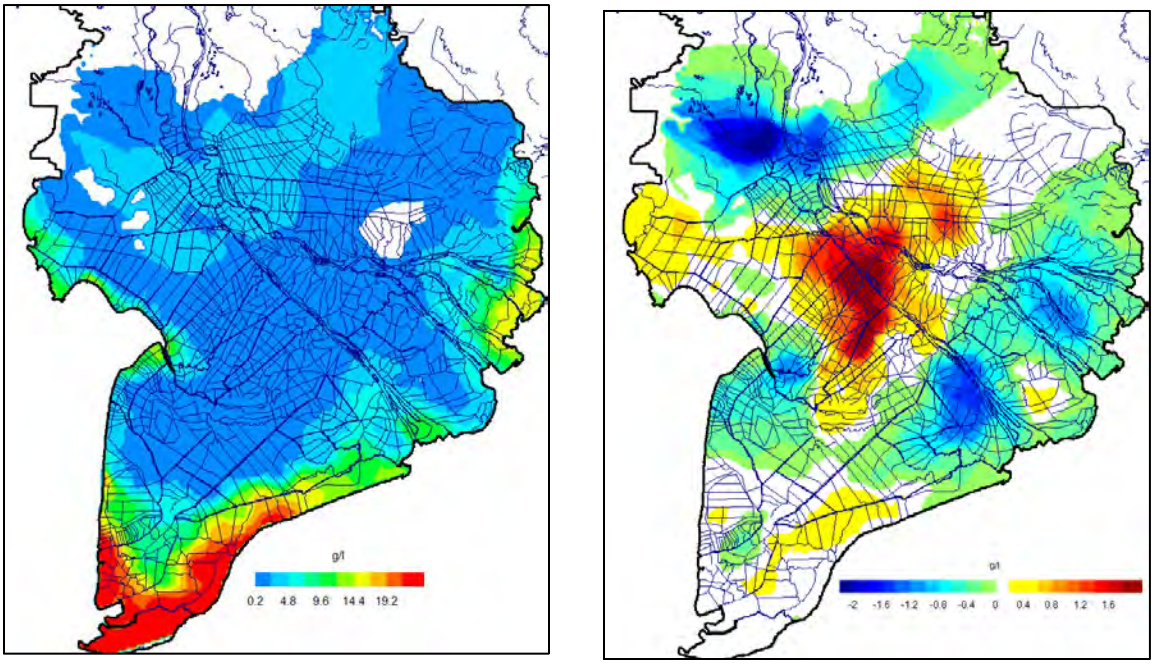


Figure 47. Average dry season baseline salinity in 1998 (left) and change in scenario M3.

Salinity intrusion in the Delta affects rice growth. Figure 48 shows change of dry season irrigated rice production in the Delta for the 2020 and 2040 scenarios compared to the baseline. Due to increased dry season flow and decreased salinity intrusion there is small increase (0.1 t/ha – 0.3 t/h) in dry season rice production in number of areas. Small areas experience also decrease of production because of the complexity of flow and in 2040 sea level rise.

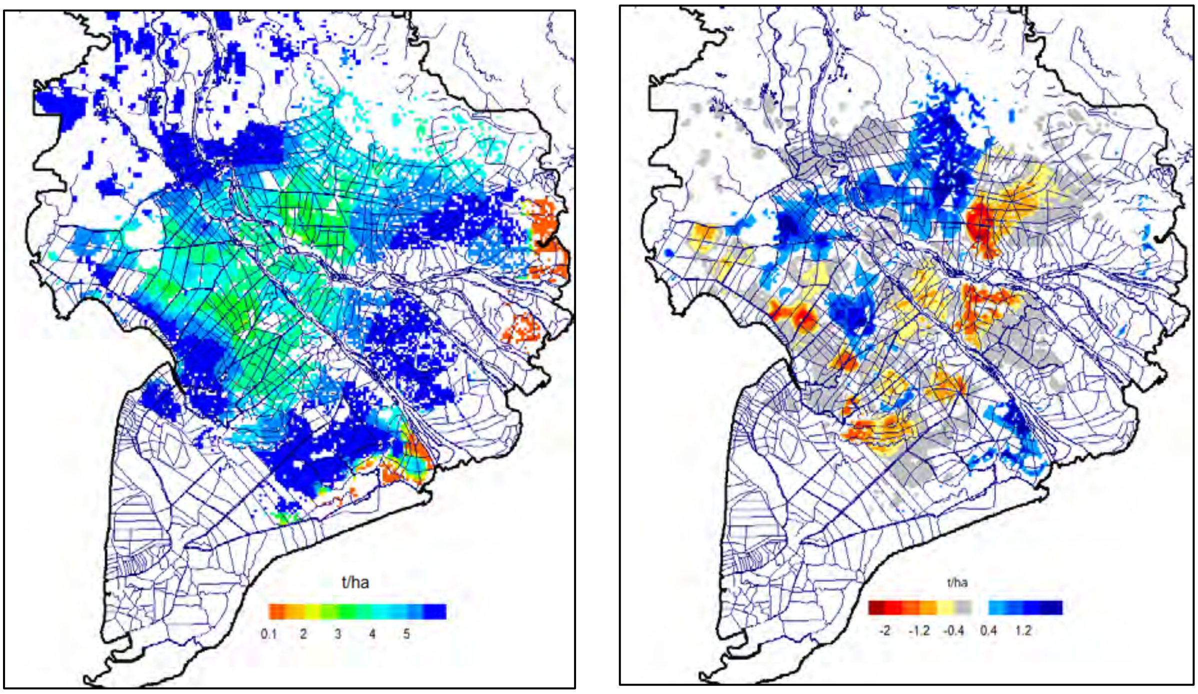


Figure 48. Baseline irrigated rice production in 1998 (left) and change in M3 scenario.

14 Lower LMB irrigated rice yields

Figure 49 presents computed average dry season irrigated rice yields. Here it is assumed that irrigation water is sufficient and because of that rice yields are generally good except some flooding or salinity prone areas.

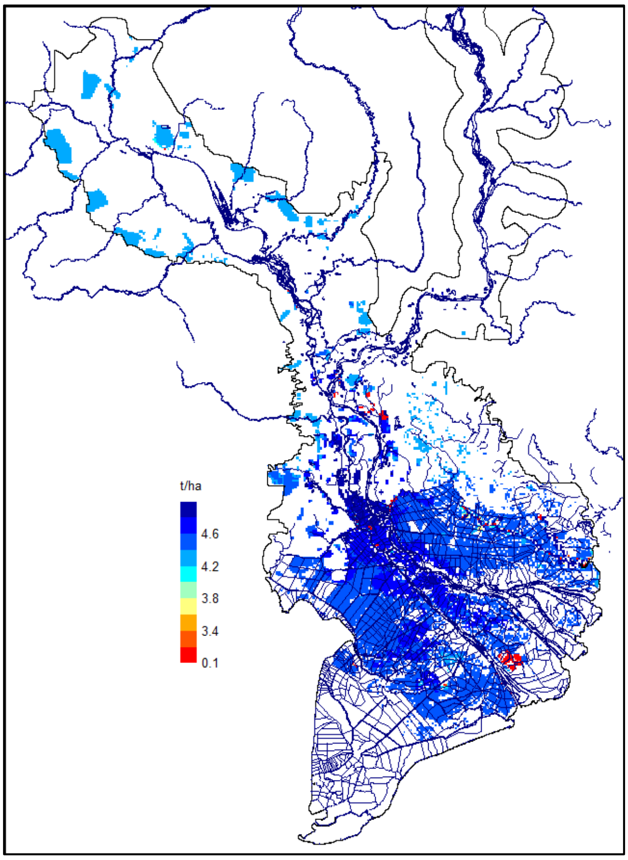
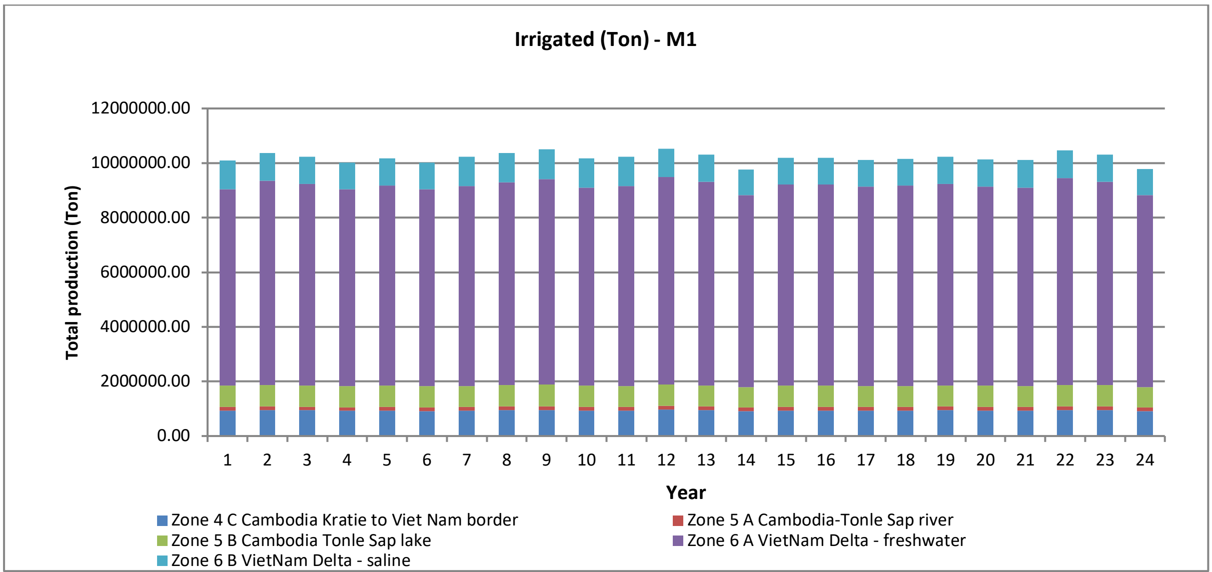
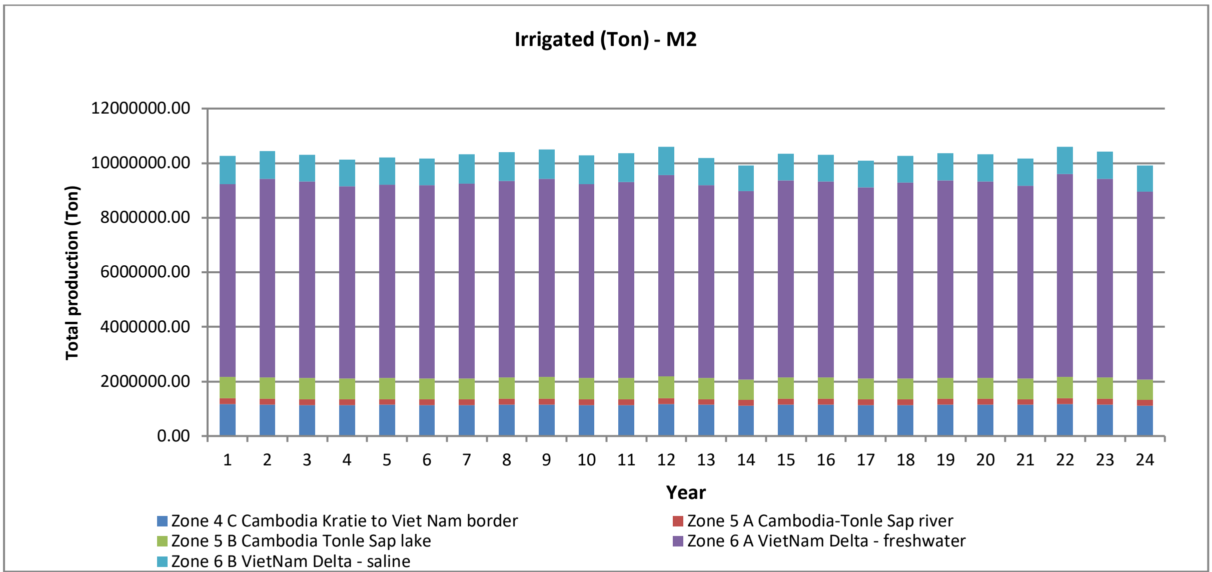


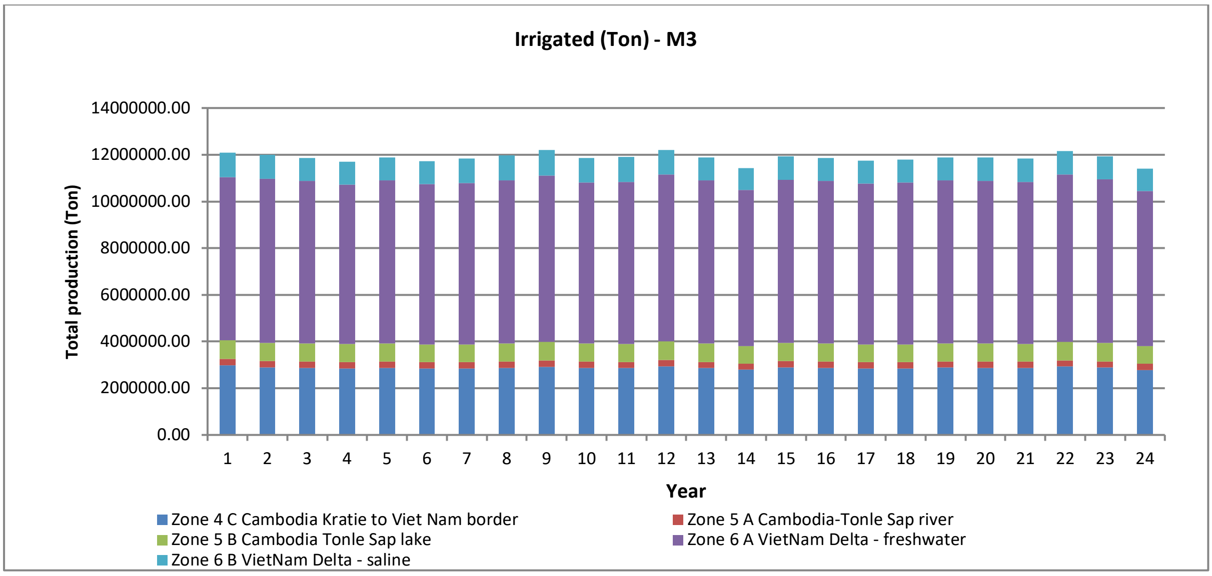
Figure 49. Baseline dry season irrigated rice yields in the lower LMB.

Figure 50 shows irrigated rice areas and average yields for the Delta and Tonle Sap SIMVA zones (Figure 19). There is decreasing yield trend for the future scenarios caused by alluvium trapping and decreased soil fertility (see next chapter). Small decrease in land area is caused by increased water levels and inundation in the dry season for the future development scenarios. The climate change scenario (to be added) is computed without CO_2. Based on laboratory experiments it has potentially large impact but real-world factors such as decrease of crop quality and resilience to pests can compensate for it.

Irrigated rice production changes are minor in Cambodia and Vietnam Delta except for the irrigated agriculture area increase in Cambodia for scenarios M3 and M3CC (Figure 50). In the main climate change scenario yields are slightly decreased because of temperature accelerated growth and consequent drop in yields.







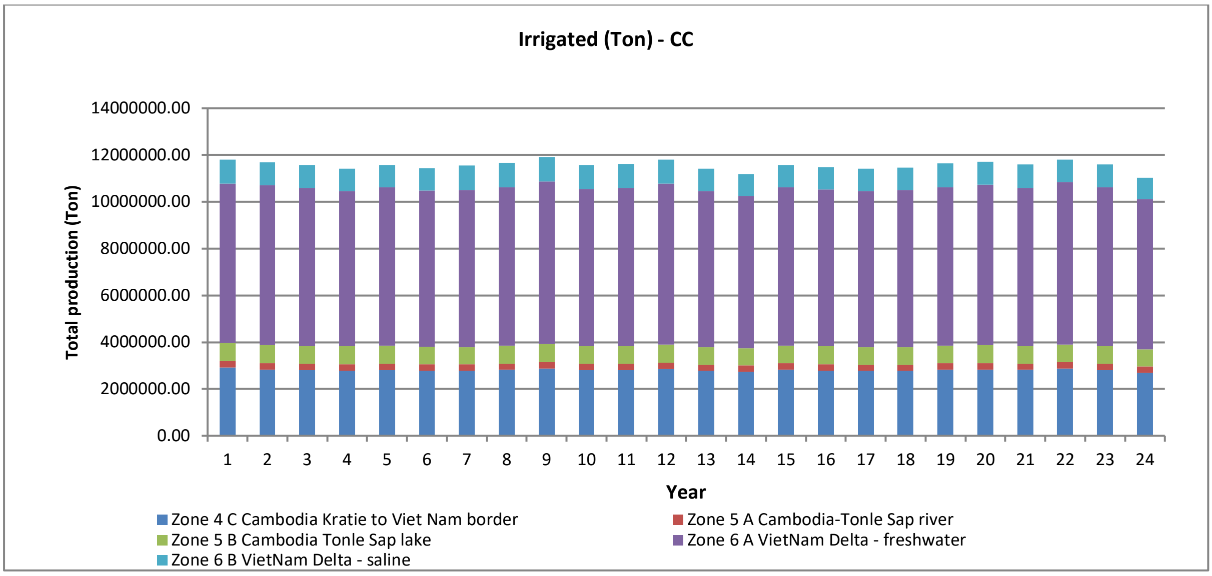


Figure 50. Annual variation of total Cambodia and Vietnam Delta irrigated rice production.

Figure 51 presents total rice production for all of the scenarios for the zone 4C (Cambodia from Kratie to the Vietnam border).

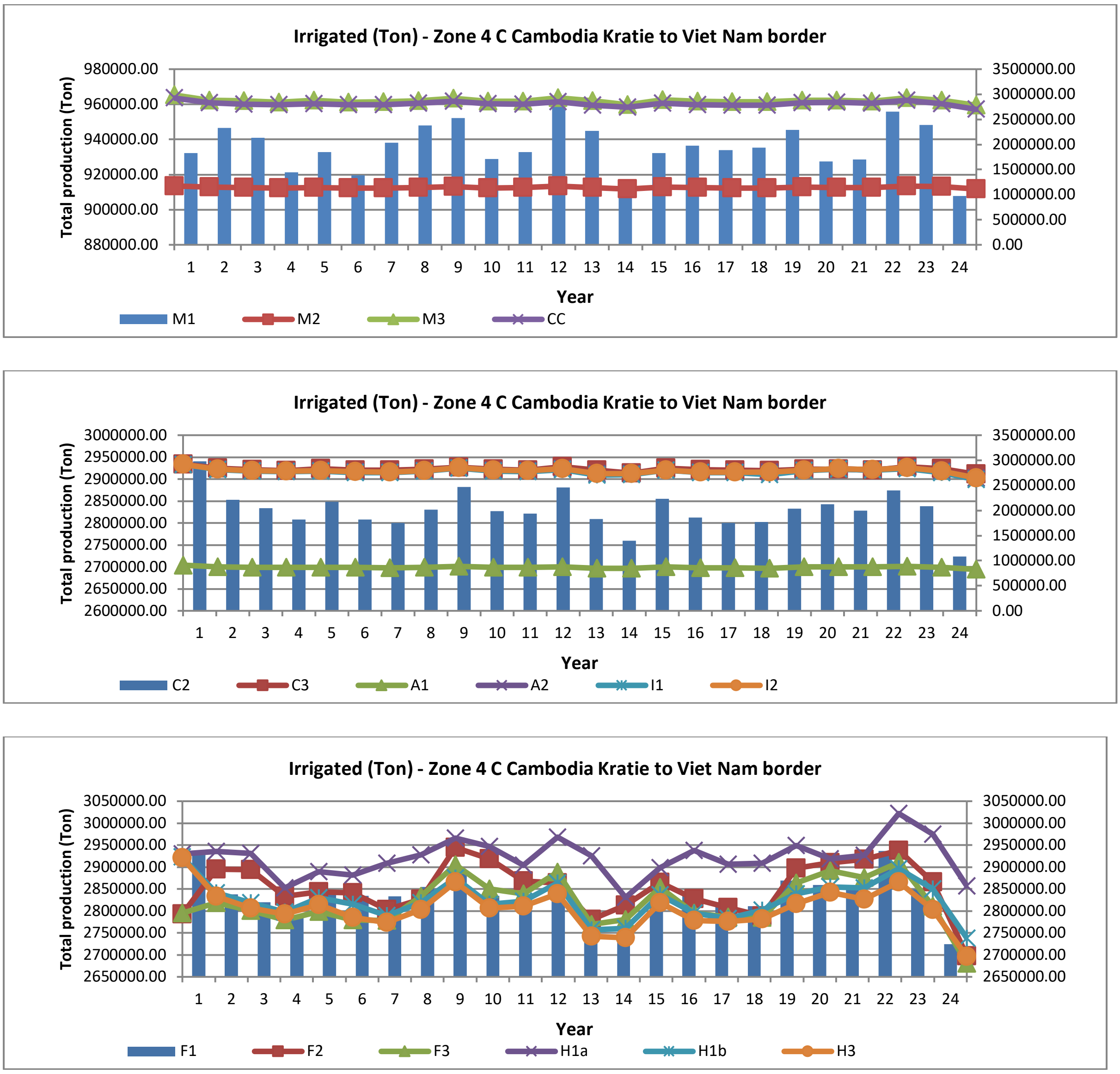
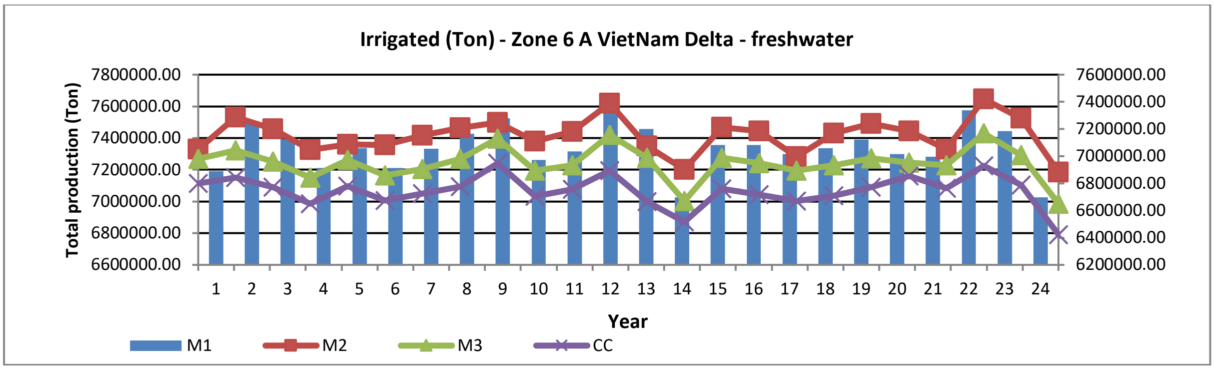
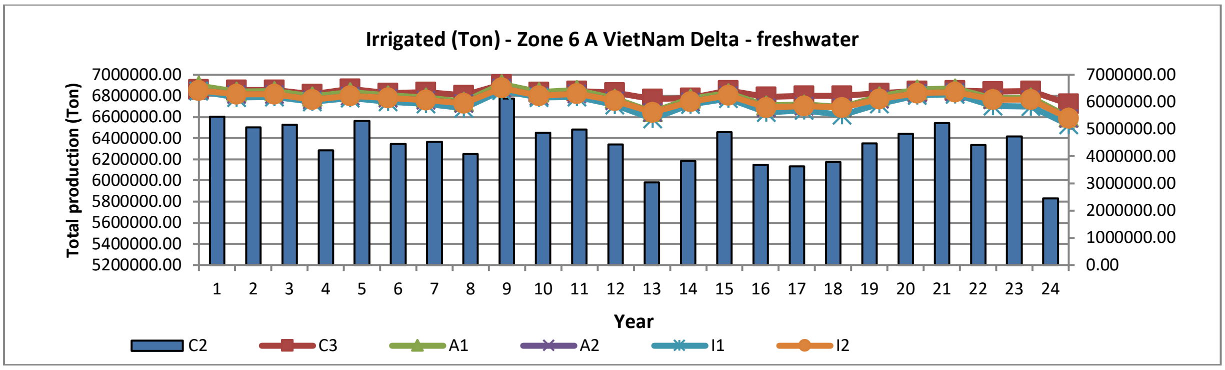


Figure 51. Sub-scenario rice production for non-irrigated rice for the Zone 4C. Observe that scales are different for the bars (left scale) and for the time series (right scale).

Similarly, total rice production in the Vietnam Delta for the zones 6A and 6B is presented below. In Vietnam irrigated area remains the same in the future but rice yields vary because of flooding and salinity impacts. It should be noted that the model overestimates flooding impacts as data for flood protections has not been available.





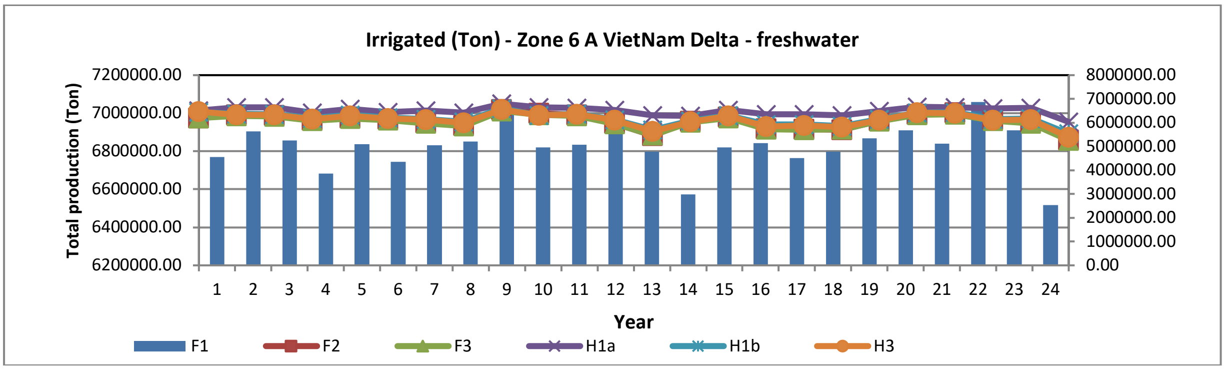
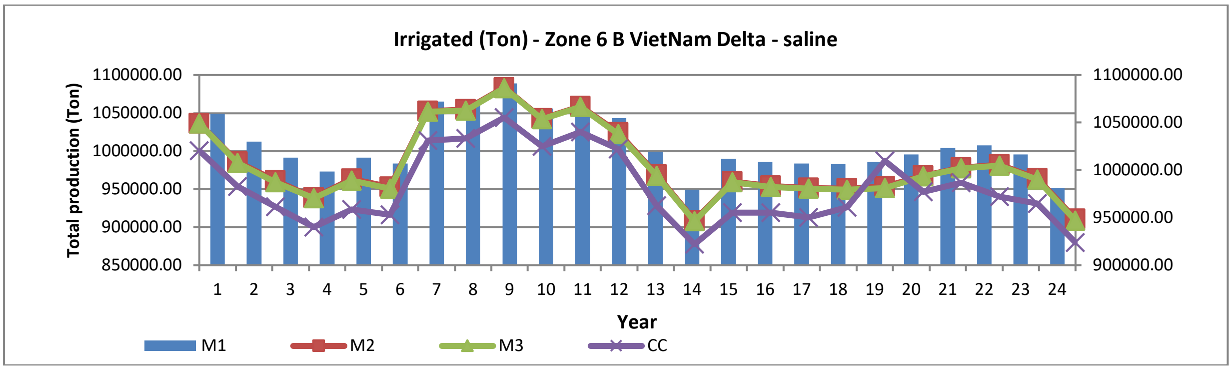
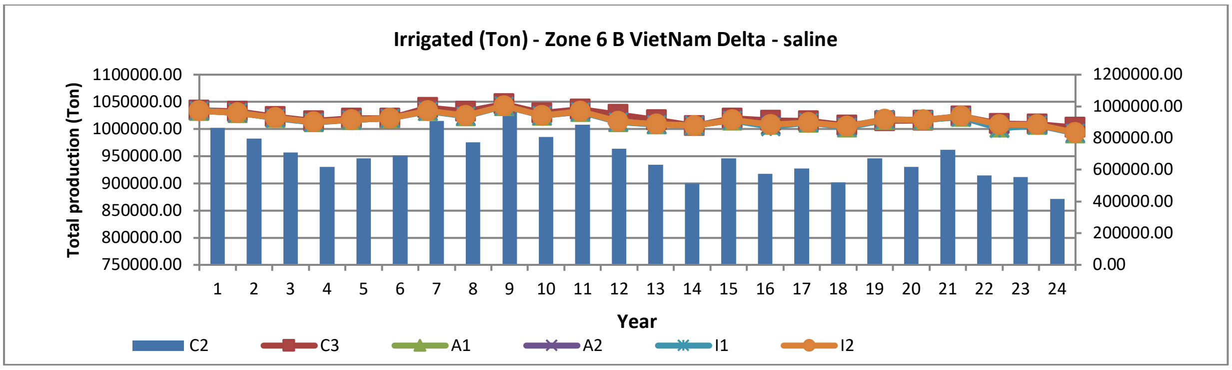


Figure 52. Sub-scenario rice production for non-irrigated rice for the Zone 6A (Vietnam Delta freshwater). Observe that scales are different for the bars (left scale) and for the time series (right scale).





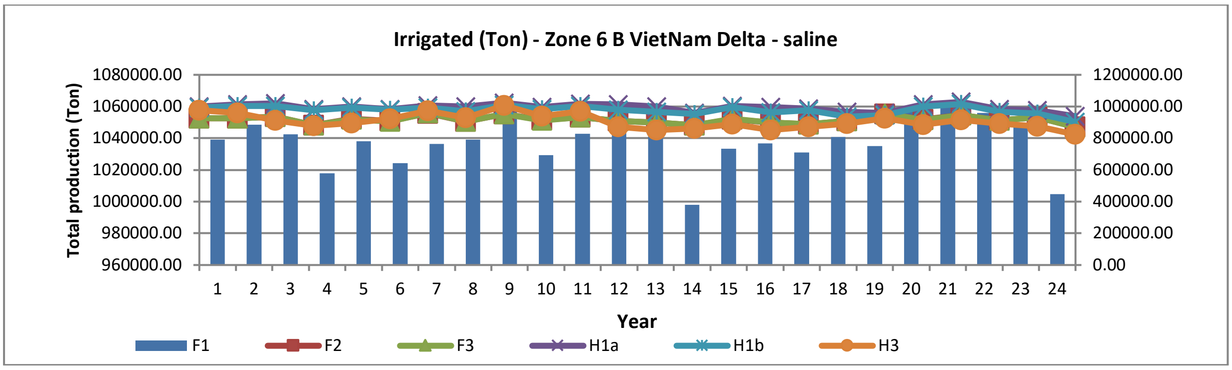


Figure 53. Sub-scenario rice production for non-irrigated rice for the Zone 6B (Vietnam Delta saline). Observe that scales are different for the bars (left scale) and for the time series (right scale).

15 Irrigation demand for the climate scenarios

15.1 Climate scenario impacts on irrigation demand for the LMB

Table 19 shows average annual irrigation demands computed with the IQQM model for the BDP sub-areas and for the climate scenarios M3, M3CC, C2 and C3.

Table 19: IQQM model computed irrigation demands (Mm³) for the climate scenarios and BDP sub-areas.

Country	BDP Sub area	SCN M3cc	SCN M3	sub SCN C2	sub SCN C3
Cambodia	6C	13	13	14	13
	7C	55	55	59	55
	8C	22	21	22	22
	9C	1,012	938	1,079	973
	10C*	3,500	3,465	3,557	3,578
	11C*	89	84	88	90
Laos	1L	438	430	476	415
	3L	32	32	35	30
	4L	2,427	2,384	2,687	2,365
	6L	839	798	872	812
	7L	916	866	933	870
Thailand	2T	355	370	392	368
	3T	1,170	1,240	1,399	1,267
	5T	5,677	5,970	6,443	5,800
Vietnam	7V	1,583	1,524	1,564	1,501
	10V*	13,847	13,422	14,152	13,695
	11V*	3,061	2,975	3,107	3,065
	Country	SCN M3cc	SCN M3	sub SCN C2	sub SCN C3
	Cambodia	4,691	4,577	4,819	4,732
	Laos	4,652	4,510	5,003	4,492
	Thailand	7,201	7,580	8,235	7,435
	Vietnam	18,491	17,921	18,823	18,260
	Total	35,036	34,589	36,879	34,919

Following conclusions can be drawn when comparing 2040 development without climate change with the M3CC (“more seasonal”), C2 (“more wet”) and C3 (“more dry”) climate change scenarios:

- Changes compared to the 2040 development scenario without climate change are small, maximum 7%.
- Sub-area irrigation demand changes don’t follow the logic of “seasonal”, “wet” and “dry”. For instance the “dry” scenario has overall smaller irrigation demands than the “wet” one.
- Different areas respond differently for climate change. For instance some sub-areas have larger irrigation demand in M3CC and some smaller compared to the M3 scenario.

These conclusions follow from the nature of the climate change scenarios selected for the Council Study: the scenarios don't differ as intended from each other and are heterogenous in terms of spatial precipitation change some areas experiencing increased and some decreased rainfall.

It is instructive to compare the irrigation demand changes to other studies. Shahid[6] used 32 global models for North-West Bangladesh rice irrigation demand modelling for the year 2100. He used same hydrological FAO56 approach as the IQQM for irrigation demand. Shahid's conclusion is: "there will be no appreciable change in total irrigation water demand due to the shortening of irrigation period by approximately 13 days and an increase of effective precipitation by 48.5 mm during irrigation period." (Shahid, 2010)

15.2 Upstream Kratie irrigation demand for the assessment corridor

shows annual irrigation demands for selected locations shown in . The planting day is 1st of January and there is only one irrigated crop included in simulation. Inter-annual variation for irrigation is rather small as dry season rainfall doesn't vary very much between the years. However, irrigation demand can be quite different depending on the locale. Factors affecting dry season irrigation demand are: soil vertical and horizontal water conductivity, slope affecting drainage, soil water storage, wet season soil water recharge, flooding affecting the recharge and dry season evapotranspiration. As an example irrigation demand for location Zone1 is double compared to nearby station Zone1V2. This is because Zone1V2 is in flatter terrain (les drainage), is in a downstream sub-watershed area receiving upstream soil and surface flow and is affected by wet season Mekong flooding. Potential evapotranspiration (PET) is very similar in both locales.

Other sources, based on modelling and field studies, estimate dry season irrigation demand to be about 15'000 – 17'000 m^3/ha (Räsänen et al. 2013). This is in line with the average irrigation demand in .

[6] Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh , Shamsuddin Shahid, 2010, Climatic Change

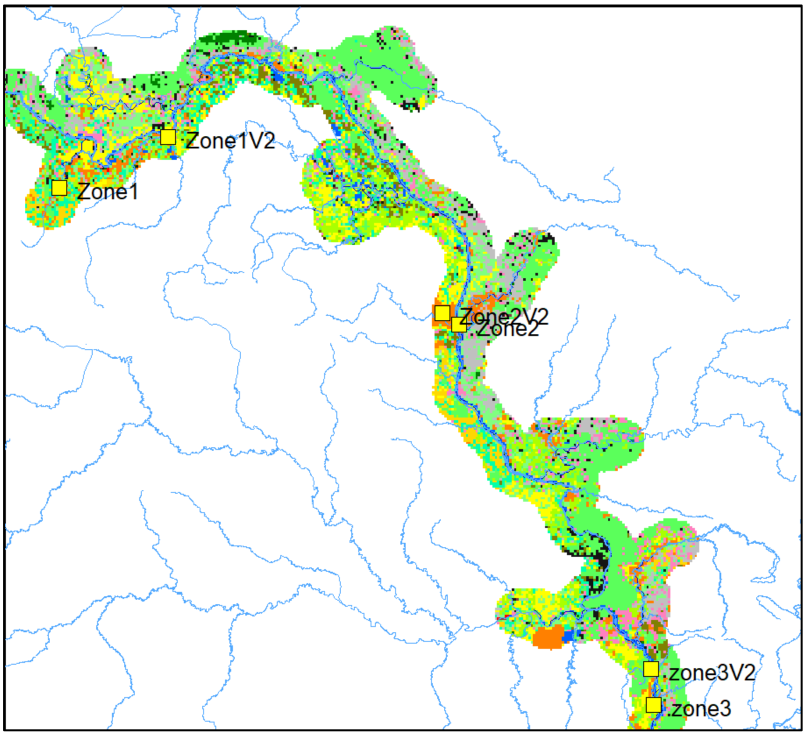


Figure 54: Locations of the model output areas.

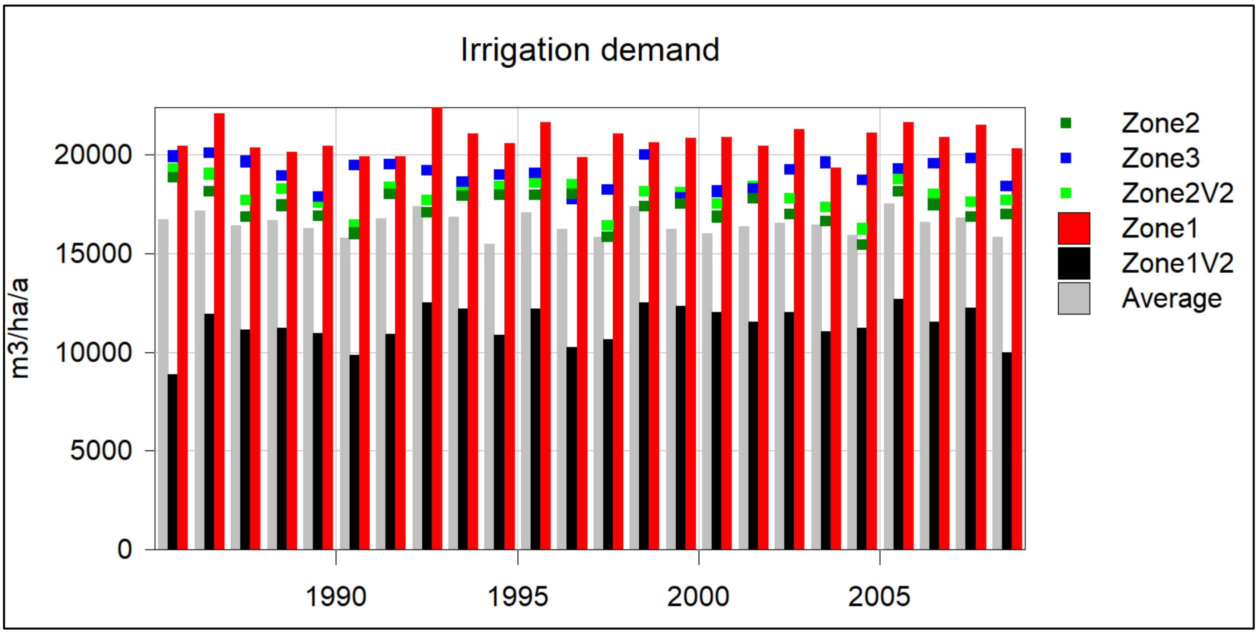


Figure 55: Annual dry season irrigation demands for selected locations shown in .

The climate change scenarios don't have large impact on average irrigation demands in the upper Kratie compared to inter-annual demand variation (). Maximal irrigation demand increase compared to the M3 is about 400 m^3 in scenarios M3CC (more seasonal) and C3 (more dry). Maximal irrigation need reduction in C2 is about 300 m^3 but some years irrigation demand increases slightly in C2.

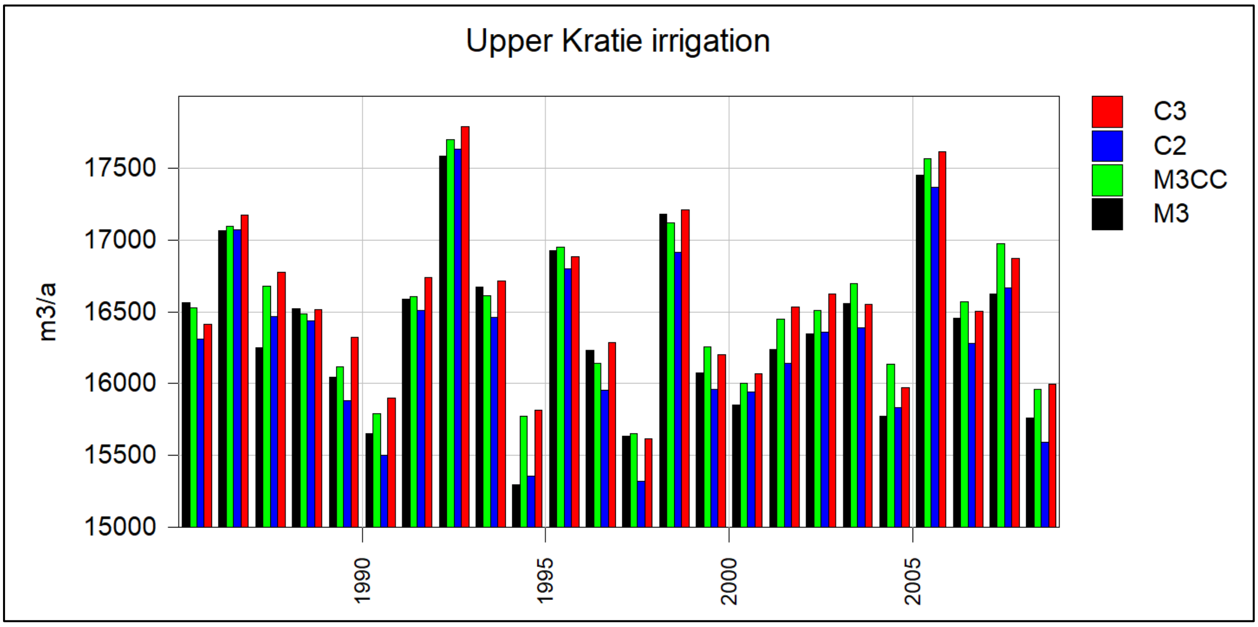
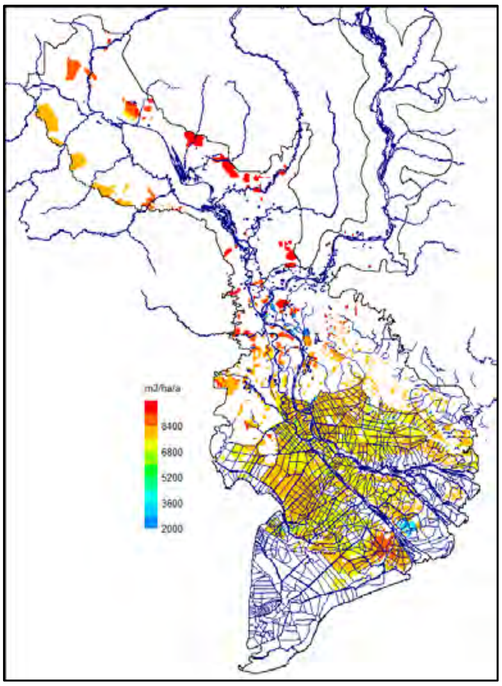


Figure 56: Dry season irrigation average upper Kratie demand for the baseline climate in 2040 (M3) and more seasonal (M3CC), wetter (C2) and dryer (C3) climate.

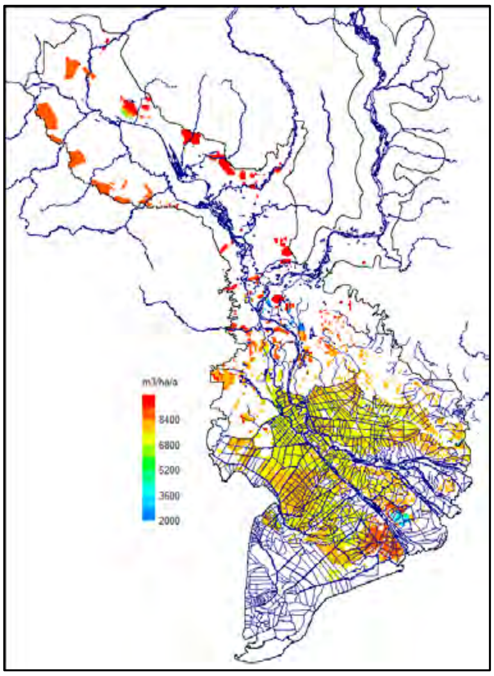
15.3 Downstream Kratie irrigation demand for the SIMVA corridor

shows modelled dry season baseline irrigation demand for the M1 (baseline), M3CC, C2 and C3 climate scenarios.

BL



M3CC



C2 **C3**

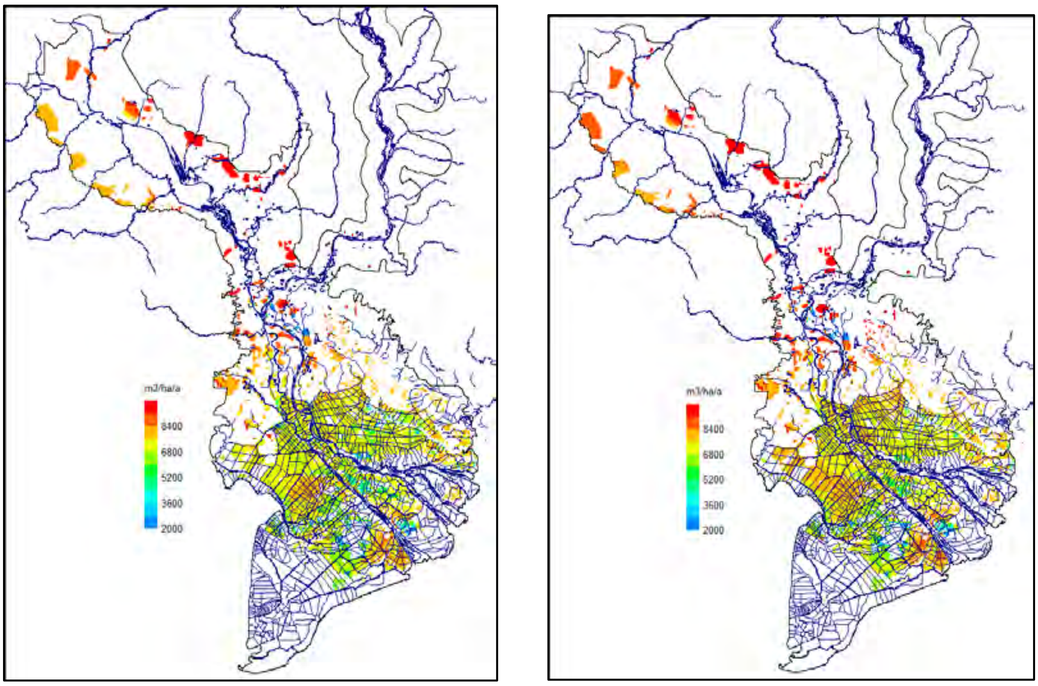


Figure 57. Dry season irrigation demand in the Delta for M1, M3CC, C2 and C3 climate scenarios.

The irrigation maps above show little change between the scenarios. This is shown also in for the annual average irrigation demands over whole lower Kratie area although for M3CC can increase irrigation demand up to 20% for more wetter years compared to M1, C2 and C3. One reason for the small changes, although temperature and evapotranspiration increase, the decreased length of the plant growth due to increased temperature. Precipitation changes play small role as the changes are relatively small and precipitation plays minor role in irrigation demand during the dry season. The main change in M3CC for some wet years where average irrigation demand increases up to 1000 m^3/ha.

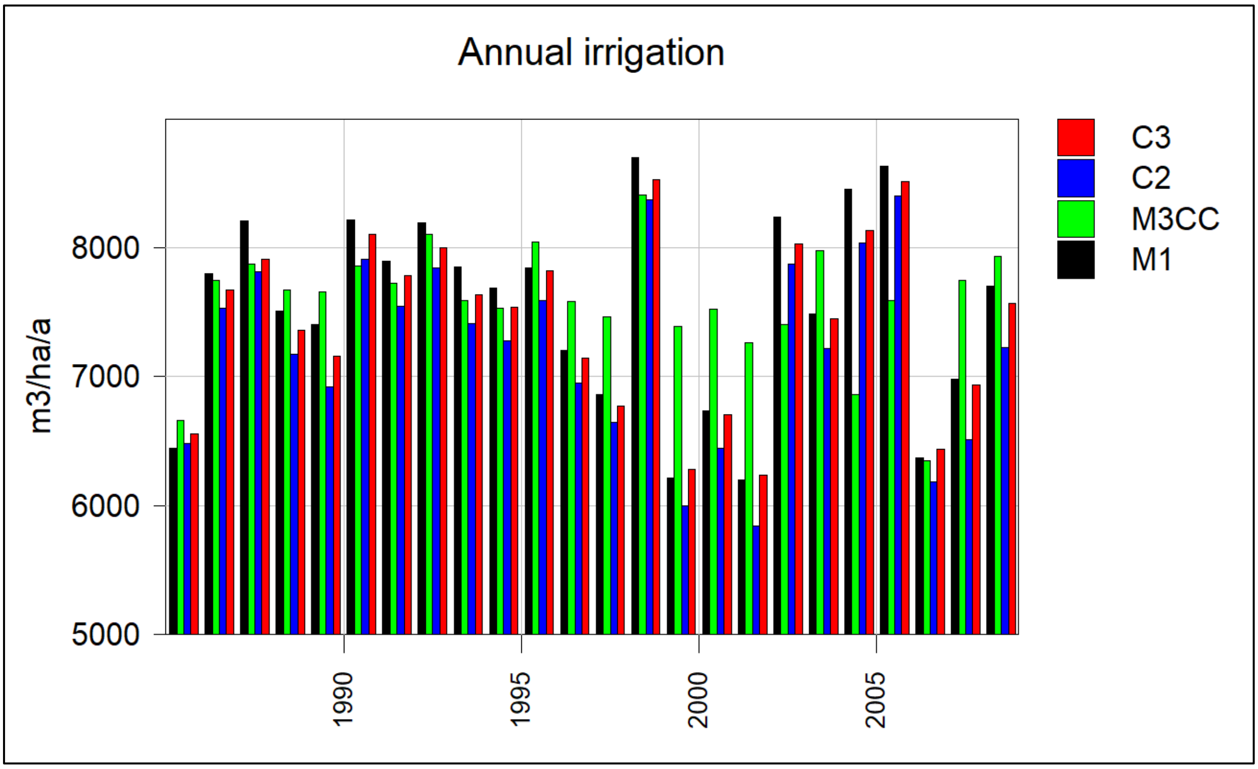


Figure 58. Downstream Kratie average dry season irrigation demand for the baseline and 2040 climate change scenarios.

15.4 Tonle Sap hydrological conditions and irrigation demand for the climate scenarios

An example of monthly average precipitation for the different climate scenarios is shown in Figure 59 for the Kampong Thom station for the year 1993. It can be seen that C3 is consistently drier than the other scenarios and October and November have increased precipitation for October and November compared to the baseline observed values. The precipitation has been projected with the IWRM (WUP-FIN) software utilizing Delta downscaling results.

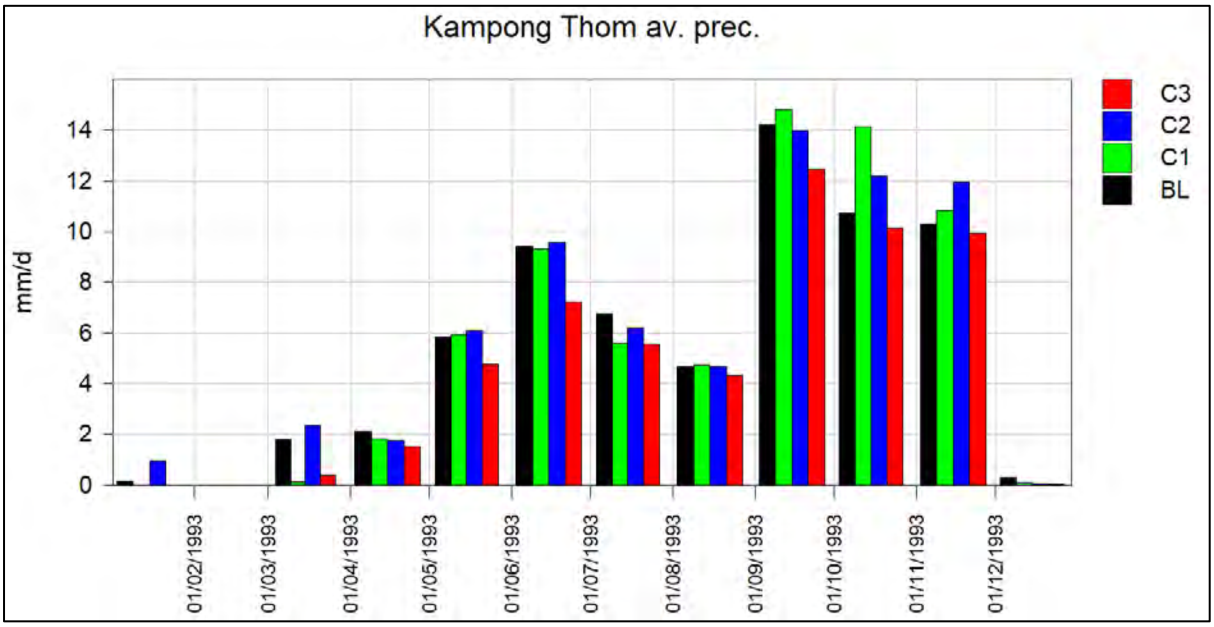


Figure 59. Kampong Thom average monthly rainfall during 1993. C1, C2 and C2 rainfall is projected from BL rainfall to the 2040 climate.

Decreased rainfall, hotter temperatures and increased evaporation affect the water availability in the Tonle Sap watershed for the scenario C3. In Figure 60 shows dry season model soil layer 2 (0.2 m – 3 m) water content. The soil in scenario C3 is up to 50% drier than in the baseline.

BL **C3**

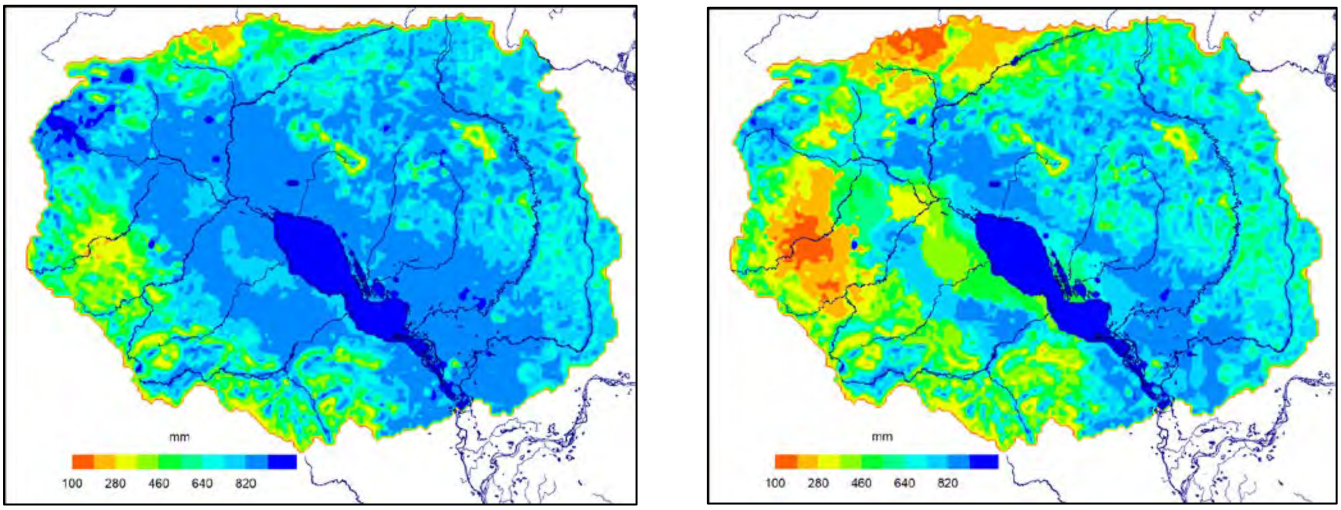


Figure 60. Model soil layer 2 (depth 0.2 m – 3 m) average water content for the dry season.

The drier conditions affect also groundwater as can be seen in the Figure 61: drier conditions drive groundwater deeper into the ground. It should be noted that the groundwater model has not been calibrated nor verified with monitoring data, so the results are illustrative and indicative only.

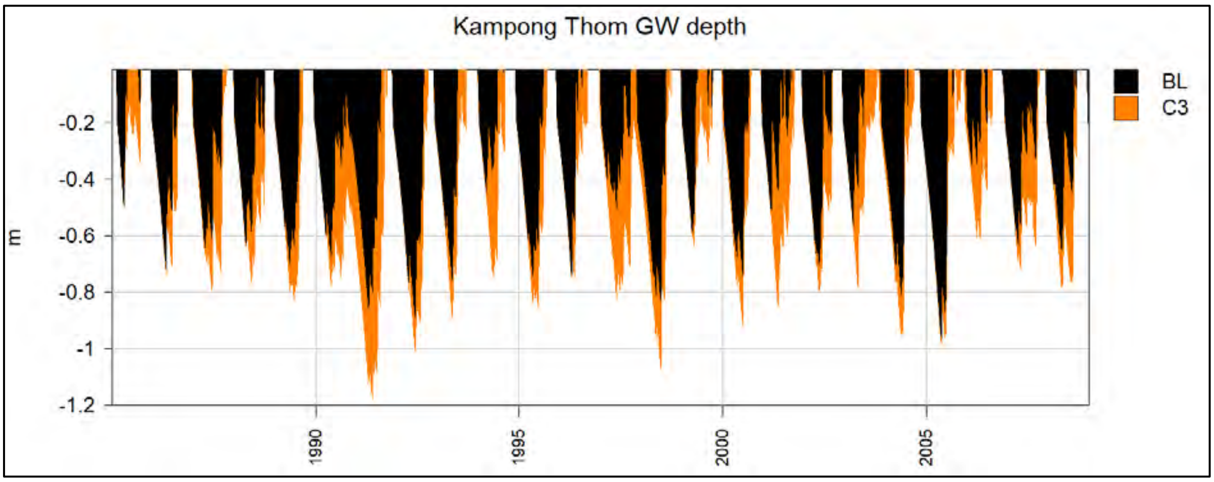


Figure 61. Groundwater depth in Kampong Thom for the baseline (BL) and C3 scenarios.

Figure 62 shows supplementary irrigation demand in the baseline and change for the wet season in C3 climate scenario. Figure 63 shows corresponding change for dry season irrigation. The wet season irrigation demand varies between 8000 m^3/ha for higher hilly area to 2000 m^3/ha to near-Mekong flat areas. The dry season irrigation demand varies between 15'000 m^3/s to 9000 m^3/s. The additional irrigation demand in C3 for wet season is 800 – 1800 m^3/s and for dry season 400 – 1100 m^3/s.

BL **C3**

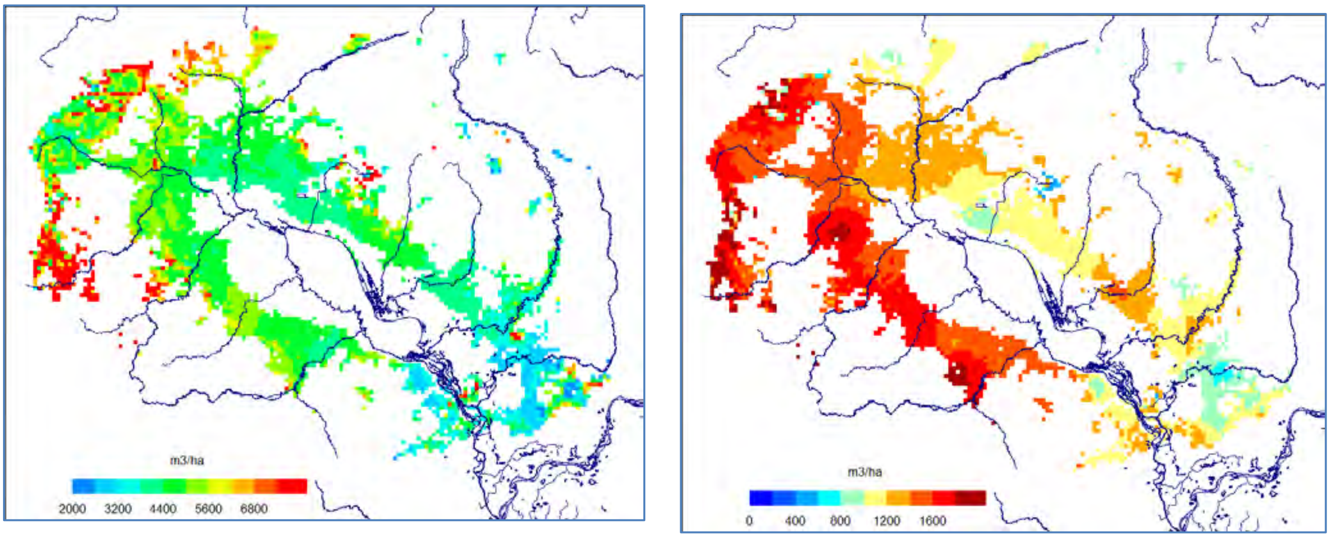


Figure 62. Average supplementary irrigation demand for rice planted in mid-June. Left baseline and right change in the dry C3 climate scenario.

BL **C3**

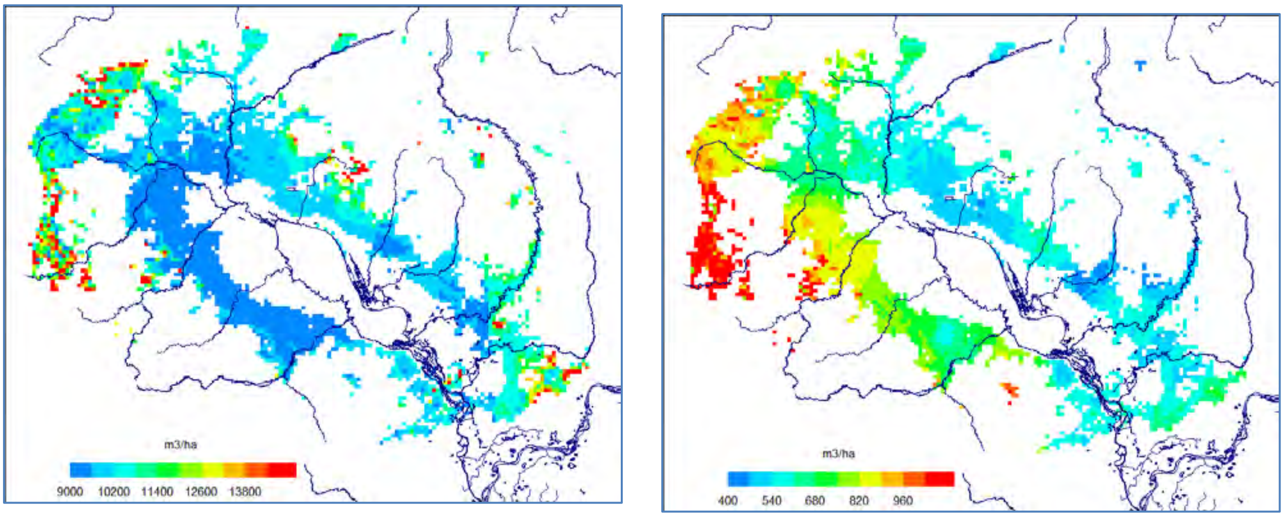


Figure 63. Average irrigation demand for rice planted in early January. Left baseline and right change in the dry C3 climate scenario.

16 Irrigation economic and ecological impacts

16.1 Macro-economic analysis

I1: Reverting the irrigation expansion to the situation of 2007 while developing all other sectors according to the assumptions of scenario M3CC creates a loss of $19.8 billion. Surprisingly, avoiding these investments translates into a gain for Vietnam, which suggests that the costs of irrigation expansion are likely to outweigh the economic benefits by $3.1 billion in net present value (Smajgl, 2017).

I2: Sub-scenario I2 sheds light on the option to increase investments into irrigation even further than defined by scenario M3CC. Thailand shows potential for further increasing economic benefits. However, these results are highly sensitive to the assumptions on costs for installing new irrigation areas. For this particular element of the council study cost information had to be derived from existing areas in absence of detailed studies of the irrigation extensions, which is not particular robust as **new areas typically come at significantly higher costs and may no more be economic**: of course, the most easy and economic areas for irrigation areas have been already developed. Irrigation investments that go beyond M3CC assumptions do not seem to be promising for the other three lower Mekong basin countries as Table 20 shows.

Table 20: Economic benefit changes in % of agriculture sector income compared to M3CC

	A1 Difference		A2 Difference		I1 Difference		I2 Difference	
	B$	%	B$	%	B$	%	B$	%
Cambodia	-$70.0	-54.1%	+10.1	+7.8%	-$7.5	-5.8%	0.0	0.0%
Lao PDR	-$5.9	-12.3%	+15.3	+31.8%	-$5.9	-12.2%	+0.2	+0.5%
Thailand	-$9.9	-6.3%	0.0	0.0%	-$9.6	-6.1%	+2.4	+1.5%
Viet Nam	-$25.3	-20.2%	0.0	0.0%	$3.1	2.5%	0.0	0.0%
LMB	-$111.2	-24.1%	+25.4	+5.5%	-$19.8	-4.3%	+2.7	+0.6%

Specific socio-economic analysis for the irrigation sub-scenarios doesn't exist. Instead food security and agricultural income analysis is presented in the *Agriculture and Land Use report* (Koponen, J., Paiboonvorachat, C. and Munoz, A., 2017).

16.2 Ecological analysis

Some of the BioRA indicators selected represented physical and chemical aspects of the river ecosystem and their predicted changes emerged from the modelling exercises. Others were ecosystem indicators whose predicted changes were provided through response curves created by the BioRA team. The indicators are linked together as shown in Figure 64 (Brown, C. et al., 2017).

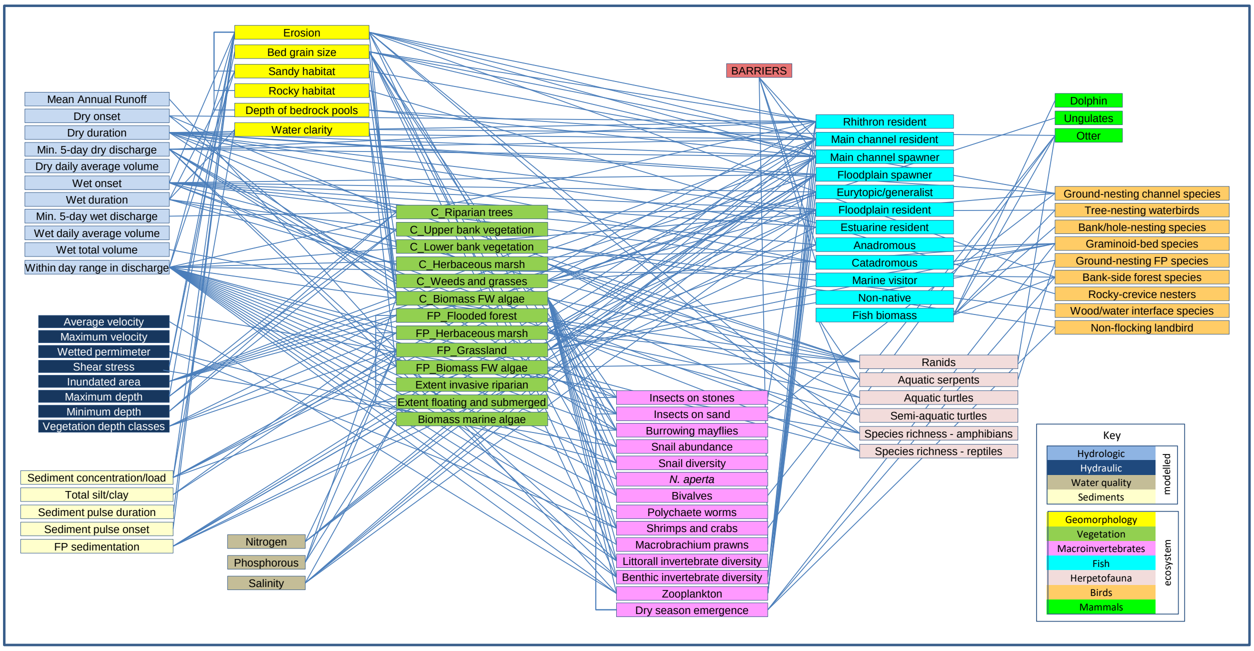


Figure 64. Links in the BioRA DRIFT ecological assessment system.

To assess the impacts of irrigation on the ecosystem, comparisons were made between 2040CC and two sub-scenarios with different levels of irrigation development, *viz*. (Table 21):

I2_IRR: 2040CC but with irrigation development at 2007 levels;

2040CCI2: 2040CC but with a higher level of irrigation development than that modelled in the 2040CC scenario.

Table 21: Sub-scenarios to test the effects of development in the irrigation sector

Scenario		Level of Development for water-related sectors						Climate
		ALU	DIW	FPI	HPP	IRR	NAV	
2040CC	Planned Development Scenario 2040CC	2040	2040	2040	2040	2040	2040	Mean warmer & wetter
I1_noIRR	Planned Development 2040 without IRR	2040	2040	2040	2040	2007	2040	
I2_IRR	Planned Development 2040 with IRR HIGH	2040	2040	2040	2040	HIGH	2040	

Values for the key BioRA summary indicators and ecosystem indicators indicate that the sub-scenarios are almost identical to Scenario 2040CC (Figure 65). This suggests that developments other than abstraction for irrigation are the drivers of ecosystem change in the Council Study development scenarios.

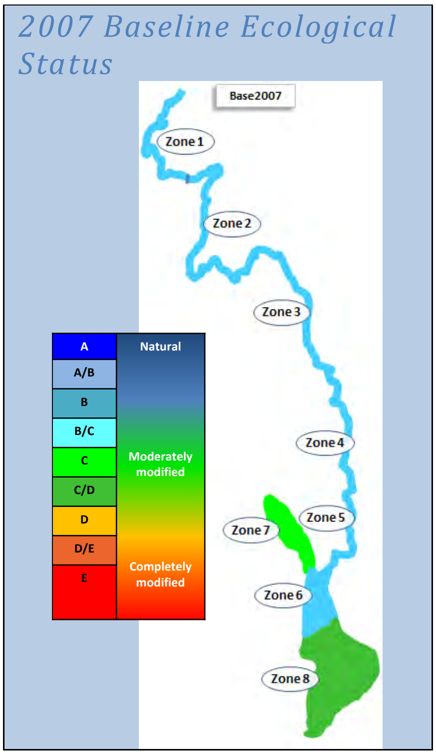


Figure 65. Estimated Baseline 2007 ecological conditions of the mainstream ecosystems the LMB

In Zone 5, 6 and 7, predicted discipline condition is higher for the I1_noIRR scenario, although this is only very slightly so (Figure 66). In Zone 6 and 8, slight improvements in condition relative to Scenario 2040CC are predicted for I2_IRR (Figure 67), but this is more likely a reflection of slight inconsistencies in the modelling than a true reflection of the impact of the level of irrigation development.

The small predicted differences between Scenario 2040CC and the irrigation sub-scenarios do not affect overall ecosystem health in the mainstream ecosystems of the LMB (Figure 68).

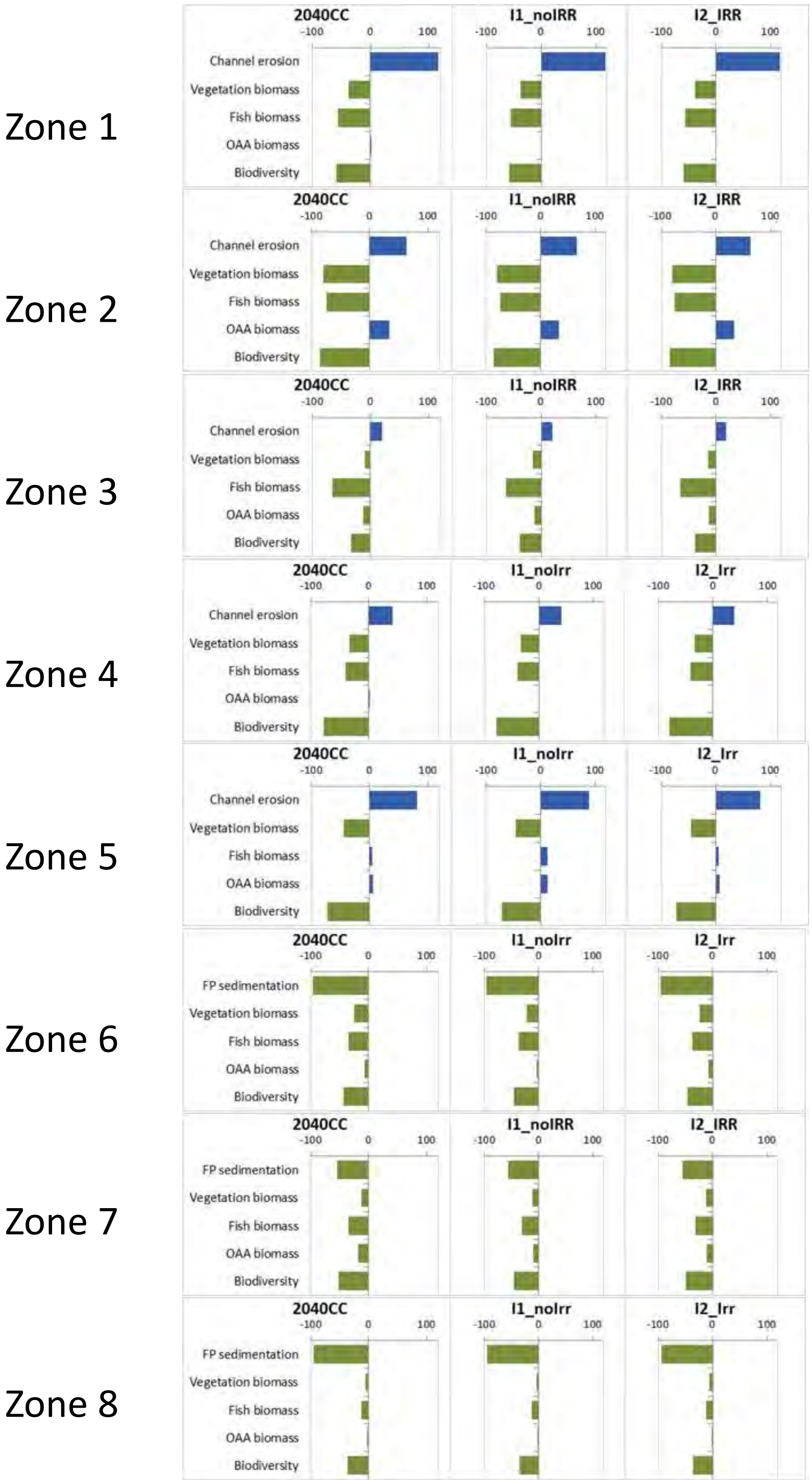


Figure 66. Predicted changes from Baseline in key ecosystem indicators for the BioRA zones for the irrigation sub-scenarios (left to right): 2040CC; I1_noIRR and I2_IRR. FP = floodplain; OAA = Other Aquatic Animals.

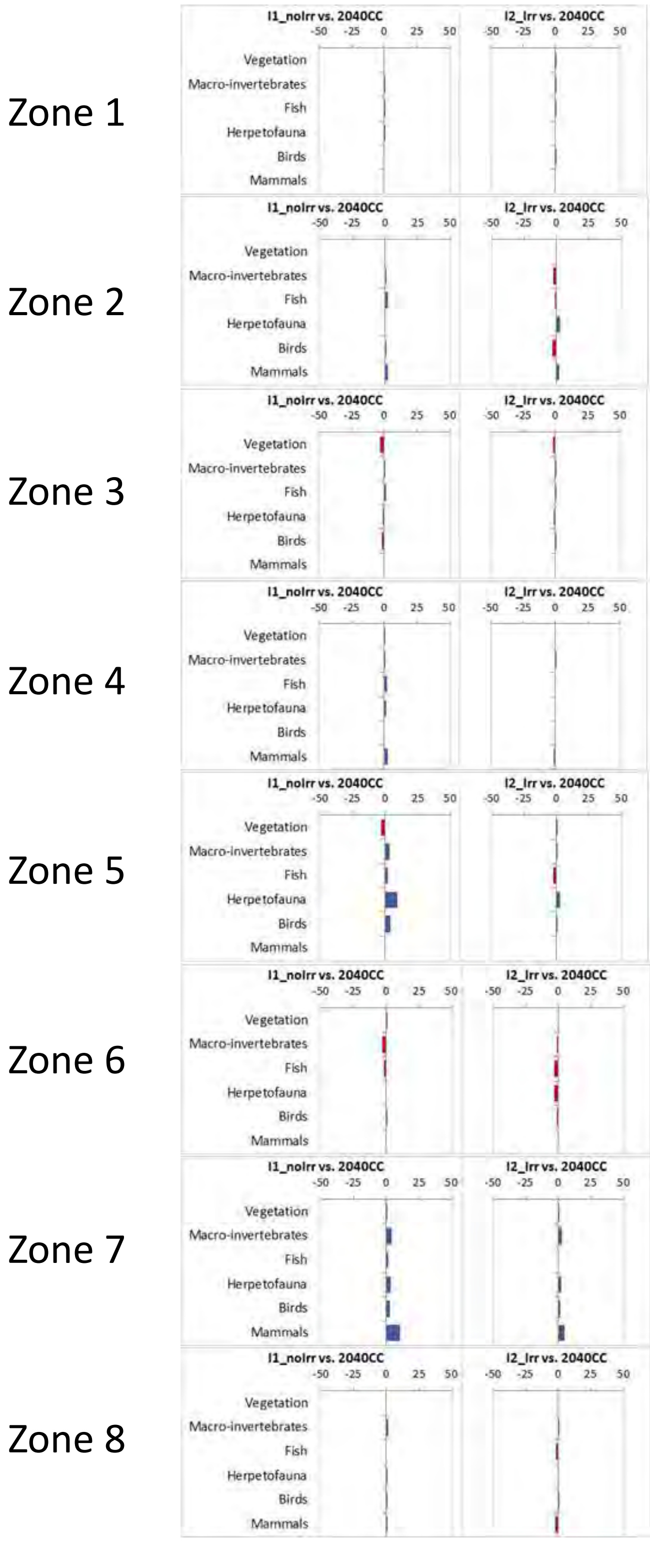


Figure 67. Difference in health for vegetation, macroinvertebrates, fish, herpetofauna, birds and mammals between 2040CC and the irrigation development sub-scenarios.

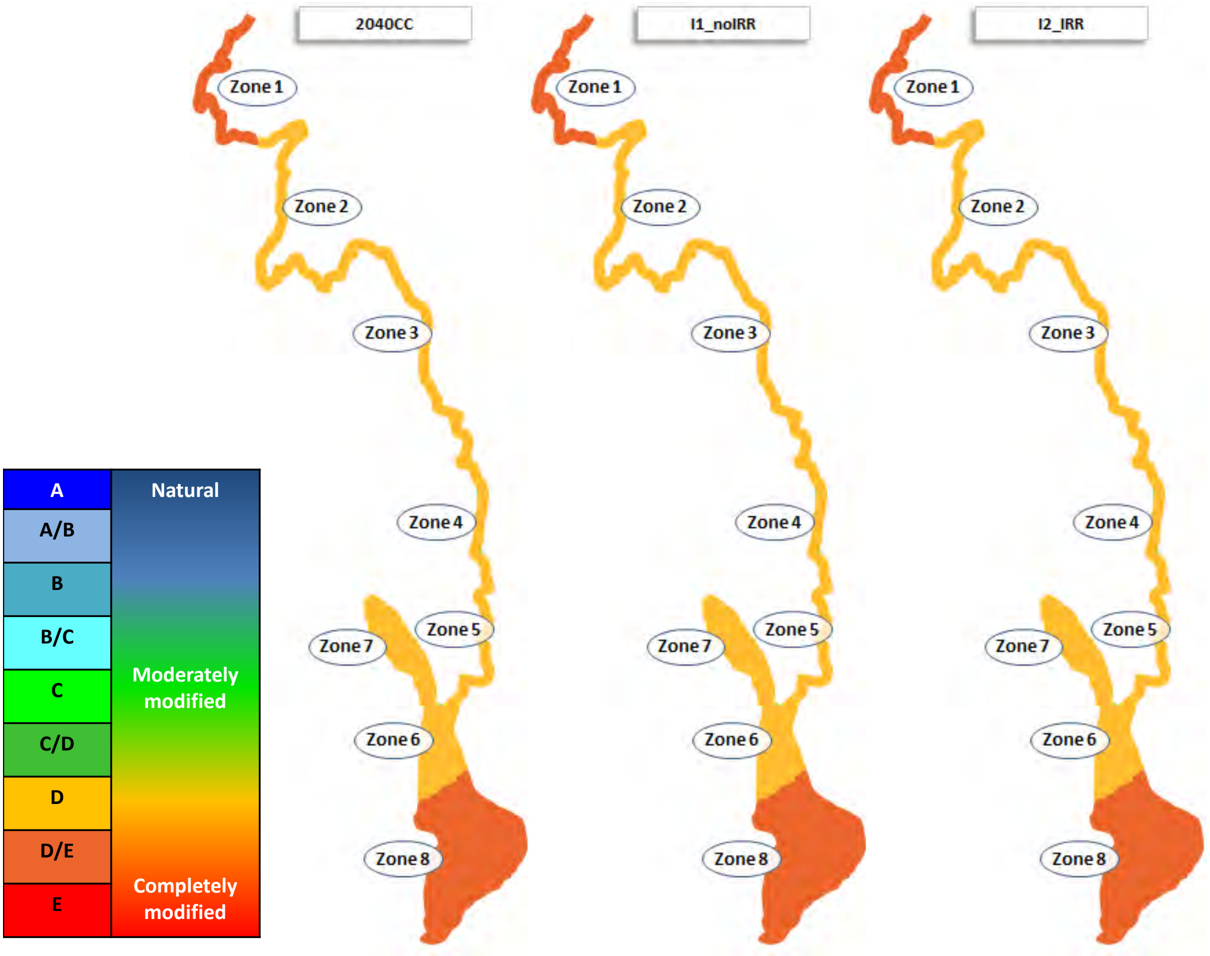


Figure 68. Mekong River condition predicted for the irrigation sub-scenarios

The key messages from the irrigation sub-scenarios are:

- The small differences in predicted change between Scenario 2040CC and the irrigation sub-scenarios do not affect overall ecosystem health in the LMB.
- In the context of the Council Study, incremental impacts associated with irrigation are masked by the much greater impacts associated with the other sector developments comprising Scenario 2040CC. Especially hydropower development and climate change need to be highlighted here.
- It is possible that the modelled data do not capture the full extent of impacts associated with irrigated crops. For instance, herbicide and pesticide use was not modelled but could have a devastating impact on the plants and animals at the base of the food chain in the LMB.

17 Study limitations and direction for future work

The Council Study has created of a fully integrated assessment framework from bio-geo-physical characteristics of the Mekong Basin reaching up to the policy level. The assessment methodology is *evidence based and quantitative* as the large economic, social and environmental values of the Mekong development require solid information basis. The assessment methodology is fully integrated as data and modelling are directly feeding into social, economic and environmental indicators and assessment and these in turn into the Thematic sectors. Other strong point of the Council Study is its thorough analysis of monitoring data, especially sediments and water quality, that has not been executed before. At the same time there are limitations involved with the study that stem from lacking data and broad scope of the exercise which constraints how far any specific discipline or thematic team has been able to pursue its sub-study.

The main limitations and constraints for the irrigation **data** requiring improvement in the future can be summarized as:

- Future irrigation change numbers may not be fully consistent and up-to-date;
- Irrigation area locations are not necessarily up-to-date or non-existent (Vietnam);
- Irrigation storage data needs to be checked and updated;
- There is no information about using hydropower reservoirs for local irrigation;
- Irrigation efficiency is not up-to-date for the latest and future Thai irrigation developments;
- Information on agrochemical (nutrients, pesticides, herbicides) releases is almost non-existent;
- Data on rice paddy fisheries and aquaculture is lacking such as how much fish is produced and how different farming practices affect the fisheries;
- Irrigated area crop calendars need to be checked;
- Information on where, when and how much other crops than rice are cultivated is seriously lacking;
- Climate scenarios need to be re-analyzed in order to capture ranges of possible future climates including more seasonal, drier, wetter and more variable climates;
- Future irrigation development, national priorities and policies and specifics of major irrigation options need to be clarified. In other words scenario definitions need to be revisited.

The main limitations and constraints for the irrigation **modelling** requiring improvement in the future can be summarized as:

- Upstream Kratie the detailed irrigation impact analysis has been conducted only in the narrow corridor around the Mekong mainstream including tributary floodplains affected by the Mekong; for the socio-economic analysis this corridor has been further restricted so that the floodplains are not included. This causes the analysis to be non-representative spatially and overly sensitive for water level changes in the mainstream such as caused by flood fluctuations and construction of the mainstream dams. The main related issue is that more detailed irrigation macro-economic analysis is not meaningful using the restricted corridor and the socio-economic analysis covers only communities in the immediate vicinity of the mainstream;

- Although on the national irrigation modelling using the DSF includes secondary and tertiary crops, the more detailed IWRM modelling has been restricted for only one dry season irrigated crop and for some indicators also for one wet season supplementary irrigation. The IWRM farming system modelling can be implemented for any type of crop calendars and crop mixes but the current Council Study scope doesn't include more realistic implementation;
- Other crops than rice have not been modeled;
- Although nutrient loads from agriculture has been included in the SWAT model there has been no possibility to calibrate or verify them because lack of data;
- It is possible to model actual return flows with the IWRM model but this has not been implemented yet because of the time required for model verification;
- Irrigation and crop modelling requires accurate daily local hydrological time series. The SWAT calibration has not been conducted on daily basis and there are anomalies in the hydrological indicators that need to be corrected.
- There should be much more emphasis on drought modelling than what has been implemented so far.
- No flood control data (dyke locations, dyke heights) has been available for the detailed irrigation modelling. This can over-emphasize flooding in the IWRM irrigation and crop model although as much ISIS data has been used as practically possible.
- Salinity intrusion is a complex issue because of many factors (sea level rise, flood control structures, upstream flow, channel morphology, water regulation) affecting it. As salinity intrusion has large impact on irrigation and crop production it should be understood better and the salinity intrusion model should be verified in detail. Also, salinity intrusion has been modelled only for two dry seasons which is too little.

The above constraints relate directly to the thematic analysis. Below some additional limitations and constraints for the irrigation **thematic analysis** requiring improvement in the future are indicated:

- Systematic risk-based approach has not been exercised in the irrigation analysis. For instance, water availability during dry periods, worst case salinity intrusion and dam operation risks have not been included in the analysis.
- Flood damages to irrigated areas have been analyzed in general terms only.
- Multi-purpose reservoir potential for irrigation expansion have not been included in the study.
- Mitigation options such as increased fertilizer use to compensate reservoir sediment and nutrient trapping have not analyzed quantitatively.
- Groundwater potential for irrigation has not been analyzed.

The Member Countries have indicated that the Council Study technology needs to be transferred to the countries for their independent update and iteration of the assessment. For instance, the countries have indicated that there is need to run new scenarios and use different future development policies and assumptions. Because of this the Council Study has been designed to be flexible, transparent, repeatable and open-ended to accommodate improved data and assessment tools in the future. The importance of the Council Study Assessment Framework is not so much that it is definitive, perfect and without information gaps but that it provides consistent scientific evidence based practical methodology and knowledge base to support further studies and processes. It would be important not to lose this knowledge and to continue improving it. In the future MRCS and the Member Countries should integrate the Council Study knowledge and methodology in the existing frameworks and activities.

18 Key findings, mitigation measures and recommendations

18.1 Impacts **on** irrigation from scenario development

Hydrology and irrigation sustainability

Finding: Kratie discharge doesn't seem to be enough to supply during the dry season massive Vietnam Delta irrigation needs. Although return flows and local rainfall increase water supply issues with salinity intrusion, low water levels, low water table, water quality and even water availability may occur locally in dry climate conditions and when Cambodia is expanding irrigation. **Recommendations**: Cambodia and Vietnam water balance should be studied together, and future risks assessed for planning and actions.

Finding: Vietnam and Lao PDR have good irrigation sustainability as 90% or more of the irrigated area is sustainable for all months. For Thailand sustainability decreases for the future development scenarios for the dry period January – April. It has not been possible to model sustainability in Cambodia. **Mitigation**: Increase of water storage or change of crops for dry season. **Recommendations**: Implement agricultural sustainability modelling for Cambodia.

Land use change

Finding: Total irrigated rice production is determined mainly by irrigated area. In the upper Kratie part of the assessment area irrigated rice production increases from about 1 Mt in baseline to about 1.6 Mt in M2 and 2.5 Mt in M3. Yields vary about 10% from year to year. In downstream Kratie yields increase from about 10 Mt to about 12 Mt in M3 and M3CC because of Cambodian increase of irrigated area. It should be emphasized here that *modelling has been implemented for one dry season rice crop only and doesn't take into account wet season or second dry season crop*.

Finding: Agricultural production changes are very heterogeneous through the Mekong basin and for different scenarios (ref. socio-economic assessment in the ALU report). However, the larger areas behave more consistently and have in increasing production trend for future due to increasing agricultural area. The exception is Vietnam where agricultural area even declines. **Recommendations**: Economic viability, availability of labor and food security should be considered when planning for agricultural expansion.

Climate change

Finding: The climate change scenarios don't have major impact on irrigation demand in the upper Kratie area (both SIMVA corridor and whole basin). In the lower part in some wetter years M3CC can increase irrigation demand up to 20% compared to the baseline. Around Tonle Sap additional irrigation demand in the dry C3 scenario is 800 – 1800 m^3/s for wet season and for dry season 400 – 1100 m^3/s.

Finding: Climate change affects agricultural production and ranges of suitable crops through water availability, flooding, temperature, salinity intrusion and susceptibility to weeds, plant diseases and pests. Modelling results indicate large increase of yields through CO_2 fertilization, but results have not been present as at the same time there is indication plants will be less resistant and more susceptible to pests and diseases. **Mitigation measures**: Climate change adaptation can be mitigated with building water storage capacity, changing crop calendars, changing crops, soil management to build plant resistance, genetic engineering etc. measures described widely. Other options are: water delivery losses can be reduced by protecting irrigation channel walls by concrete, planning water distribution according to crop growth stages and promoting participatory irrigation management. **Recommendations**: Special attention needs to be dedicated to obtain as realistic future climate projections as possible. It is important to focus climate variability including flood and drought events instead of monthly average scaling of precipitation and temperature.

Finding: Modelling results show significant decline of soil water in the Tonle Sap watershed and consequent large decline in rainfed agriculture yields for the dry climate scenario C3. Also required irrigation amounts would increase in scenario C3 up to 20%. **Recommendations and mitigation measures**: Planning and actions for water storage and maintaining food security need to be taken early enough.

<u>Hydropower development</u>

Finding: Hydropower development changes flooding, water availability, water quality, salinity and sediment and nutrient input to the paddies, river gardens and other flooding affected areas. Hydropower development is partly beneficial for agriculture as it increases dry season flows, decreases salinity intrusion and decreases flood peaks. Gains can be very substantial, 1 – 3 t/ha in specific areas in the Delta. On the other hand hydropower decreases sediment and nutrient inputs to agricultural areas through sediment and nutrient trapping causing soil fertility to decline. Yield losses are up to 20% if sediments are not compensated by fertilizers and maintenance of soil structure with organic material. Unlike the Delta, Kratie upstream part of the basin has limited floodplains and hydropower development has limited impact on rice. **Mitigation measures**: Sediment and nutrient trapping can be mitigated in the source at least partially by reservoir sediment management. In the receiving end soil management measures can be implemented including addition of nutrients and organic material to soil. **Recommendations**: Sediment, nutrient and other water quality processes in the reservoirs should be better understood through targeted monitoring and (3D) modelling in order to asses impacts and mitigation measures.

Finding: As defined in the Council Study, total national irrigation water demand increases 40% - 70% depending on the country in the M2 scenario and nearly triples in the M3 scenario compared to the baseline M1 scenario in Thailand, Lao PDR and Cambodia. Vietnam has slightly decreasing demand trend. Although in relative terms large increase, this expansion will have small impact on overall water budgets in the mainstream. During the dry season return flows compensate for increased losses by irrigation evaporation and dry season flows decrease 3% after Pakse in I2-scenario (intensive irrigation) compared to the M3CC scenario. In the M3CC scenario dry season water uptake by irrigation is 1% – 11% depending on the location. At the same time mainstream dry season flows will increase up to 28% in M3 compared to the baseline M1 scenario. During wet season increased water storage for irrigation is insignificant compared to the mainstream flows. **Recommendation**: As increased dry season flows caused by hydropower enable more water extraction and climate change poses increases risks for water security, options for larger water diversions for securing Member Country water supplies can be studied in the future.

Finding: Multi-purpose use of the hydropower reservoirs for local irrigation is not in the scope of the Council Study. However, other studies give indication of the issues involved. In a recent study[7] that utilized the IWRM/WUP-FIN model and dynamic optimization: "The results indicate that the development of multipurpose reservoirs would potentially increase rice production and the overall benefits of hydropower projects in the Sesan River Catchment with minor losses in hydropower generation. In this case study, the irrigation of 28,348 ha resulted in the reduction of −1.6% in the total annual hydropower generation of nine dams. However, the results revealed that the development of multipurpose reservoirs would have major impacts on flow regimes and land cover." and "In general, the Sesan case study emphasizes that the development of irrigation in conjunction to hydropower results in increasingly complicated management systems and competition between the water users." **Recommendation**: Comprehensive analysis of the benefits and trade-offs of multi-purpose reservoirs should be conducted in the future.

Salinity intrusion

Finding: Salinity intrusion development in the future scenarios is complex because many factors affect it including upstream flow, water levels, sea level rise and water controls.

18.2 Impacts of irrigation development on other sectors

Mekong flows

Finding: Basin irrigation has negligible impact on wet season flows. Dry season flows increase due to the irrigation. Consequently, dry season navigation, domestic and industrial water use and hydropower benefit slightly from irrigation based on increased flow and water levels, less salinity intrusion and better water quality.

Sediment loads

Finding: Upstream Kratie whole basin agricultural development will have only marginal impact on Mekong sediment loads. It has not been possible to assess reliably fertilizer and agro-chemical use impacts with the current data and modelling. **Recommendations**: (i) It would be important to have better understanding of nutrient and agro-chemical loads from agriculture based on targeted monitoring and improved modelling. (ii) Impact of very large number of small irrigation water storages needs to be clarified. (iii) Accuracy of current modelling for paddy rice hydrology and loads needs to be assessed. (iv) Modelling needs to be applied to the Cambodian floodplains also as they will experience large agriculture expansion.

[7] Model-Based Assessment of Water, Food, and Energy Trade-Offs in a Cascade of Multipurpose Reservoirs: Case Study of the Sesan Tributary of the Mekong Rive, Räsänen et. al., 2014, Journal of Water Resources Planning and Management

Irrigation efficiency

Finding: Return flow factors have been provided modelling. This is not ideal as return flows depend strongly on local terrain and soil characteristics as well as climate. **Recommendation**: Use the IWRM/WUP-FIN or other similar model to compute return flows.

Finding: Irrigation efficiency is best of the four countries in Vietnam. Cambodia and Thailand have worst efficiency. **Mitigation**: More efficient irrigation channel system and irrigation application can improve efficiency. **Recommendation**: As CS has not received updated information from Thailand old BDP numbers for efficiency have been used in the study. However, Thailand has improved greatly efficiency in the latest irrigation development and this will be also the case for the future irrigation. Consequently Thai irrigation efficiency numbers should be updated in the future studies.

Ecological impacts

Finding: Irrigation ecological impacts are minor. **Mitigation measures**: Intensification of agriculture, for instance in terms of triple rice cropping, has limits in terms of productivity. Also, more ecological crop rotation, ecological soil management and promotion of rice-fish systems can be more productive in the long run than increasing use of agro-chemicals.

Socio-economic and macro-economic impacts

Finding: In terms of food security, Cambodia can face occasional food crises related to rice (vulnerability of rice surplus) and Lao food security is not strong in the future scenarios in some specific SIMVA zones because of population growth and small agriculture areas. However, to pay greater attention to the role of transportation and logistics can overcome the challenge on food security. (ref. socio-economic assessment in the ALU report) **Mitigation measures**: Obvious measures include decreasing rice production, storage and transportation losses, making agriculture more efficient and curbing population growth.

Finding: Irrigation expansion is expected to bring significant economic benefits to the other countries than Vietnam. However, this result is highly sensitive to the assumptions used and further gains beyond the M3 scenario seem to be questionable except for Thailand. **Recommendations**: Countries should not assume agriculture development to be easily achievable in the future and not necessarily profitable. Countries should build more versatile economies to become more resilient.

19 Conclusions and recommendations for the future work

Irrigation expansion promises major economic and food security gains. In the upper Kratie part of the assessment area irrigated rice production increases from about 1 Mt in baseline to about 1.6 Mt in M2 and 2.5 Mt in M3. In downstream Kratie yields increase from about 10 Mt to about 12 Mt in M3 and M3CC because of Cambodian increase of irrigated area. (It should be emphasized here that *modelling has been implemented for one dry season rice crop only and doesn't take into account wet season or second dry season crop*.) However, the gains need to be qualified with economic and labor constraints. For Vietnam irrigation expansion to the proposed M3 level is likely to cost $3.1 billion more than what can be gained from the expansion in net present value. The other countries would gain net benefits from expansion until M3 development level but only Thailand has potential for further gains beyond that. Even for Thailand costs may be more than estimated because expansion to new areas costs more than previous ones.

Food security will decrease in the future scenarios for some Lao PDR areas and for Cambodia. This is mostly because of population growth and can become acute for specific flood and drought events. Driest climate change scenario C3 needs to be highlighted here.

Irrigation impacts are focused mostly on dry season flows. M3 level or irrigation will decrease mainstream flow up to 11% and I2 intensive irrigation further 3%. At the same time mainstream dry season flows will increase up to 28% in M3 compared to the baseline M1 scenario. Irrigation sustainability is good for Lao PDR and Vietnam but further analysis is needed for the latter in terms of irrigation expansion upstream, dry climate scenarios and increased salinity intrusion due to river channel erosion, lowering of water table and sea level rise. Thailand sustainability decreases in the future scenarios for the driest months. It has not been possible to model Cambodian sustainability.

Hydropower development has both negative and positive impacts on rice production. Gains through flood mitigation and decreased salinity can be locally up to 1 – 3 t/ha. On the other hand fertile sediment inputs decrease and yields decrease up to 20% in the most affected areas without mitigation measures.

Climate change has obvious risks involved especially if drier climate projections are realized. Modelling indicates that in the assessment corridor Tonle Sap surroundings are quite sensitive to drier climate.

Council Study Irrigation Thematic Area has made substantial strides forward in terms of implementing an integrated methodology connecting the thematic work to the triple bottom line assessment and modelling. What remains is to bring the methodology to the general use, evaluation and update of the MRCS and the Member Countries. Number of further developments are required to increase applicability and reliability of the assessment including:

- Farming practices including crop calendars, irrigation, multiple crops, application of agro-chemicals etc. should be included in the modelling. This is not an issue for the Council Study model technology but supporting data needs to be obtained, ordered and implemented in the models.

- Irrigation scenarios need clarification including areas to be developed and storage capacity to be built.
- In climate change modelling more emphasis should be on extreme events (floods and droughts) as well general climate variability. So far only monthly average changes have been included in the study.
- Flood and drought risks and damages should be analyzed more rigorously than has been possible so far.
- Role of numerous small-scale water storages (on-farm ponds) should be clarified in comparison to large-scale reservoirs.
- Other crops than rice should be included in the study.
- Major water diversion projects should be included in the study to clarify their impact.
- Rice-fish potential should be examined as fish can be significant source of animal protein.
- The scope of detailed crop modelling should be expanded from the impact corridor to the whole basin.
- Erosion, sediment, nutrient and agro-chemical modeling requires much more thorough approach than has been so far exercised under the Council Study as these are linked to the main development factors in the Mekong, that is hydropower reservoirs and their processes, land use change, agriculture and climate change.

ANNEX I: DSF irrigation areas and computed irrigation indicators

Table 22: Monthly Irrigation areas by country in each main scenario

Monthly Average Irrigation Areas (Ha) for EDS 2007 M1												
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cambodia	296,788	279,961	279,961	547,113	290,507	290,507	307,334	199,007	16,827	16,827	16,827	296,788
Laos	84,479	97,284	97,284	96,980	49,562	208,197	208,755	208,755	208,755	237,215	284,600	115,479
Thailand	186,850	195,066	167,107	90,649	380,682	584,834	820,085	786,675	776,985	776,985	302,140	186,850
Vietnam	1,988,207	1,988,207	1,988,207	3,518,246	1,625,080	2,117,858	2,117,858	2,286,687	661,607	661,607	2,550,106	2,480,986
Monthly Average Irrigation Areas (Ha) for Dev2020 M2												
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cambodia	437,809	408,012	408,012	838,778	483,146	483,146	512,942	331,034	29,797	29,797	29,797	437,809
Laos	140,414	157,824	157,824	157,600	121,208	308,120	308,486	308,486	308,486	346,996	383,362	180,689
Thailand	483,436	506,125	434,436	260,695	712,979	1,029,737	1,655,418	1,569,985	1,544,296	1,544,296	772,651	483,436
Vietnam	1,971,717	1,971,717	1,971,717	3,394,667	1,540,637	2,016,847	2,016,847	2,176,131	635,495	635,495	2,484,837	2,447,928
Monthly Average Irrigation Areas (Ha) for Dev2040 M3												
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cambodia	809,239	777,400	777,400	1,783,478	1,069,326	1,069,326	1,101,165	704,328	31,839	31,839	31,839	809,239
Laos	291,654	325,903	325,903	325,471	260,201	596,099	596,774	596,774	596,774	672,514	737,735	370,458
Thailand	707,127	744,396	639,905	406,394	1,126,007	1,500,296	2,325,579	2,179,128	2,145,159	2,145,159	1,048,316	707,127
Vietnam	1,928,811	1,928,811	1,928,811	3,357,124	1,546,683	1,986,751	1,986,751	2,136,223	589,542	589,542	2,395,544	2,368,879
Monthly Average Irrigation Areas (Ha) for Dev2040 M3 (CC)												
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cambodia	809,239	777,400	777,400	1,783,478	1,069,326	1,069,326	1,101,165	704,328	31,839	31,839	31,839	809,239
Laos	291,654	325,903	325,903	325,471	260,201	596,099	596,774	596,774	596,774	672,514	737,735	370,458
Thailand	707,127	744,396	639,905	406,394	1,126,007	1,500,296	2,325,579	2,179,128	2,145,159	2,145,159	1,048,316	707,127
Vietnam	1,928,811	1,928,811	1,928,811	3,357,124	1,546,683	1,986,751	1,986,751	2,136,223	589,542	589,542	2,395,544	2,368,879

Table 23: Monthly Irrigation Water Diversion (MCM) by country in each main scenario

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

Table 24: Monthly Sustainable Areas for Irrigation by country in each main scenario

Monthly Average Sustainable Areas (%) for EDS 2007 M1													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	84%	68%	63%	75%	73%	72%	74%	73%	100%	100%	100%	98%	82%
Laos	95%	95%	94%	94%	97%	99%	98%	98%	98%	99%	99%	96%	97%
T%iland	89%	81%	79%	88%	97%	97%	98%	98%	98%	98%	98%	97%	93%
Vietnam	94%	93%	92%	93%	88%	90%	90%	91%	98%	98%	98%	96%	93%
Monthly Average Sustainable Areas (%) for Dev2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	79%	64%	59%	73%	70%	69%	71%	71%	100%	100%	100%	97%	79%
Laos	92%	92%	91%	91%	98%	99%	98%	98%	98%	99%	99%	93%	96%
T%iland	68%	58%	53%	58%	94%	95%	96%	98%	98%	98%	98%	90%	84%
Vietnam	93%	92%	92%	94%	89%	91%	91%	91%	98%	98%	98%	96%	94%
Monthly Average Sustainable Areas (%) for Dev2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	67%	54%	50%	62%	52%	52%	53%	53%	100%	100%	100%	90%	69%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	99%	99%	89%	94%
T%iland	70%	61%	57%	65%	94%	95%	96%	98%	98%	98%	98%	91%	85%
Vietnam	94%	93%	92%	93%	86%	89%	89%	89%	98%	98%	98%	96%	93%
Monthly Average Sustainable Areas (%) for Dev2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	70%	55%	50%	60%	46%	46%	48%	47%	100%	100%	100%	91%	68%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	98%	99%	89%	94%
T%iland	73%	64%	59%	64%	94%	95%	96%	97%	98%	98%	97%	93%	86%
Vietnam	94%	93%	92%	92%	85%	88%	88%	89%	98%	98%	98%	96%	93%

Table 25: Proportion of Sustainable to total Irrigation Area by country in each main scenario (assumes no significant new water diversions)

Monthly Average Sustainable Areas (%) for EDS 2007 M1													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	84%	68%	63%	75%	73%	72%	74%	73%	100%	100%	100%	98%	82%
Laos	95%	95%	94%	94%	97%	99%	98%	98%	98%	99%	99%	96%	97%
T%iland	89%	81%	79%	88%	97%	97%	98%	98%	98%	98%	98%	97%	93%
Vietnam	94%	93%	92%	93%	88%	90%	90%	91%	98%	98%	98%	96%	93%
Monthly Average Sustainable Areas (%) for Dev2020 M2													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	79%	64%	59%	73%	70%	69%	71%	71%	100%	100%	100%	97%	79%
Laos	92%	92%	91%	91%	98%	99%	98%	98%	98%	99%	99%	93%	96%
T%iland	68%	58%	53%	58%	94%	95%	96%	98%	98%	98%	98%	90%	84%
Vietnam	93%	92%	92%	94%	89%	91%	91%	91%	98%	98%	98%	96%	94%
Monthly Average Sustainable Areas (%) for Dev2040 M3													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	67%	54%	50%	62%	52%	52%	53%	53%	100%	100%	100%	90%	69%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	99%	99%	89%	94%
T%iland	70%	61%	57%	65%	94%	95%	96%	98%	98%	98%	98%	91%	85%
Vietnam	94%	93%	92%	93%	86%	89%	89%	89%	98%	98%	98%	96%	93%
Monthly Average Sustainable Areas (%) for Dev2040 M3 (CC)													
Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aaverage**
Cambodia	70%	55%	50%	60%	46%	46%	48%	47%	100%	100%	100%	91%	68%
Laos	87%	88%	87%	87%	98%	99%	98%	98%	98%	98%	99%	89%	94%
T%iland	73%	64%	59%	64%	94%	95%	96%	97%	98%	98%	97%	93%	86%
Vietnam	94%	93%	92%	92%	85%	88%	88%	89%	98%	98%	98%	96%	93%

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