MRC SEA FOR HYDROPOWER ON THE MEKONG MAINSTREAM

IMPACTS ASSESSMENT

(Opportunities and Risks)

Volume III: Annexes & supporting materials

11 June 2010

The MRC SEA of Hydropower on the Mekong mainstream comprises 4 main phases: (i) scoping, (ii) baseline assessment, (iii) opportunities & risks assessment, and (iv) Avoidance, enhancement and mitigation assessment.

The assessment of opportunities and risks comprises three volumes: (i) Vol I: Summary, (ii) Vol II: Main report, (iii) Vol III: Annexes & supporting materials

This 3 volume report formally concludes the impacts assessment phase of the SEA and documents the development opportunities and risks presented by the 12 LMB mainstream projects in the context of sustainable development of the Mekong River Basin.

Disclaimer

This document was prepared for the Mekong River Commission Secretariat (MRCS) by a consultant team engaged to facilitate preparation of a Strategic Environment Assessment (SEA) of proposals for mainstream dams in the Lower Mekong Basin.

While the SEA is undertaken in a collaborative process involving the MRC Secretariat, National Mekong Committees of the four countries as well as civil society, private sector and other stakeholders, this document was prepared by the SEA Consultant team to assist the Secretariat as part of the information gathering activity. The views, conclusions, and recommendations contained in the document are not to be taken to represent the views of the MRC. Any and all of the MRC views, conclusions, and recommendations will be set forth solely in the MRC reports.

This document incorporates impact analysis of issues raised in the consultation process as prepared by the consultant team and is to be considered a discussion draft only for the multi-stakeholder Regional Workshop in May 2010 in Vientiane.

For further information on the MRC initiative on Sustainable Hydropower (ISH) and the implementation of the SEA of proposed mainstream developments can be found on the MRC website: http://www.mrcmekong.org/ish/ish.htm and http://www.mrcmekong.org/ish/SEA.htm

The following position on mainstream dams is provided on the MRC website in 2009.

MRC position on the proposed mainstream hydropower dams in the Lower Mekong Basin

More than eleven hydropower dams are currently being studied by private sector developers for the mainstream of the Mekong. The 1995 Mekong Agreement requires that such projects are discussed extensively among all four countries prior to any decision being taken. That discussion, facilitated by MRC, will consider the full range of social, environmental and cross-sector development impacts within the Lower Mekong Basin. So far, none of the prospective developers have reached the stage of notification and prior consultation required under the Mekong Agreement. MRC has already carried out extensive studies on the consequences for fisheries and peoples livelihoods and this information is widely available, see for example report of an expert group meeting on dams and fisheries. MRC is undertaking a Strategic Environmental Assessment (SEA) of the proposed mainstream dams to provide a broader understanding of the opportunities and risks of such development. Dialogue on these planned projects with governments, civil society and the private sector is being facilitated by MRC and all comments received will be considered.

About the MRC SEA of Hydropower on the Mekong mainstream

The Mekong River Commission (MRC) is an inter-governmental river basin organization that provides the institutional framework to implement the 1995 Mekong Agreement. The Governments of Cambodia, Lao PDR, Thailand and Viet Nam signed the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin. They agreed on joint management of their shared water resources by cooperating in a constructive and mutually beneficial manner for sustainable development, utilization, conservation and management of the Mekong River Basin water and related resources.

Poverty alleviation as a contribution to the UN Millennium Development Goals is also a priority. The two upper states of the Mekong River Basin, the People's Republic of China and the Union of Myanmar, are dialogue partners to the MRC.

In a region undergoing rapid change and economic growth, the MRC considers the development of hydropower on the Mekong mainstream as one of the most important strategic issues facing the Lower Mekong region. Through the knowledge embedded in all MRC programs, the MRC is conducting this Strategic Environment Assessment (SEA) to assist Member states to work together and make the best decisions for the basin.

Twelve hydropower schemes have been proposed for the Lao, Lao-Thai and Cambodian reaches of the Mekong mainstream. Implementation of any or all of the proposed mainstream projects in the Lower Mekong Basin (LMB) could have profound and wide-ranging socio-economic and environmental impacts in all four riparian countries.

This SEA seeks to identify the potential opportunities and risks, as well as contribution of these proposed projects to regional development, by assessing alternative mainstream Mekong hydropower development strategies. In particular the SEA focuses on regional distribution of costs and benefits with respect to economic development, social equity and environmental protection. As such, the SEA supports the wider Basin Development Planning (BDP) process by complementing the MRC Basin Development Plan (BDP) assessment of basin-wide development scenarios with more in-depth analysis of power related and cross-sector development opportunities and risks of the proposed mainstream projects in the lower Basin.

The SEA is being coordinated by MRC's cross-cutting MRC Initiative for Sustainable Hydropower (ISH) working with all MRC programmes. The SEA will directly enhance the baseline information and assessment framework for subsequent government review of project-specific EIAs prepared by developers. It will also inform how the MRC can best enhance its support to Member Countries when the formal process under the 1995 Mekong Agreement for prior consultation on any individual mainstream proposal is triggered (i.e. the Procedures for Notification, Prior Consultation and Agreement or PNPCA). The SEA findings will also inform steps that MRC programmes may consider in the next MRC Strategic Plan Cycle (2011-2015) to help address the knowledge gaps and the key areas of uncertainty and risk concerning proposed mainstream developments.

The SEA began in May 2009 and is scheduled to complete the final report and recommendations by mid-2010. This document is one of a series of documents arising from an intensive program of consultations in the Lower Mekong Basin and detailed expert analysis of the issues associated with developing hydropower on the Mekong mainstream. The intention is to consolidate SEA activities and progressively make conclusions and outputs available for public and critical review, so that stakeholder engagement can contribute to the SEA in a meaningful way. A full list of documents is available on the MRC SEA website.

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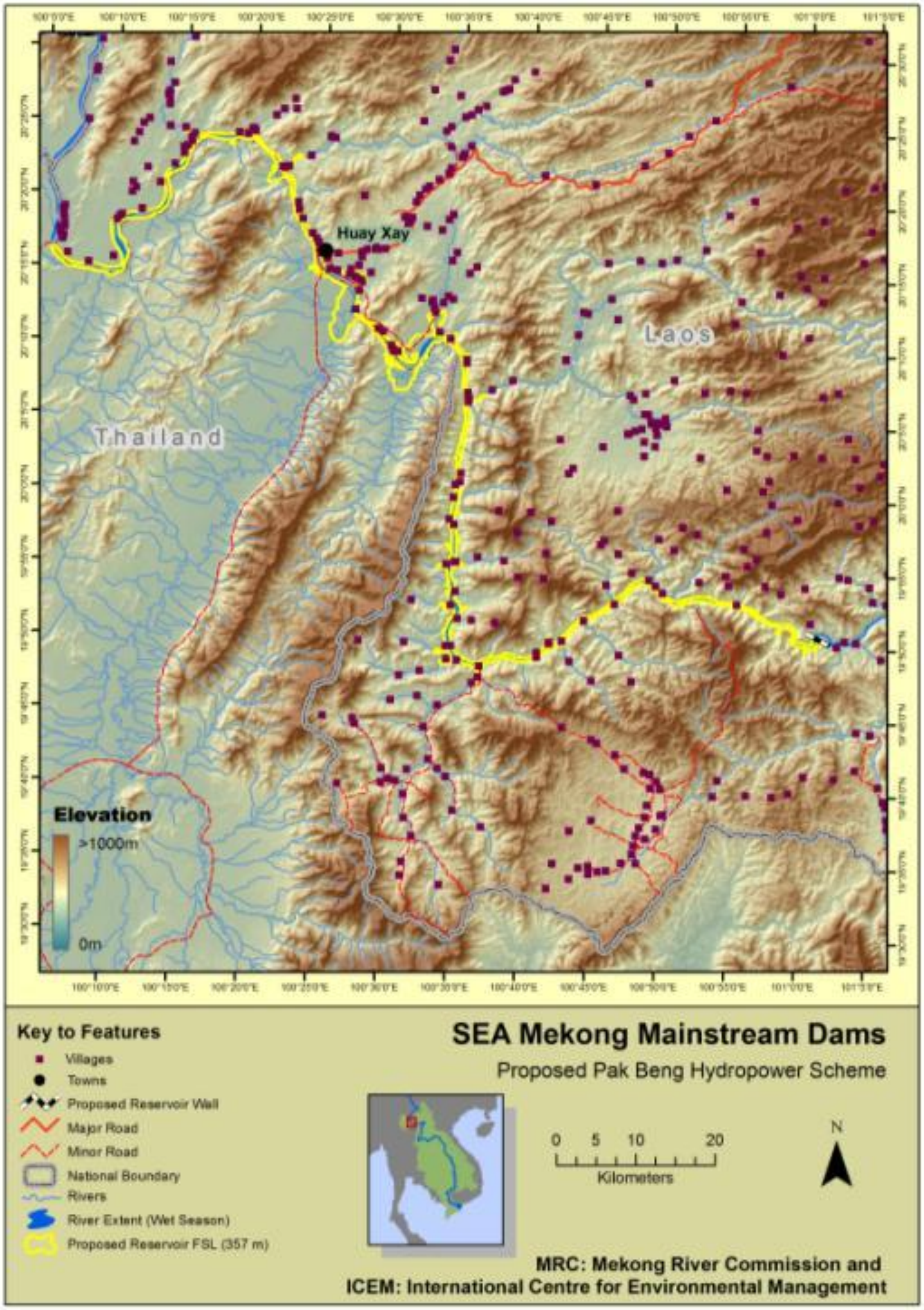
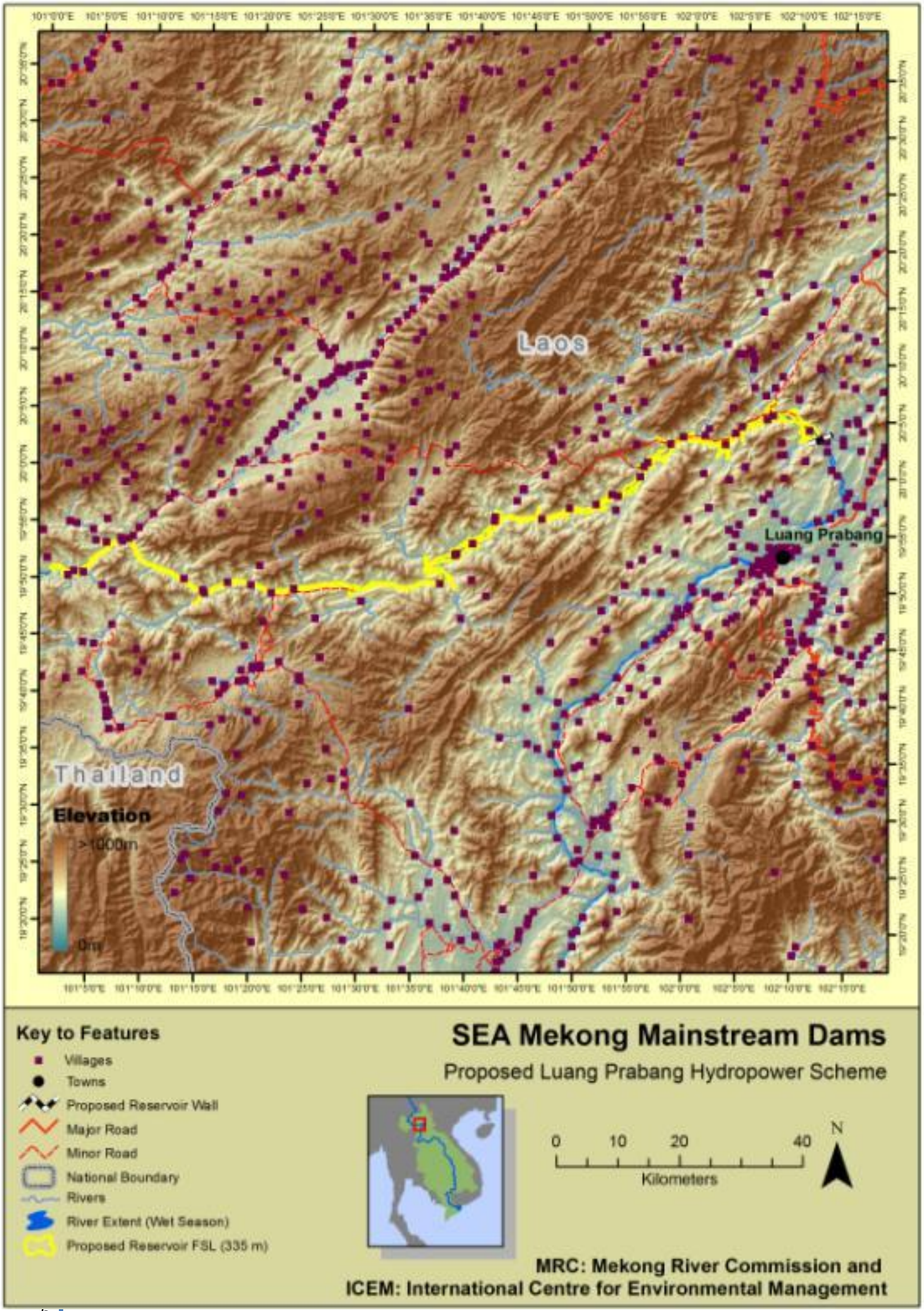
ANNEX I: RESERVOIR INUNDATION MAPS

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Thailand
Luang Prabang
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Key to Features
Villages
Towns
Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
Rivers
River Extent (Wet Season)
Proposed Reservoir FSL (335 m)
SEA Mekong Mainstream Dams
Proposed Luang Prabang Hydropower Scheme
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Kilometers
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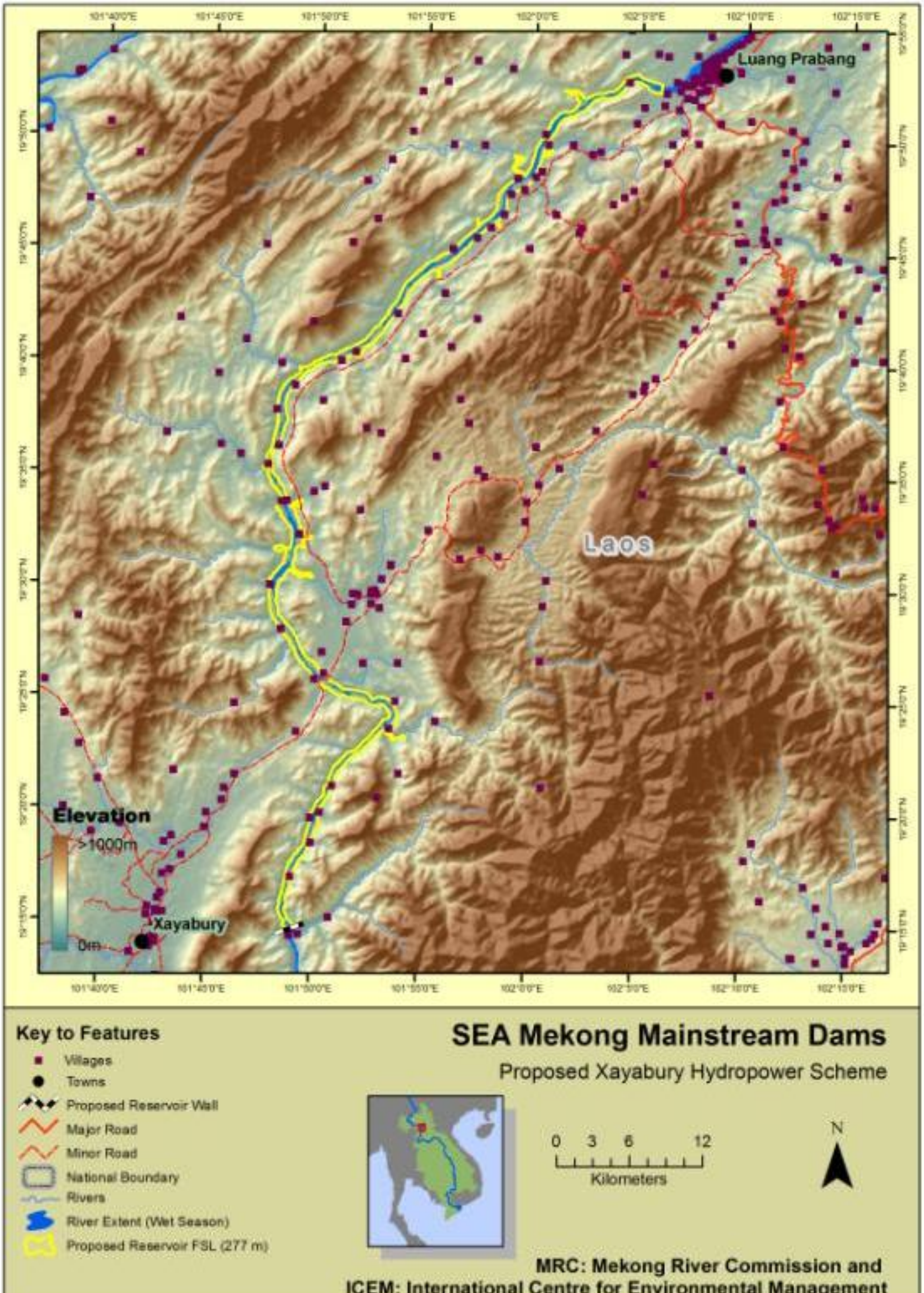
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Laos
Xayabury
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Towns
Proposed Reservoir Wall
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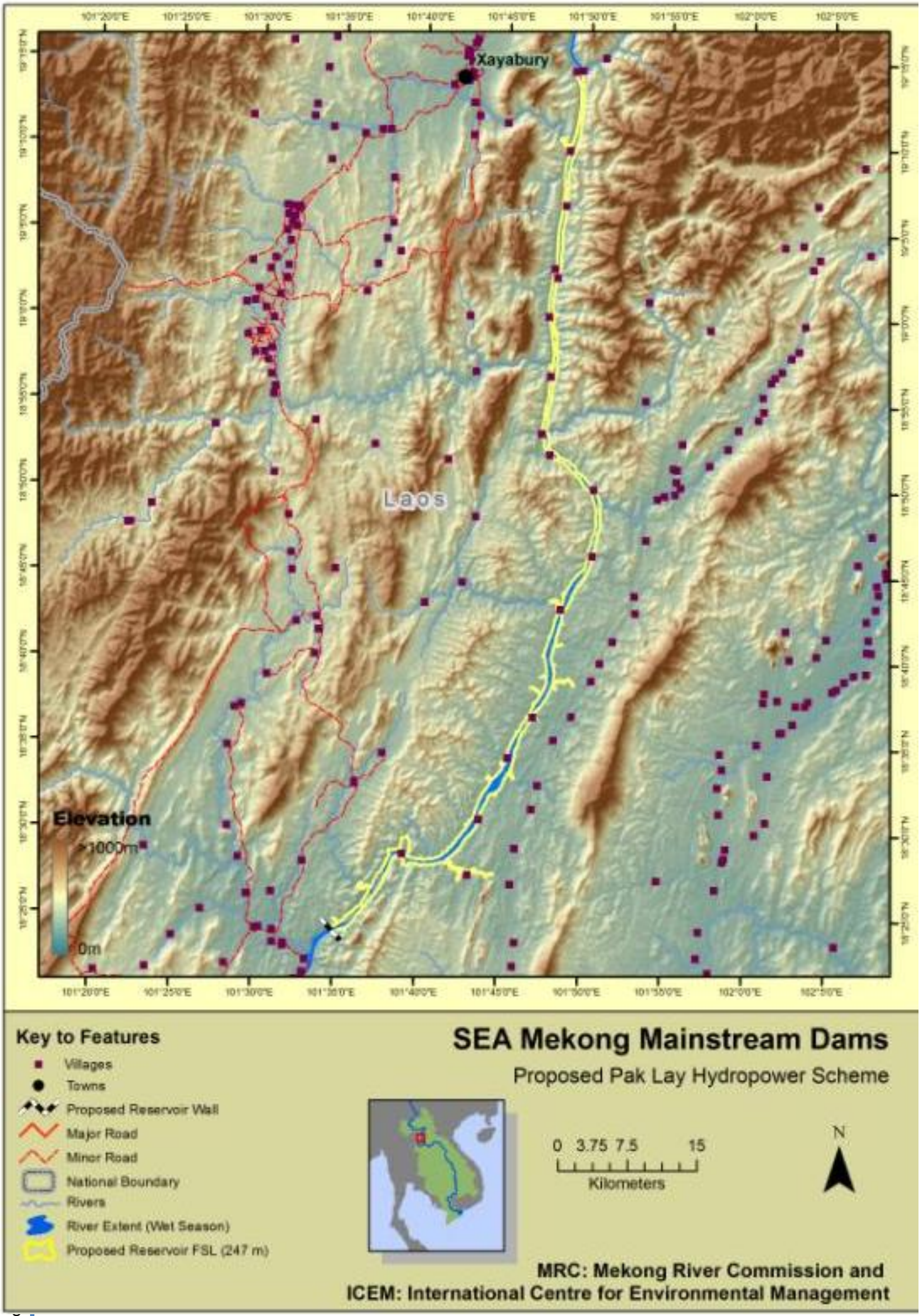
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Laos
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Villages
Towns
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Major Road
Minor Road
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Proposed Reservoir FSL (247 m)
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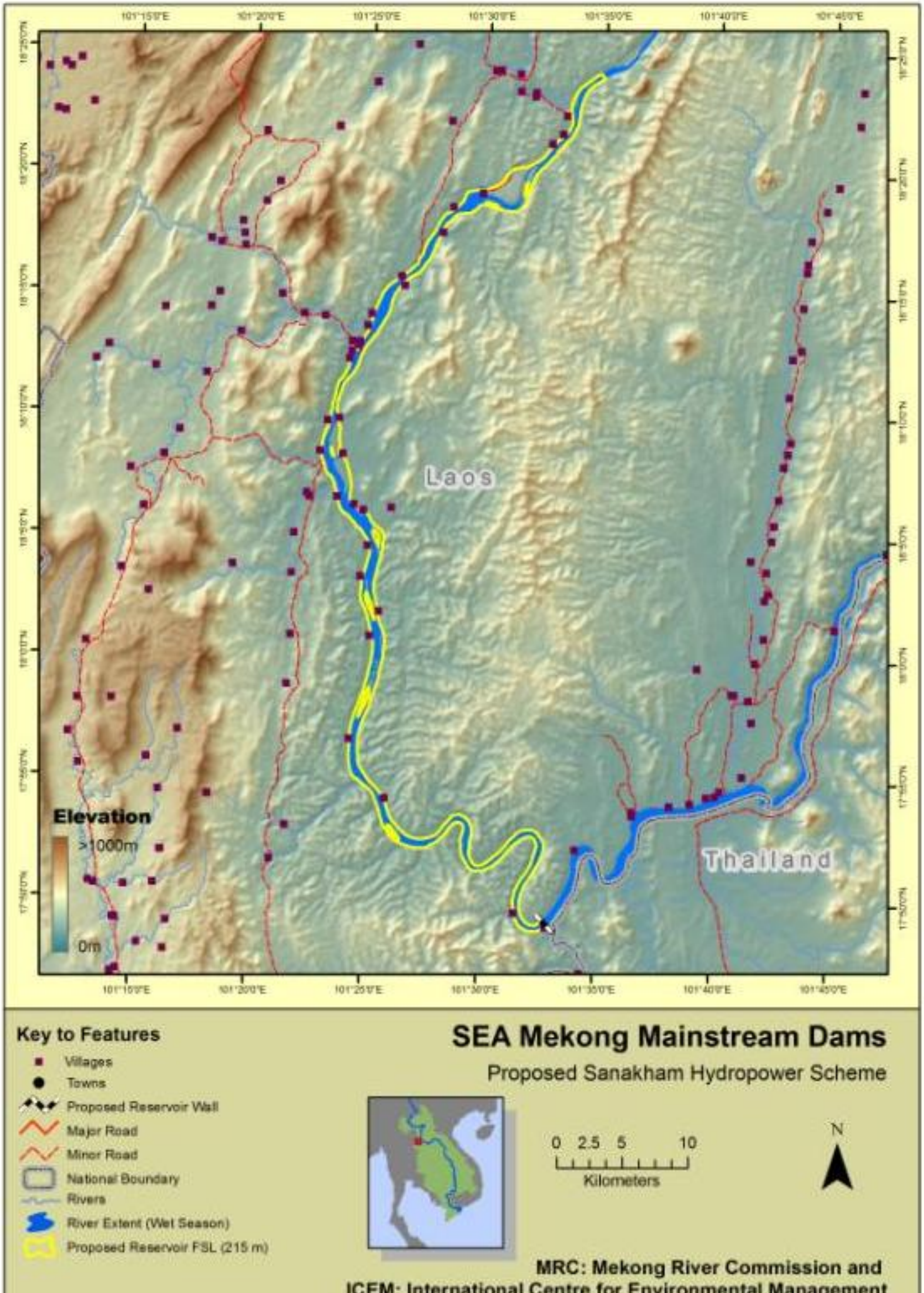
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management


Laos
Thailand
Elevation
>1000m
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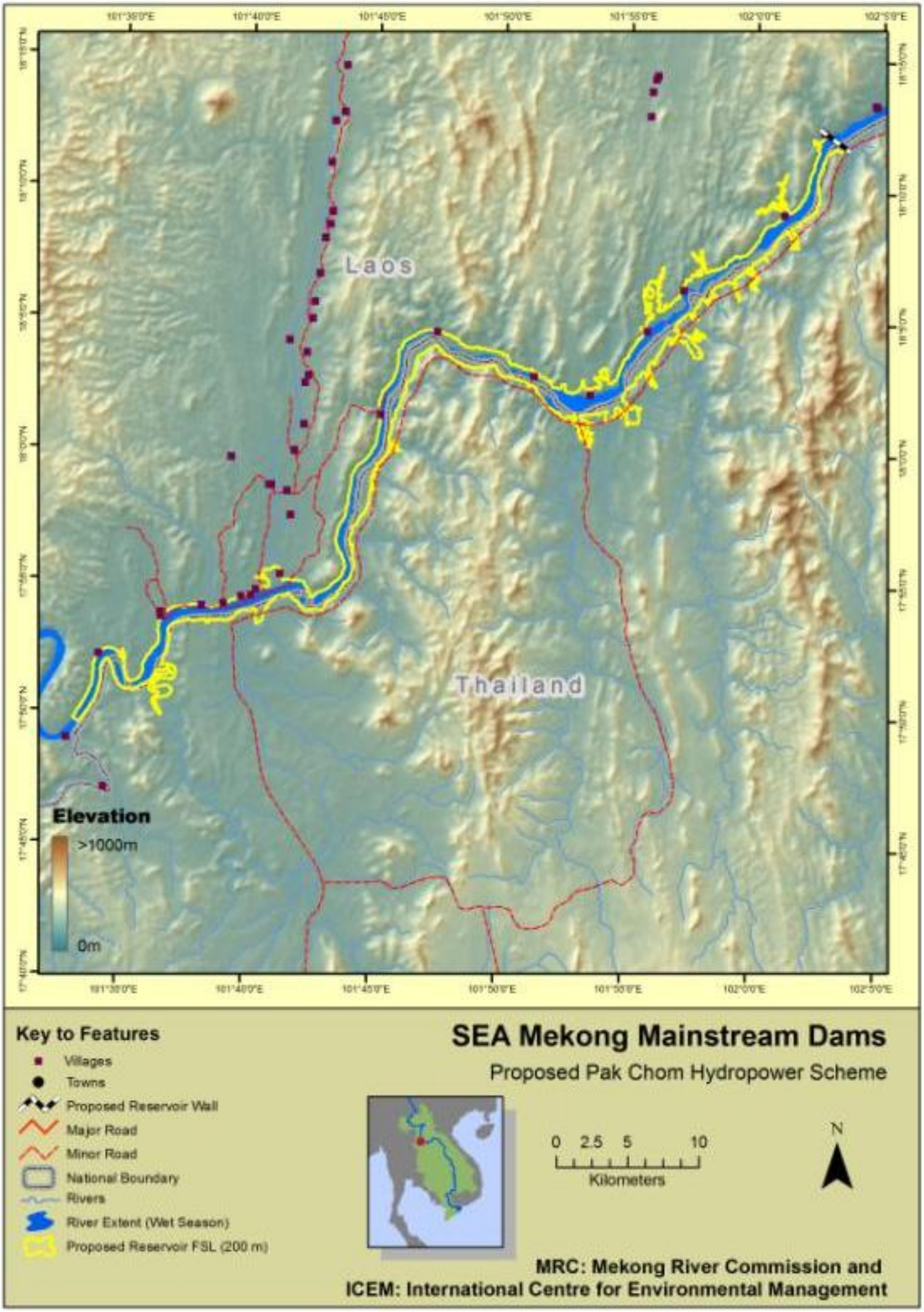
Key to Features
Villages
Towns
Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
Rivers
River Extent (Wet Season)
Proposed Reservoir FSL (215 m)
SEA Mekong Mainstream Dams
Proposed Sanakham Hydropower Scheme
0 2.5 5 10
Kilometers
N
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Towns
Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
Rivers
River Extent (Wet Season)
Proposed Reservoir FSL (200 m)
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Proposed Pak Chom Hydropower Scheme
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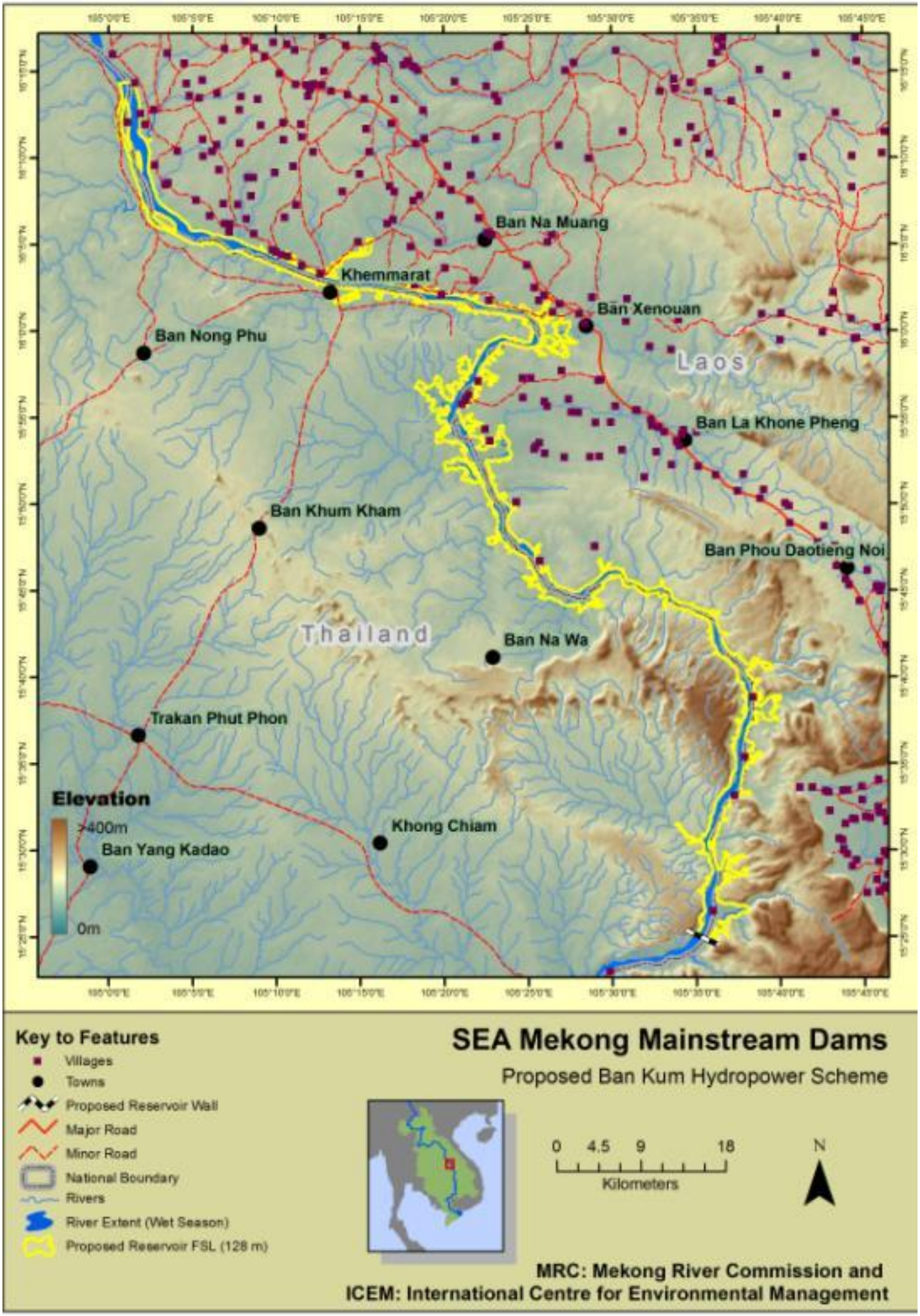
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Khemmarat
Ban Xenouan
Ban Nong Phu
Laos
Ban La Khone Pheng
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Ban Phou Daotieng Noi
Thailand
Ban Na Wa
Trakan Phut Phon
Elevation
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Khong Chiam
Ban Yang Kadao
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Towns
Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
Rivers
River Extent (Wet Season)
Proposed Reservoir FSL (128 m)
SEA Mekong Mainstream Dams
Proposed Ban Kum Hydropower Scheme
0 4.5 9 18
Kilometers
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MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management


Pakse
Laos
Elevation
>400m
0m
Key to Features
Villages
Towns
Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
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River Extent (Wet Season)
Proposed Reservoir FSL (90 m)
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Proposed Latsua Hydropower Scheme
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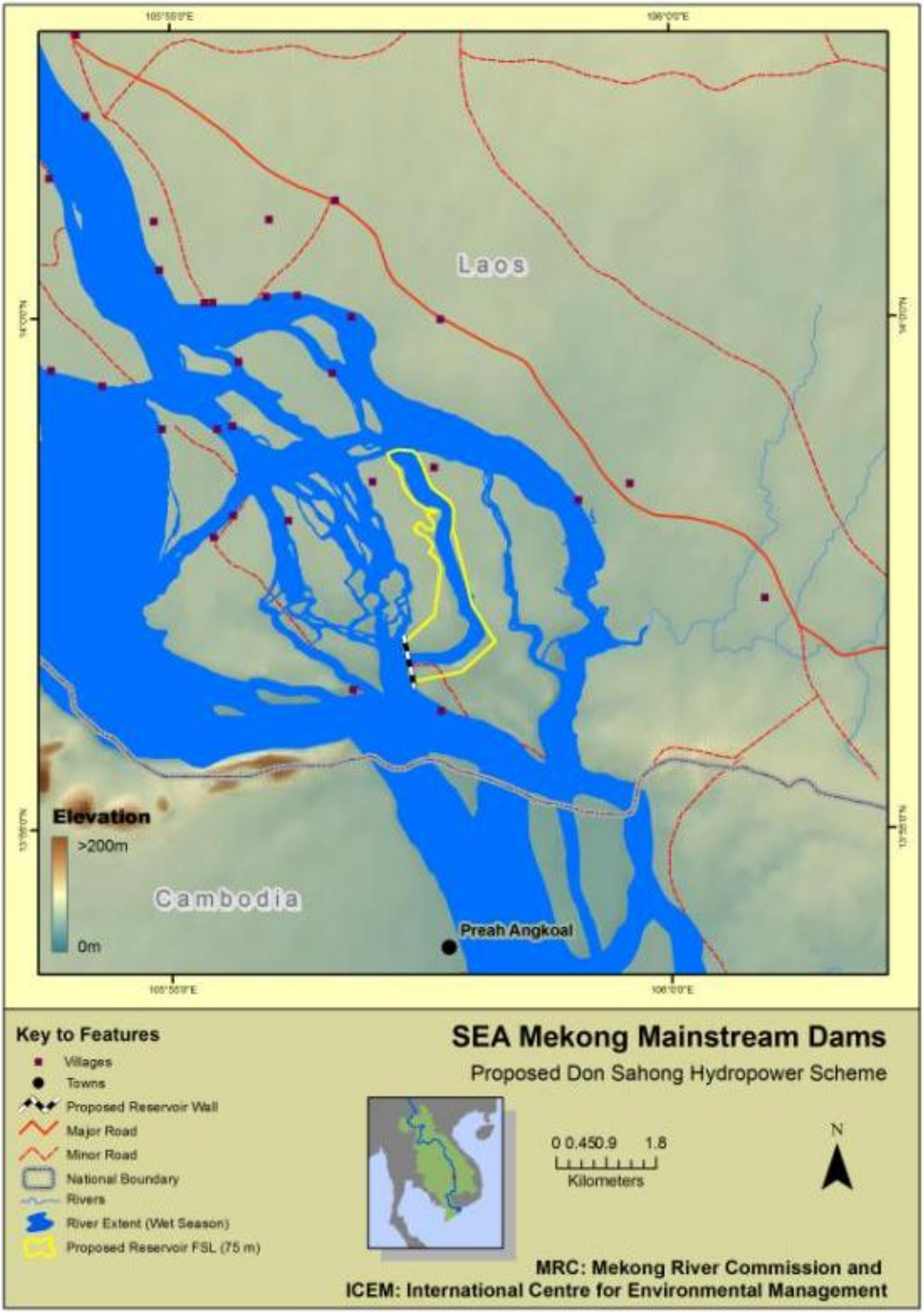
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Cambodia
Preah Angkoal
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Proposed Reservoir Wall
Major Road
Minor Road
National Boundary
Rivers
River Extent (Wet Season)
Proposed Reservoir FSL (75 m)
SEA Mekong Mainstream Dams
Proposed Don Sahong Hydropower Scheme
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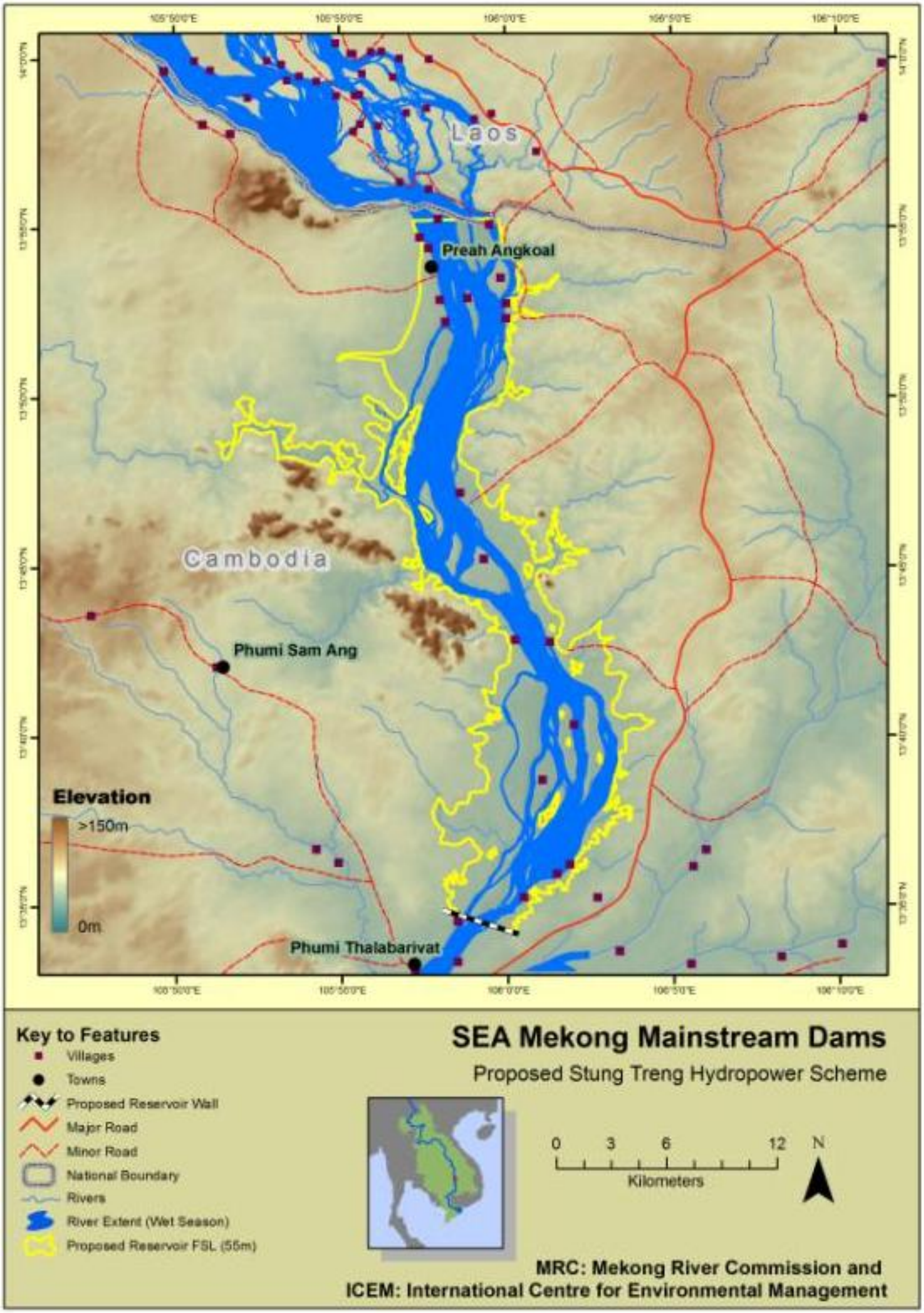
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Cambodia
Phumi Sam Ang
Phumi Thalabarivat
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Key to Features
Villages
Towns
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Major Road
Minor Road
National Boundary
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River Extent (Wet Season)
Proposed Reservoir FSL (55m)
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Proposed Stung Treng Hydropower Scheme
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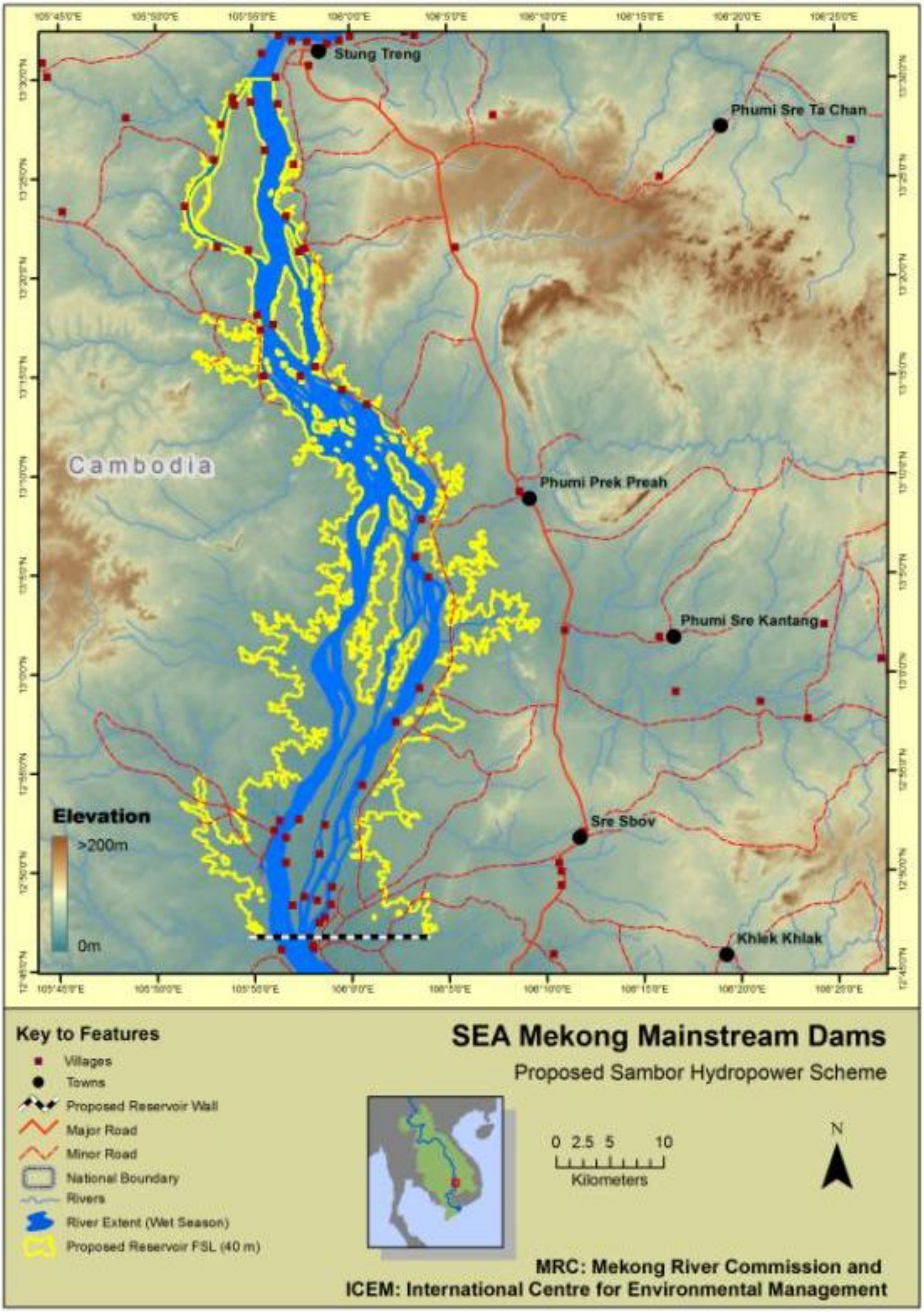
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management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Khlek Khlak
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Villages
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Major Road
Minor Road
National Boundary
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River Extent (Wet Season)
Proposed Reservoir FSL (40 m)
SEA Mekong Mainstream Dams
Proposed Sambor Hydropower Scheme
0 2.5 5 10
Kilometers
N
MRC: Mekong River Commission and
ICEM: International Centre for Environmental Management

ANNEX II: BDP SCENARIOS & CORRESPONDING CHARACTERISTICS

						2000		2015		2030							
Project name	**Basin**	**River**	**Cluster zone**	**Year**	**Watershed area**	**S1. Baseline**	**Area S1**	**S2. Definite future**	**Area S2**	**S3. No MS dams**	**Area S3**	**S4. 6 MS dams in upper LMB MS**	**Area S4**	**S5. No Cam MS dams**	**Area S5**	**S6. All 11 MS dams**	**Area S6**
Dochashan	Mainstream	Mainstream	China	2003				1	-	1	-	1	-	1	-	1	-
Ganlanba	Mainstream	Mainstream	China														
Gongouqiao	Mainstream	Mainstream	China					1	-	1	-	1	-	1	-	1	-
Jinghong	Mainstream	Mainstream	China	2008				1	-	1	-	1	-	1	-	1	-
Manwan	Mainstream	Mainstream	China	1996		1	-	1	-	1	-	1	-	1	-	1	-
Mengsong	Mainstream	Mainstream	China														
Nuozhadu	Mainstream	Mainstream	China	2014				1	-	1	-	1	-	1	-	1	-
Xiaowan	Mainstream	Mainstream	China	2013				1	-	1	-	1	-	1	-	1	-
Nam Beng	Nam Beng	Nam Beng	Ups.	2014	1,908					1	1,908	1		1		1	
Nam Dong	Nam Dong	Nam Dong	Ups.	1970	4	1	4	1	4	1	4	1	-	1	-	1	-
Nam Ko	Nam Ko	Nam Ko	Ups.	1996	223	1	223	1	223	1	223	1	-	1	-	1	-
Nam Long	Nam Ma	Nam Ma	Ups.	2013	156					1	156	1	-	1	-	1	-
Nam Ngay	Nam Ngay	Nam Ngay	Ups.	2002	315			1	315	1	315	1	-	1	-	1	-
Nam Ou 1	Nam Ou	Nam Ou	Ups.	2013	25,979					1	25,979	1	-	1	-	1	-
Nam Ou 2	Nam Ou	Nam Ou	Ups.	2014	22,568					1	-	1	-	1	-	1	-
Nam Ou 3	Nam Ou	Nam Ou	Ups.	2013	19,774					1	-	1	-	1	-	1	-
Nam Ou 4	Nam Ou	Nam Ou	Ups.	2014	11,799					1	-	1	-	1	-	1	-
Nam Ou 5	Nam Ou	Nam Ou	Ups.	2013	10,371					1	-	1	-	1	-	1	-
Nam Ou 6	Nam Ou	Nam Ou	Ups.	2014	5,527					1	-	1	-	1	-	1	-

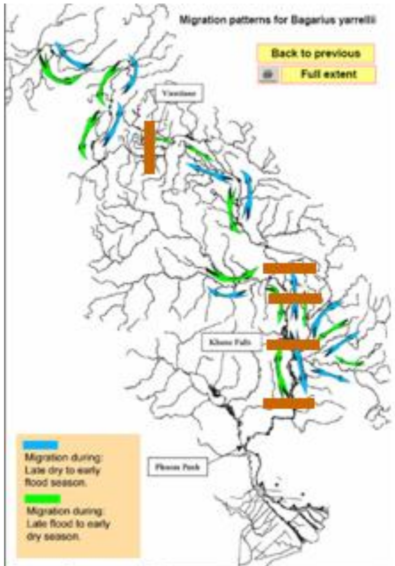
						2000		2015		2030							
Project name	**Basin**	**River**	**Cluster zone**	**Year**	**Watershed area**	**S1. Baseline**	**Area S1**	**S2. Definite future**	**Area S2**	**S3. No MS dams**	**Area S3**	**S4. 6 MS dams in upper LMB MS**	**Area S4**	**S5. No Cam MS dams**	**Area S5**	**S6. All 11 MS dams**	**Area S6**
Nam Ou 7	Nam Ou	Nam Ou	Ups.	2015	3,477					1	-	1	-	1	-	1	-
Nam Nga	Nam Ou	Nam Ou	Ups.	2017	2,477					1	-	1	-	1	-	1	-
Nam Pha	Nam Pha	Nam Pha	Ups.	2016	2,837					1	2,837	1	-	1	-	1	-
Nam suang 1	Nam Suang	Nam Suang	Ups.	2016	5,755					1	5,755	1	-	1	-	1	-
Nam Suang 2	Nam Suang	Nam Suang	Ups.	2016	5,195					1	-	1	-	1	-	1	-
Nam Tha 1	Nam Tha	Nam Tha	Ups.	2013	8,990					1	8,990	1	-	1	-	1	-
Pakbeng	Mainstream	Mainstream	Ups.	2016	218,000							1	-	1	-	1	-
Luangprabang	Mainstream	Mainstream	Ups.	2016	230,000							1	-	1	-	1	-
Xayabuly	Mainstream	Mainstream	Ups.	2016	272,000							1	-	1	-	1	-
Paklay	Mainstream	Mainstream	Ups.	2016	283,000							1	-	1	-	1	-
Sanakham	Mainstream	Mainstream	Ups.	2016	292,000							1	-	1	-	1	-
Pakchom	Mainstream	Mainstream	Ups.	2017	295,500							1	295,500	1	-	1	-
Sirindhorn	Lam Dom Noi	Lam Dom Noi	Middle	1971	2,097	1	2,097	1	2,097	1	2,097	1	2,097	1	-	1	-
Lam Ta Khong P.S.	Lam Ta kong	Lam Ta kong	Middle	2001	1,430			1	1,430	1	1,430	1	1,430	1	-	1	-
Pak Mun	Mun	Mun	Middle	1994	117,000	1	117,000	1	117,000	1	117,000	1	117,000	1	-	1	-
Nam Kong 1	Nam kong	Nam kong	Middle	2014	1,250					1	1,250	1	1,250	1	-	1	-
Nam Lik 1	Nam Lik	Nam Lik	Middle	2014	5,050					1	5,050	1	5,050	1	-	1	-
Nam Lik 2	Nam Lik	Nam Lik	Middle	2010	1,993			1	1,993	1	-	1	-	1	-	1	-
Nam Ngiep-regulating dam	Nam Ngiep	Nam Ngiep	Middle	2015	3,750					1	3,750	1	3,750	1	-	1	-
NamNgiep 1	Nam Ngiep	Nam Ngiep	Middle	2015	3,700					1	-	1	-	1	-	1	-
Nam Ngum 1	Nam Ngum	Nam Ngum	Middle	1971	8,460	1	8,460	1	8,460	1	8,460	1	8,460	1	-	1	-
Nam Ngum 2	Nam Ngum	Nam Ngum	Middle	2010	5,640			1	-	1	-	1		1	-	1	-
Nam Ngum 3	Nam Ngum	Nam Ngum	Middle	201	3,888					1	-	1	-	1	-	1	-

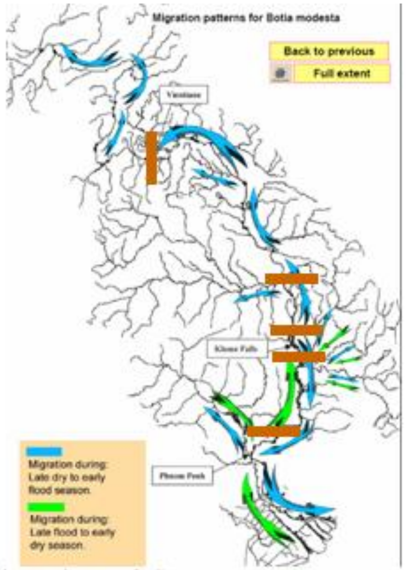
						2000		2015		2030							
Project name	**Basin**	**River**	**Cluster zone**	**Year**	**Watershed area**	**S1. Baseline**	**Area S1**	**S2. Definite future**	**Area S2**	**S3. No MS dams**	**Area S3**	**S4. 6 MS dams in upper LMB MS**	**Area S4**	**S5. No Cam MS dams**	**Area S5**	**S6. All 11 MS dams**	**Area S6**
				4													
Nam Ngum 5	Nam Ngum	Nam Ngum	Middle	2011	483			1	-	1	-	1	-	1	-	1	-
Nam Leuk	Nam Ngum	Nam Leuk	Middle	2000	274	1	-	1	-	1	-	1	-	1	-	1	-
Nam Mang 3	Nam Ngum	Nam Mang	Middle	2004	82			1	-	1	-	1	-	1	-	1	-
Chulabhorn	Nam Phrom	Nam Phrom	Middle	1972	545	1	545	1	545	1	545	1	545	1	-	1	-
Huai Kum	Nam Phrom	Nam Phrom	Middle	1982	282	1	-	1	-	1	-	1	-	1	-	1	-
Ubol Ratana	Nam Pong	Nam Pong	Middle	1966	12,104	1	12,104	1	12,104	1	12,104	1	12,104	1	-	1	-
Nam Pung	Nam Pung	Nam Pung	Middle	1965	296	1	296	1	296	1	296	1	296	1	-	1	-
Nam San 3	Nam San	Nam San	Middle	2014	155					1	155	1	155	1	-	1	-
Nam Theun1	Nam Theun	Nam Theun	Middle	2014	14,070					1	14,070	1	14,070	1	-	1	-
Theun-Hinboun expansion	Nam Theun	Nam Theun	Middle	2012	8,937			1	8,937	1	-	1	-	1	-	1	-
Theun-Hinboun	Nam Theun	Nam Theun, Hinboun	Middle	1998	8,927	1	8,927	1	-	1	-	1	-	1	-	1	-
Theun-Hinboun exp. (NG8)	Nam Theun	Nam Theun	Middle	2012	2,942			1	-	1	-	1	-	1	-	1	-
Xekaman-Sanxay (Xekaman2)	Xe Kaman	Xe Kaman	Middle	2011	3,740			1	3,740	1	3,740	1	3,740	1	-	1	-
Xekaman 1	Xe Kaman	Xe Kaman	Middle	2011	3,580			1	-	1	-	1	-	1	-	1	-
Nam Theun 2	Xebangfai	Nam Theun, Xe Bangfai	Middle	2009	4,013			1	4,013	1	4,013	1	4,013	1	-	1	-
Xelabam	Xedon	Xedon	Middle	1969	6,360	1	6,360	1	6,360	1	6,360	1	6,360	1	-	1	-
Houayho	Xekong	Houayho	Middle	1999	192	1	192	1	-	1	-	1	-	1	-	1	-
Xe Katam	Xenamnoy	Xenamnoy	Middle	2013	263					1	263	1	263	1	-	1	-
Xepian-Xenamnoy	Xepian/Xenamnoy	Xepian/Xenamnoy	Middle	2013	820					1	820	1	820	1	-	1	-
Ban Kum	Mainstream	Mainstream	Middle	2017	418,400									1	-	1	-
Latsua	Mainstream	Mainstream	Middle	2018	550,000									1	-	1	-
Don sahong	Mainstream	Mainstream	Middle	201	553,000									1	553,00	1	-

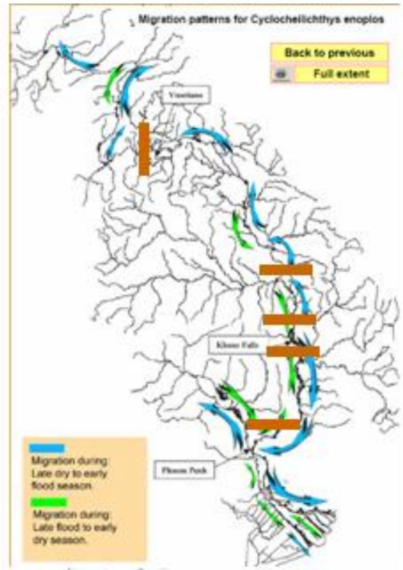
Project name	Basin	River	Cluster zone	Year	Watershed area	2000		2015		2030							
						S1. Baseline	Area S1	S2. Definite future	Area S2	S3. No MS dams	Area S3	S4. 6 MS dams in upper LMB MS	Area S4	S5. No Cam MS dams	Area S5	S6. All 11 MS dams	Area S6
				3											0		
O Chum 2	O Chum	O Chum	Downs.	1992	45			1	45	1	45	1	45	1	45	1	-
Lower Se San2 / Sre Pok 2	Se San	Se San	Downs.	2016	49,200					1	49,200	1	49,200	1	49,200	1	-
Se San 4A	Se San	Se San	Downs.	2008	9,368			1	9,368	1	-	1	-	1	-	1	-
Se San 4	Se San	Se San	Downs.	2009	9,326			1	-	1	-	1	-	1	-	1	-
Se San 3A	Se San	Se San	Downs.	2007	8,084			1	-	1	-	1	-	1	-	1	-
Se San 3	Se San	Se San	Downs.	2006	7,788			1	-	1	-	1	-	1	-	1	-
Yali	Se San	Se San	Downs.	2001	7,455	1	7,455	1	-	1	-	1	-	1	-	1	-
Plei Krong	Se San	Kroong Po Ko	Downs.	2008	3,216			1	-	1	-	1	-	1	-	1	-
Upper Kontum	Se San	Dak Bla/Dak Nghe	Downs.	2011	350					1	-	1	-	1	-	1	-
Sre Pok 4	Sre Pok	Sre Pok	Downs.	2009	9,568			1	9,568	1	9,568	1	9,568	1	9,568	1	-
Sre Pok 4A	Sre Pok	Sre Pok	Downs.	2009	9,568			1	-	1	-	1	-	1	-	1	-
Sre Pok 3	Sre Pok	Sre Pok	Downs.	2009	9,410			1	-	1	-	1	-	1	-	1	-
Dray Hlinh 2	Sre Pok	Sre Pok	Downs.	2007	8,880			1	-	1	-	1	-	1	-	1	-
Dray Hlinh 1	Sre Pok	Sre Pok	Downs.	1990	8,880			1	-	1	-	1	-	1	-	1	-
Buon Kuop	Sre Pok	Sre Pok	Downs.	2009	7,980			1	-	1	-	1	-	1	-	1	-
Buon Tua Srah	Sre Pok	Krong Kno	Downs.	2009	2,930			1	-	1	-	1	-	1	-	1	-
Duc Xuyen	Sre Pok	Krong Kno	Downs.		1,100					1	-	1	-	1	-	1	-
Xeset 1	Xe Set	Xe Set	Downs.	1994	485	1	485	1	485	1	485	1	485	1	485	1	-
Xeset 2	Xe Set	Xe Set	Downs.	2009	392			1	-	1	-	1	-	1	-	1	-
Xe Kong 3d	Xekong	Xekong	Downs.	2012	9,700					1	9,700	1	9,700	1	9,700	1	-
Xe Kong 3up	Xekong	Xekong	Downs.	2012	5,882					1	-	1	-	1	-	1	-
Xekong 4	Xekong	Xekong	Downs.	2014	5,400					1	-	1	-	1	-	1	-

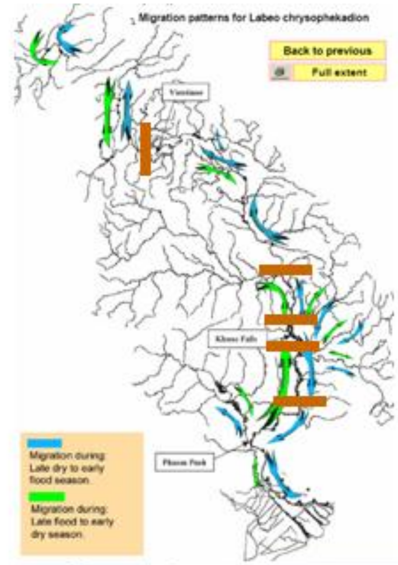
						2000		2015		2030							
Project name	**Basin**	**River**	**Cluster zone**	**Year**	**Watershed area**	**S1. Baseline**	**Area S1**	**S2. Definite future**	**Area S2**	**S3. No MS dams**	**Area S3**	**S4. 6 MS dams in upper LMB MS**	**Area S4**	**S5. No Cam MS dams**	**Area S5**	**S6. All 11 MS dams**	**Area S6**
Xe Kong 5	Xekong	Xekong	Downs.	2016	2,615					1	-	1	-	1	-	1	-
Xekaman 3	Xekong	Houayho	Downs.	2009	712			1	712	1	-	1	-	1	-	1	-
Stung Treng	Mainstream	Mekong	Downs.	NA	635,000											1	-
Sambor	Mainstream	Mekong	Downs.	2020	646,000											1	646,000
		Nb of dams / km2 obstructed for migrations				*16*	164148	*47*	187695	*77*	296568	*83*	545901	*86*	621998	*88*	646000
LMB area (km2)		% of LMB obstructed for migrations				20.6		23.6		37.3		68.7		78.2		81.3	
795,000		Km2 obstructed specifically by LMB mainstream dams				0		0		0		S4 - S3 =	249333	S5 - S3 =	325430	S6 - S3 =	349432
		% of LMB obstructed specifically by mainstream dams				0		0		0		31		41		44	

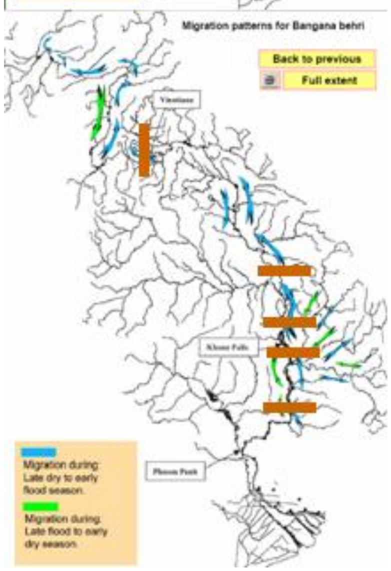
ANNEX III: MIGRATION PATTERNS OF 23 MIGRANT FISH SPECIES

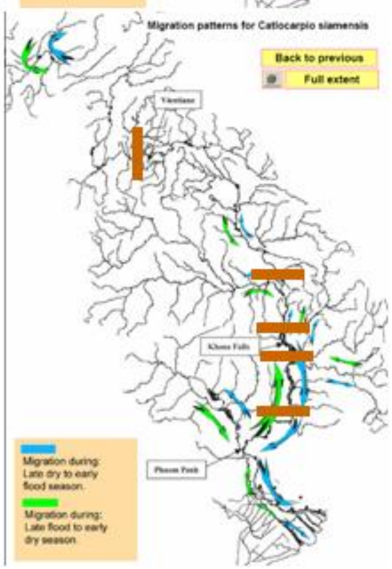


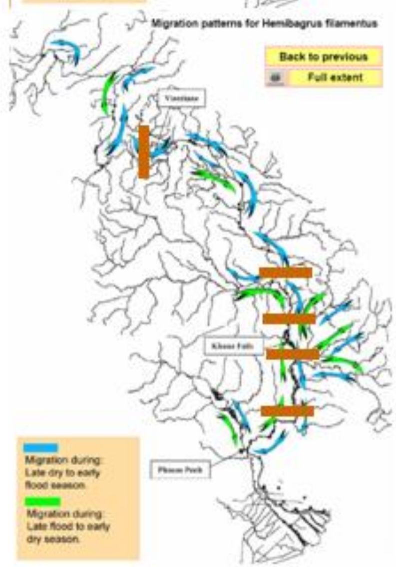


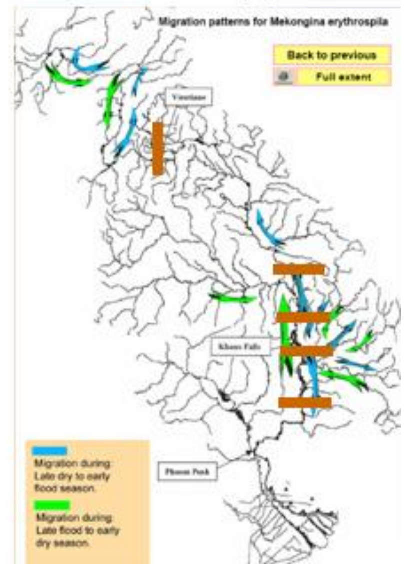


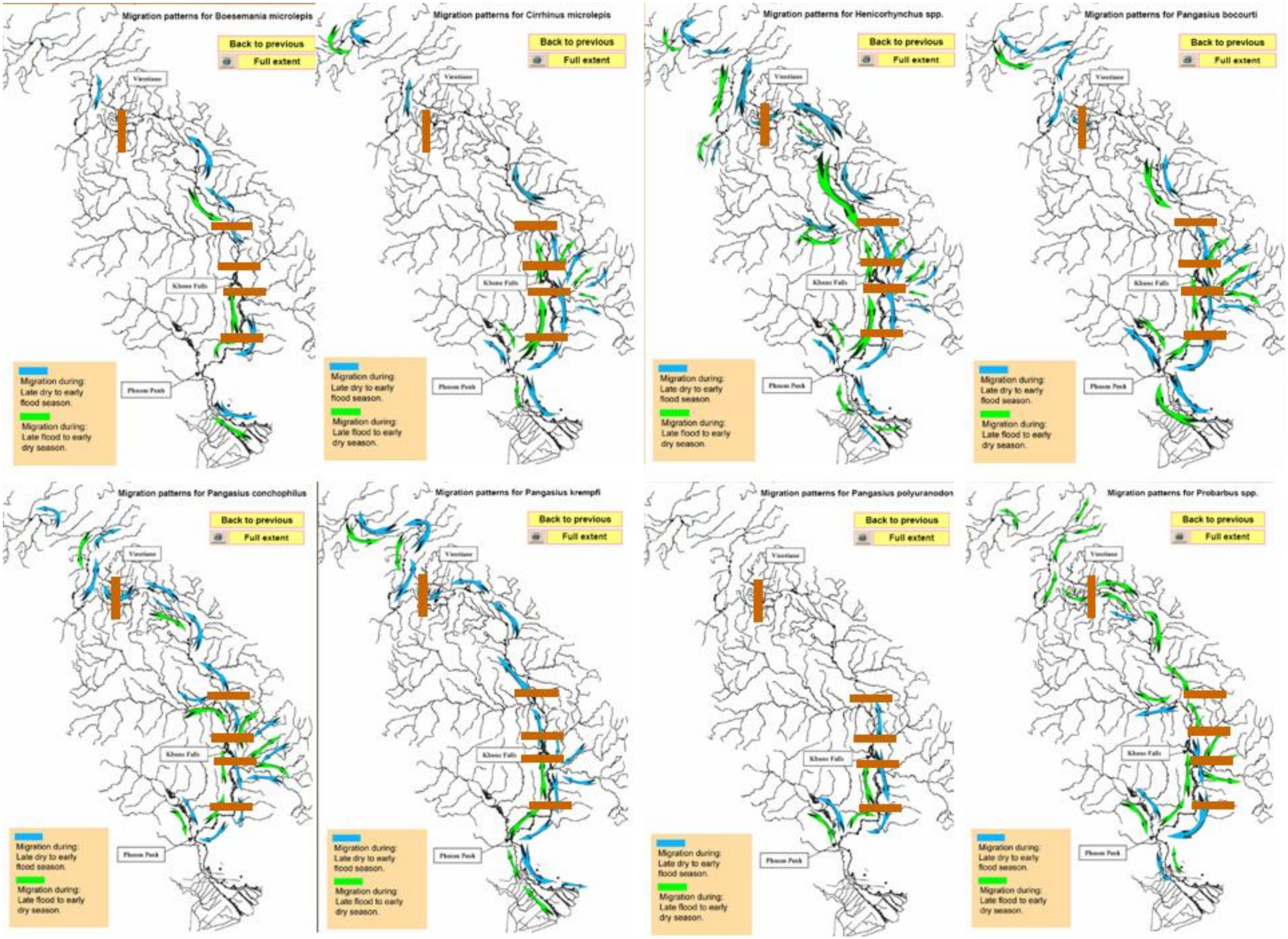




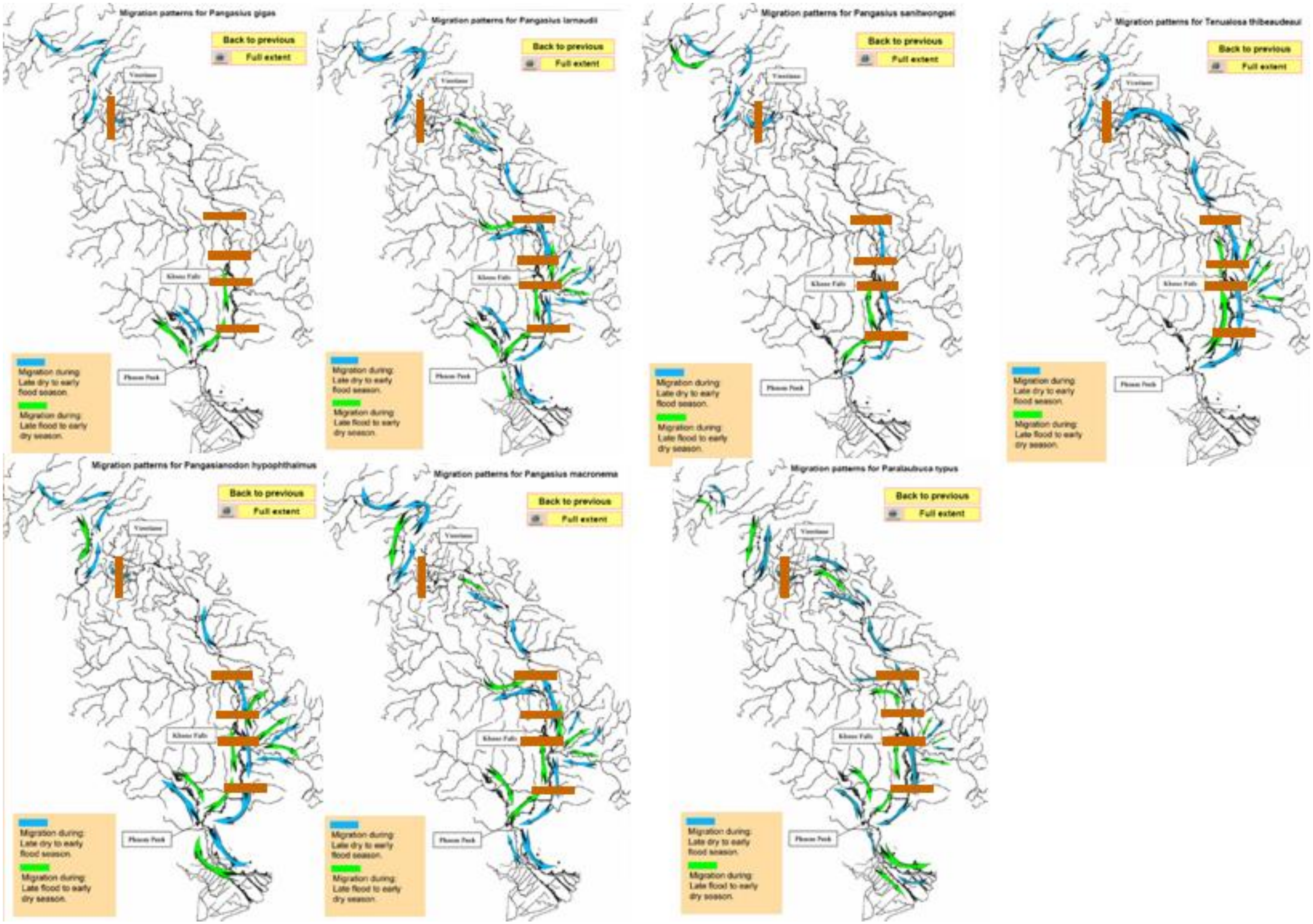








Migration patterns for Boesemania microlepis
Migration patterns for Cirrhinus microlepis
Migration patterns for Henicorhynchus spp.
Migration patterns for Pangasius bocourti
Migration patterns for Pangasius conchophilus
Migration patterns for Pangasius krempfi
Migration patterns for Pangasius polyuranodon
Migration patterns for Probarbus spp.
Back to previous
Full extent
Migration during: Late dry to early flood season.
Migration during: Late flood to early dry season.


Migration patterns for Pangasius gigas
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Pangasius larnaudii
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Pangasius sanitwongsei
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Tenualosa thibeaudeaui
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Pangasianodon hypophthalmus
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Pangasius macronema
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.
Migration patterns for Paralaubuca typus
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during Late flood to early dry season.

ANNEX IV: DOMINANT SPECIES IN MEKONG CATCH AND THEIR MIGRATORY PATTERNS

Species	Migrates up to Sambor	Migrates through KF	Migrates up to Vientiane	Migrates upstream of Vientiane	Migrates to 3S	Migrates to Mun	% of total catch
Cynoglossus microlepis	Yes	?	?	?	?	?	1.32
Lycothrissa crocodilus	Yes	?	?	?	?	?	0.03
Amblyrhynchichthys truncatus	Yes	Yes	?	?	?	?	0.17
Bagarius suchus	Yes	Yes	?	?	?	?	0.3
Botia helodes	Yes	Yes	?	?	?	?	0.7
Brachirus harmandi	Yes	Yes	?	?	?	?	0.06
Cirrhinus prosemion	Yes	Yes	?	?	?	?	0.03
Cosmocheilus harmandi	Yes	Yes	?	?	?	?	2.87
Kryptopterus bicirrhis	Yes	Yes	?	?	?	?	0.01
Labiobarbus siamensis	Yes	Yes	?	?	?	?	0.35
Osteochilus waandersi	Yes	Yes	?	?	?	?	0.01
Cyclocheilichthys furcatus	Yes	Yes	?	?	?	Yes	0.25
Hypsibarbus lagleri	Yes	Yes	?	?	Yes	?	0.38
Hypsibarbus wetmorei	Yes	Yes	?	?	Yes	?	0.27
Pangasius polyuranodon	Yes	Yes	No	No	No	No	0.6
Catlocarpio siamensis	Yes	Yes	Yes	No	Yes	Yes	-
Pangasius pleurotaenia	Yes	Yes	Yes	Yes	?	?	0.1
Pangasianodon gigas	Yes	Yes	Yes	Yes	?	Yes	0.01
Boesemania microlepis	Yes	Yes	Yes	Yes	No	No	-
Cyclocheilichthys enoplos	Yes	Yes	Yes	Yes	No	No	1.11
Pangasius sanitwongsei	Yes	Yes	Yes	Yes	No	No	-
Anguilla marmorata	Yes	Yes	Yes	Yes	Yes	?	0
Cirrhinus molitorella	Yes	Yes	Yes	Yes	Yes	?	0
Luciosoma bleekeri	Yes	Yes	Yes	Yes	Yes	?	1.05
Probarbus jullieni	Yes	Yes	Yes	Yes	Yes	?	0.27
Probarbus labeamajor	Yes	Yes	Yes	Yes	Yes	?	0.1
Bangana behri	Yes	Yes	Yes	Yes	Yes	No	0.24
Pangasianodon hypophthalmus	Yes	Yes	Yes	Yes	Yes	No	0.37
Pangasius bocourti	Yes	Yes	Yes	Yes	Yes	No	0.33
Pangasius krempfi	Yes	Yes	Yes	Yes	Yes	No	0.49
Tenualosa thibeaudeaui	Yes	Yes	Yes	Yes	Yes	No	0.03
Yasuhikotakia modesta	Yes	Yes	Yes	Yes	Yes	Yes	0.37
Cirrhinus microlepis	Yes	Yes	Yes	Yes	Yes	Yes	0.41
Hemibagrus filamentus	Yes	Yes	Yes	Yes	Yes	Yes	-
Bagarius yarrelli	Yes	Yes	Yes	Yes	Yes	Yes	-
Henicorhynchus lobatus	Yes	Yes	Yes	Yes	Yes	Yes	4.07
Henicorhynchus siamensis	Yes	Yes	Yes	Yes	Yes	Yes	8.09
Labeo chrysophekadion	Yes	Yes	Yes	Yes	Yes	Yes	-
Mekongina erythrospila	Yes	Yes	Yes	Yes	Yes	Yes	0.33
Pangasius conchophilus	Yes	Yes	Yes	Yes	Yes	Yes	2.07
Pangasius larnaudii	Yes	Yes	Yes	Yes	Yes	Yes	0.57
Pangasius macronema	Yes	Yes	Yes	Yes	Yes	Yes	0.8
Paralaubuca typus	Yes	Yes	Yes	Yes	Yes	Yes	1.65
					26	*Total =*	*29.81*

ANNEX V: ECOLOGICAL INFORMATION ON TWO SPECIES DOMINANT IN MEKONG CATCH

This information is extracted from the recent report:
Baran E., So N. Information on migrant fish species dominant in Mekong fisheries. WorldFish Center and IFReDI, Phnom Penh, Cambodia. 62 pp.
prepared in February 2010 for the project "*Scenario-based assessment of the potential effects of alternative dam construction schemes on freshwater fish diversity in the Lower Mekong Basin" funded by the* Mitsui &. Co., Ltd. Environment Fund.

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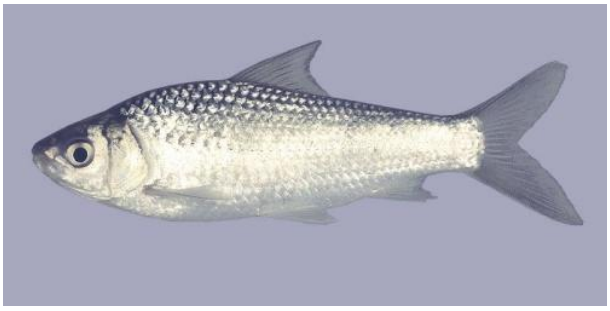
Henicorhynchus siamensis (Chavalit Vidthayanon)



Henicorhynchus siamensis (Rainboth, W)

Species	% of total catch	Cumulative % of total catch	Cumulative % among guilds at risk
Henicorhynchus siamensis	8.09	8.1	21

IDENTIFICATION:
- Family: Cyprinidae
- Species name: ***Henicorhynchus siamensis***
- Remark: Formerly *Cirrihinus siamensis*

BIOLOGY:
- Max. standard length (cm): 20
- Length at maturity (cm): 12.9
- Status: Native

REPRODUCTION:

Spawning: Mature eggs are reported from April to July with a strong peak during May-June (Poulsen and Valbo-Jørgensen, 2000, Singanouvong et al. 1996). Spawns in the rainy season (Baird et al., 1999).
- Breeds in reservoirs: not known to prosper in impoundments (Rainboth, 1996).
- No information on breeding in reservoirs
- Spawns in rivers (%respondents): 100
- Nurses in floodplain (%respondents): 100

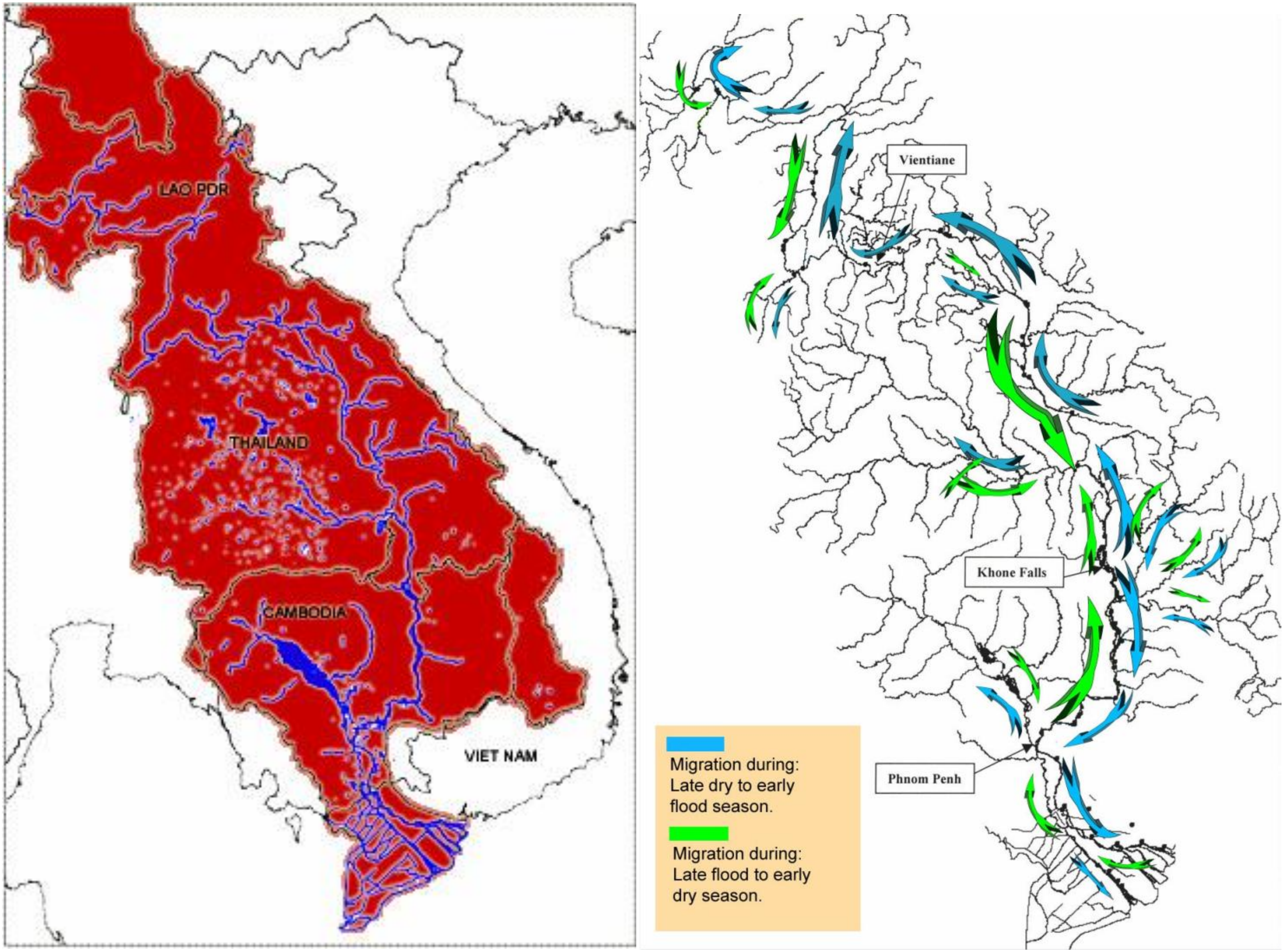
ECOLOGY:

- Habitat: Benthopelagic. Often found in great abundance at midwater to bottoms depths in large and small rivers. Distribution: occurs from the Mekong Delta all the way along the Mekong mainstream to Chiang Khong (Poulsen and Valbo-Jørgensen, 2000); also recorded from the Xe Bangfai Basin (Roberts, 1997).

Migration: From Xayaboury to Chiang Khong, the fish migrates upstream from March to July, first the juveniles, later followed by the adults. At Khone Falls medium sized fish migrate downstream, while large individuals migrate upstream during the wet season. These migrations are for reproductive purposes, and during the migration the fish feeds very little relying on fat deposits around the viscera (Singanouvong et al., 1996). From the Khone Falls the fish migrate downstream from May to July, towards the large floodplains located north and south of Phnom Penh and all the way to the Mekong Delta. Here, the fish migrate out of the Mekong into canals and flooded areas during August-September (Poulsen and Valbo-Jørgensen, 2000). When the water recedes it enters the Tonle Sap from the flooded areas along the river and the Great Lake (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000, Rainboth 1996), when in the Tonle Sap, they migrate down to the Mekong (Lieng et al. 1995) and from October to February continue their journey upstream the Mekong, at least until they reach the Khone Falls (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000).

- Discharge as migration trigger: Discharge variation is a migration trigger (So Nam, pers. comm., 2007)
- Water level as migration trigger: no information

GUILD: White (So Nam, pers. comm., 2007)



Records, distribution (in red) and migrations of ***Henicorhynchus siamensis***

Pangasius conchophilus (IFReDI collection)

Pangasius conchophilus (Rainboth, W.)

Species	% of total catch	Cumulative % of total catch	Cumulative % among guilds at risk
Pangasius conchophilus	2.07	17.1	44

IDENTIFICATION:

- Family: Pangasiidae
- Species name: ***Pangasius conchophilus***

BIOLOGY:

- Max. standard length (cm): 120
- Length at maturity (cm): 62.9
- Status: Native

REPRODUCTION:

Spawning: Based on eggs reports from March to August with a strong peak in May-July (Poulsen and Valbo-Jørgensen, 2000) and the presence of females in spawning condition in March, June and August (Baird and Phylavanh, 1999); and juveniles of 6 to 7cm by late June (Rainboth, 1996); it seems likely that the species spawn at various times of the year (Baird and Phylavanh, 1999) although it probably mainly reproduces early in the flood season (Rainboth, 1996, Poulsen and Valbo-Jørgensen, 2000) the spawning period may extend to October (Singanouvong et al., 1996). An important spawning ground appears to be in the Mekong mainstream somewhere between Kompong Cham and Khone Falls (Poulsen and Valbo-Jørgensen, 2000); and in rapids and riffles of the Mun river (Schouten et al. 2000).- Breeds in reservoirs: No information on breeding in reservoirs

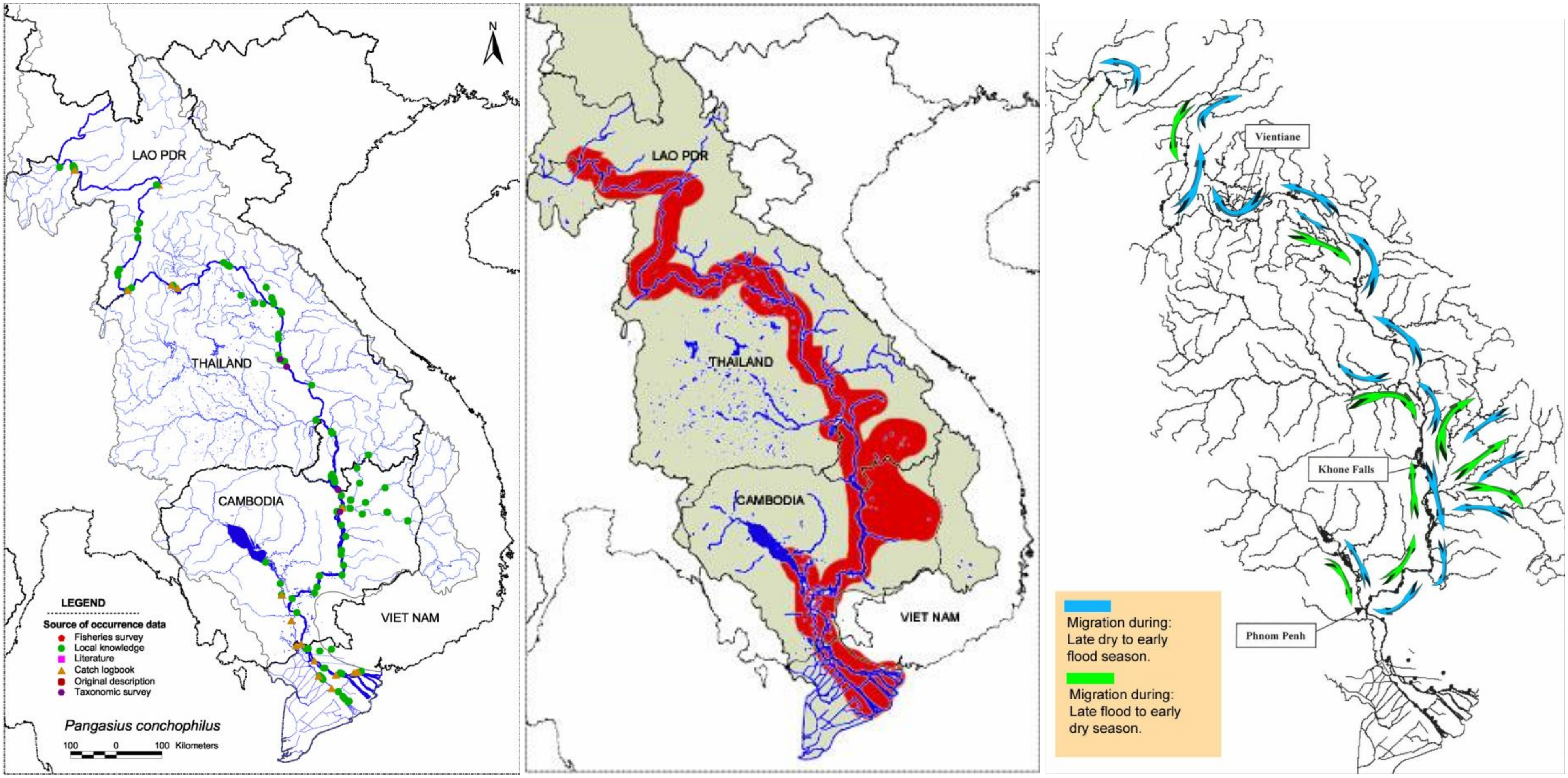
ECOLOGY:

Distribution: The distribution range is from the Mekong Delta all the way along the Mekong to Chiang Saen. In the Mekong Delta in Viet Nam, mainly juveniles less than 30cm are reported (Poulsen and Valbo-Jørgensen, 2000). There seem to be one population below Khone Falls and one (to several) above the Falls (Poulsen and Valbo-Jørgensen, 2000). Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al., 2002).

Migration: it is migratory and mainly moves at night. It is a very important species in the fishery and is caught with nets, traps, and hooks (MFD 2003). It migrates upstream from just upstream Khone Falls to Chiang Saen when the Mekong River rises quickly with the beginning of the monsoon season around May (Baird and Phylavanh, 1999, Singanouvong et al., 1996, Rainboth, 1996, Poulsen and Valbo-Jørgensen, 2000), it mainly moves in large schools at night (Baird and Phylavanh, 1999); and the migration continues until August; However this migration of 40 - 90cm sexually mature fish seem to be preceded by a migration of 10 to 40cm sub-adults in the period March to May (Poulsen and Valbo-Jørgensen, 2000). It migrates up the Mun river to spawn in the rainy season (Schouten et al. 2000). - - Discharge as migration trigger: no information

- Water level as migration trigger: Water level variation is a migration trigger

GUILD: A white fish species (Bardach, 1959)



Records, distribution (in red) and migrations of ***Pangasius conchophilus***

ANNEX VI: MAINSTREAM FISH SPECIES HIGHLY VULNERABLE TO DAM DEVELOPMENT

Table A: Vulnerable guilds of Mekong migratory fish at risk of mainstream dam development

Migratory guild	Potential range of habitat utilized	Typical characteristics*	Likely impact of mainstream dams on migrations.
Migratory main channel spawner guild	Floodplains to running river upstream	• Spawn in the mainstream, in tributaries and around floodplains • Adults and drifting larvae return to floodplains to feed. • May migrate to deep pools in the mainstream during the dry season. • Sensitive to damming	Very high
Migratory main channel refuge seeker guild	Floodplains to slow river downstream	• Spawn in floodplains • Migrations between floodplains and mainstream deep pools in the dry season. • Sensitive to damming	Very high
Semi-anadromous guild	Estuary and lower slow river downstream	• Enters fresh/brackish waters to breed. • Enters freshwaters as larvae and juveniles (bligate or opportunistic) • Impacted by river mouth dams that stop migration into the river.	High (for dams located in river mouths or lower potamon)
Catadromous guild	Marine to running river upstream	• Reproduction, early feeding and growth at sea. • Juvenile or sub-adult migration to freshwater habitats • Vulnerable to overexploitation and tend to disappear when river is dammed preventing longitudinal upstream migration. • May respond favorably to fish passage facilities.	Very high

Source: adapted from Halls and Kshatriya *in press*.

Table B: List of species belonging to vulnerable guilds and their contribution to catches

Family	Species	Guild	Total weight	Cumulative weight (kg)	Cumulative %	% of total catch	Cumulative %
Cyprinidae	Henicorhynchus siamensis	3	9838	9838	21	8.09	8.1
Cyprinidae	Henicorhynchus lobatus	3	4946	14784	32	4.07	12.2
Cyprinidae	Cosmochilus harmandi	3	3489	18273	39	2.87	15
Pangasiidae	Pangasius conchophilus	2	2516	20789	44	2.07	17.1
Cyprinidae	Paralaubuca typus	3	2013	22801	49	1.65	18.8
Gyrinocheilidae	Gyrinocheilus pennocki	2	1976	24778	53	1.63	20.4
Pangasiidae	Helicophagus waandersii	2	1925	26703	57	1.58	22
Palaeomonidae	Macrobrachium sp.	9	1854	28557	61	1.52	23.5
Cyprinidae	Hypsibarbus malcolmi	2	1798	30354	65	1.48	25
Cynoglossidae	Cynoglossus microlepis	2	1606	31960	68	1.32	26.3

Family	Species	Guild	Total weight	Cumulative weight (kg)	Cumulative %	% of total catch	Cumulative %
Cyprinidae	Cyclocheilichthys enoplos	3	1346	33306	71	1.11	27.4
Cyprinidae	Luciosoma bleekeri	3	1281	34587	74	1.05	28.4
Pangasiidae	Pangasius kunyit	2	1149	35736	76	0.94	29.4
Pangasiidae	Pangasius macronema	2	977	36713	78	0.8	30.2
Cobitidae	Botia helodes	3	849	37562	80	0.7	30.9
Cyprinidae	Puntioplites proctozysron	3	780	38342	82	0.64	31.5
Pangasiidae	Pangasius polyuranodon	2	725	39068	83	0.6	32.1
Pangasiidae	Pangasius larnaudii	2	697	39765	85	0.57	32.7
Pangasiidae	Pangasius krempfi	2	596	40361	86	0.49	33.2
Cyprinidae	Cirrhinus microlepis	3	503	40864	87	0.41	33.6
Cyprinidae	Hypsibarbus lagleri	2	460	41323	88	0.38	34
Pangasiidae	Pangasianodon hypophthalmus	2	451	41774	89	0.37	34.4
Cobitidae	Botia modesta	3	449	42223	90	0.37	34.7
Cyprinidae	Labiobarbus siamensis	3	421	42643	91	0.35	35.1
Cyprinidae	Mekongina erythrospila	2	401	43045	92	0.33	35.4
Pangasiidae	Pangasius bocourti	2	399	43443	93	0.33	35.7
Sisoridae	Bagarius suchus	2	369	43812	94	0.3	36
Cyprinidae	Probarbus jullieni	2	330	44143	94	0.27	36.3
Cyprinidae	Hypsibarbus wetmorei	2	329	44471	95	0.27	36.6
Cyprinidae	Cyclocheilichthys furcatus	2	309	44781	96	0.25	36.8
Schilbeidae	Clupisoma sinensis	2	298	45078	96	0.24	37.1
Cyprinidae	Bangana behri	2	286	45365	97	0.24	37.3
Cyprinidae	Amblyrhynchichthys truncatus	3	213	45577	97	0.17	37.5
Cyprinidae	Bangana sp.	2	194	45771	98	0.16	37.6
Pangasiidae	Pangasius micronemus	2	139	45911	98	0.11	37.8
Cyprinidae	Probarbus labeamajor	2	121	46032	98	0.1	37.9
Dasyatidae	Dasyatis laosensis	2	116	46149	99	0.1	37.9
Pangasiidae	Pangasius pleurotaenia	2	116	46265	99	0.1	38
Cobitidae	Botia sp. cf. lecontei	2	99	46364	99	0.08	38.1
Soleidae	Brachirus harmandi	2	68	46432	99	0.06	38.2
Pangasiidae	Pangasius pangasius	2	58	46491	99	0.05	38.2
Cyprinidae	Garra fasciacauda	2	56	46547	99	0.05	38.3
Pangasiidae	Pangasius siamensis	2	51	46598	100	0.04	38.3
Clupeidae	Tenualosa thibaudeaui	8	41	46639	100	0.03	38.4
Engraulidae	Lycothrissa crocodilus	8	35	46674	100	0.03	38.4
Cyprinidae	Cirrhinus prosemion	3	31	46705	100	0.03	38.4
Pangasiidae	Pangasius spp.	2	23	46728	100	0.02	38.4
Siluridae	Kryptopterus bicirrhis	2	15	46743	100	0.01	38.4
Pangasiidae	Pangasianodon gigas	2	13	46756	100	0.01	38.4
Cyprinidae	Osteochilus waandersii	2	10	46766	100	0.01	38.5
Megalopidae	Megalops cyprinoides	9	9	46775	100	0.01	38.5
Cyprinidae	Puntioplites bulu	2	8	46782	100	0.01	38.5
Cobitidae	Botia sp. Cf. beauforti	2	6	46789	100	0.01	38.5
Clupeidae	Tenualosa toli	8	4	46793	100	0	38.5
Anguillidae	Anguilla marmorata	9	2	46796	100	0	38.5
Cyprinidae	Cirrhinus molitorella	3	2	46798	100	0	38.5
Cyprinidae	Puntioplites waandersi	2	1	46799	100	0	38.5
Cyprinidae	Aaptosyax grypus	2	0	46800	100	0	38.5
	Total catch of 58 species (kg)			*46800*			
	Overall catch of 233 species (kg)			*121607*			

Source: Halls and Kshatriya *in press*, Annex 1.

ANNEX VII: CALCULATING THE LIKELIHOOD OF EXTREME EVENTS WITH CLIMATE CHANGE

BACKGROUND TO PROJECTS AND AVAILABLE INFORMATION

The LMB mainstream projects have spillway dimensions designed according to the following table. These projects have been designed to withstand a level of risk characterised by the return period for certain design extreme events. MRC is producing design guidelines for hydropower development in the LMB which suggests the use of the PMP (Probable Maximum Flood), but this has not yet influenced the project planning.

Table 1: Characteristics of the LMB mainstream project spillway and sediment flushing design
(Source SEA Inception Report Vol 2)

	Spillway					Sediment flushing gates			
Reservoir Name	no. of gates	Dimensions (m)	total Area (m2)	Design Q(m3/s)	equivalent return period	no. of gates	Dimensions	total Area (m2)	Design Q(m3/s)
Pak Beng	15	15x23	5,175	27,300	-	3	3x5	45	-
Luang Prabang	10	18x22	3,960	44,838	10,000	-	-	-	-
Xayaburi	12	18x22	4,752	47,500	10,000	2	3x3	18	140
Pak Lay	12	294x67	19,698	32,526	1,000	-	-	-	-
Sanakham	-	-	-	-	-	-	-	-	-
Pak Chom	14	20x25	7,000	33,526	100	-	-	-	-
Ban Koum	20	20x25.5	10,200	60,972	100	-	-	-	-
Latsua	24	20x25	12,000	89,590	10,000	-	-	-	-
Don Sahong	*no spillway*					-	-	-	-
Thakho	*no spillway*					-	-	-	-
Stung Treng	-	-	-	73,500	-	-	-	-	-
Sambor*	-	-	-	149,300	-	37	15x20	11,100	5,883

** Sambor project also quotes a "peak inflow" flow of 161,000m3/s. This is likely to be the probable maximum flood event*

The MRC has provided the annual maxima series for five gauging stations along the Mekong mainstream: Chiang Saen, Luan Prabang, Vientiane, Pakse and Kratie. The length of the time series is typically 50-100years and the relationship between the stations and the mainstream projects is presented in the table below:

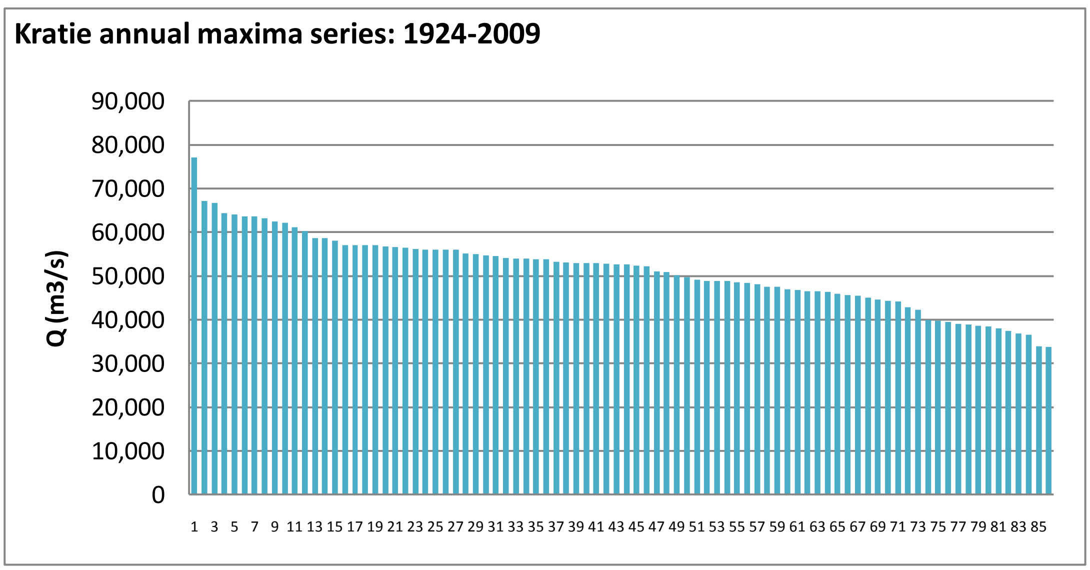
Figure 1 presents the ranked annual maxima series for Kratie as an example (graphs for the other stations are presented in the Annex). The series represents the largest flow event to occur at Kratie during each calendar year at a daily-time step. The average annual maximum value over the 86 year period is 51,264m3/s and the series hasd a standard deviation of 8,395m3/s.

Table 2: Summary of the available hydrological data and the relation to the mainstream projects

Station	Zone	Mainstream dam	Start of record	End of record	Length of record	Origin of data
Chiang Saen	1/2	Pak Beng	1960	2009	50	DB of origin ThaiLand1\Db\Hymos
Luang Prabang	2	Luang Prabang Xayaburi Pak Lay	1939	2009	71	DB of origin Laos1\Db\Hymos.mdb
Vientiane	2/3	Xanakham Pak Chom	1913	2009	97	DB of origin ThaiLand1\Db\Hymos
Pakse	3/4	Ban Koum Lat Sua Don Sahong*	1923	2009	87	DB of origin ThaiLand1\Db\Hymos
Kratie	4	Stung Treng Sambor	1924	2009	86	

** Don Sahong is on one channel of the Mekong River*

Figure 1: Ranked annual maxima series for Kratie 1924 - 2009



Adamson (2009) has already estimated the flood risk in Zone 2 at Chiang Saen, Luang Prabang and Vientiane (Table 2). Adamson used the General Extreme Value Distribution method. He compared the type I, type II and type III distributions and found that type III suggested that annual maximum floods of the Mekong are bounded by some upper asymptote and provided a lower estimate for larger events than the Type I distribution (See figure 2), therefore he selected the Type I distribution so that a conservative estimate is used.

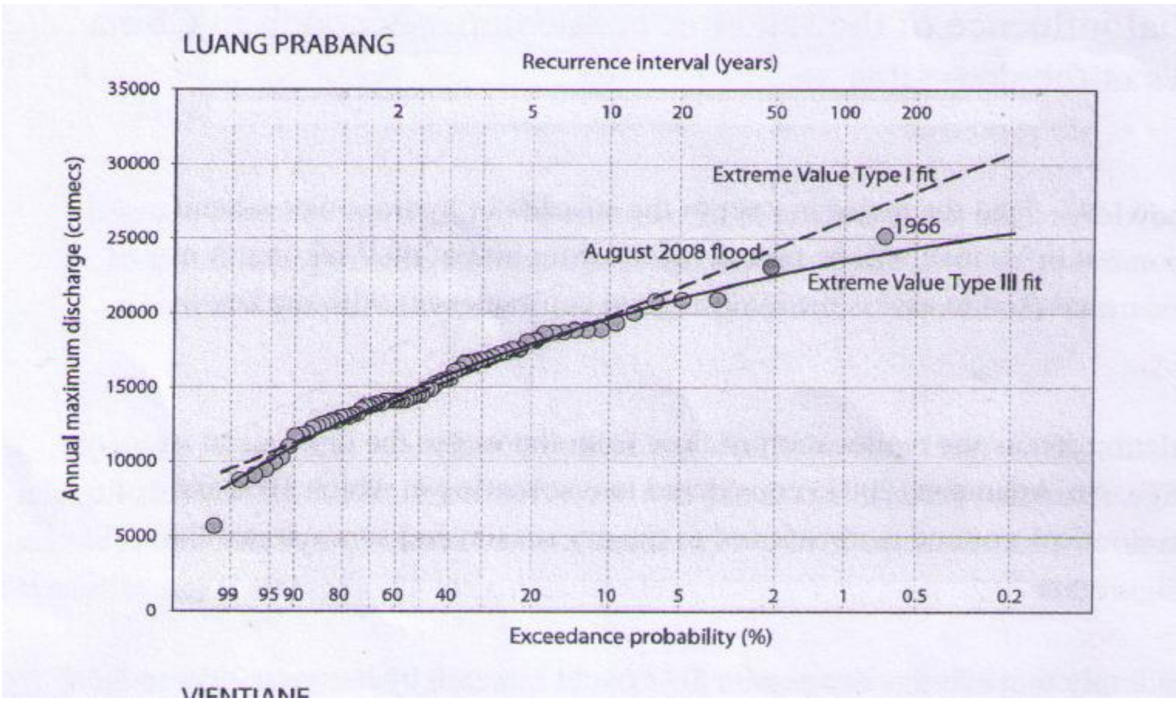
Table 3: Estimate flood risk on the Mekong River in Zone 2 *(Source: Adamson, 2009)*

	GENERAL EXTREME VALUE DISTRIBUTION
	Return period flow (GV dist)

Station	10yr	100yr	1,000yr	10,000
Chiang Saen	14,000	19,000	24,000	-
Luang Prabang	19,800	26,500	32,800	-
Vientiane	21,100	27,200	33,000	-

Comparing Table 1 and table 3 it can be seen that the 1 in 1,000yr event at Pak Lay is comparable to the same event at Vientiane gauging station.

Figure 2: Plot of the Extreme Value Distributions for Luang Prabang: *the exceedance probability is related to the recurrence interval as its inverse (Source: Adamson, 2009)*



SUMMARY OF CLIMATE CHANGE IMPLICATIONS FOR EXTREME EVENTS

Predictions of climate change for the LMB estimate that there will be:

i. An average 22% increase in annual run-off by 2030 (~107,000mcm for the basin). This will be concentrated in the wet season (Eastham et al, 2008).

ii. Increased flooding will affect the entire basin but will be most exaggerated in downstream sections where the low elevation flood plain dominates the hydrology (Eastham et al, 2008).

iii. For Kratie, Eastham et al (2008) estimated there will be a significant decrease in normal, significant and extreme dry events, with an increase in significant and extreme wet events. The extreme event is the 1 in 20yr event and the significant event is the 1 in 10yr event. These definitions are based on the MRC, and are designed for flooding in relation to agricultural use and irrigation. They do not define extreme events for large infrastructure like the proposed hydropower development

iv. The CSIRO study identifies an extreme event as one with an annual probability of 5% under historic conditions (i.e. a return interval of 1 in 20yrs). With moderate estimates of climate change this same event will have an annual probability of 76% (i.e. a return interval of 1 in 1.3 years).[1] For wet climate change projections the 1 in 20yr event will become the annual flood event.

v. The increase in extreme flood is driven by a greater peak and increased duration (Eastham et al, 2008).

vi. For Kratie, the historic wet season mean annual peak monthly discharge is 85,000mcm. With the projected 2030 climate this will increase to 111,000mcm. This corresponds to a 31% increase in the mean annual peak monthly discharge at Kratie during the wet season. Figure 3 below indicates that this increase in wet season flows is likely to affect extreme events more so than normal events.

Figure 3: Historical (1951-200) and future (2030) flood frequency for normal, significant (1 in 10 yr) and extreme (1 in 20yr) events at Kratie (Source: Eastham et al, 2008).

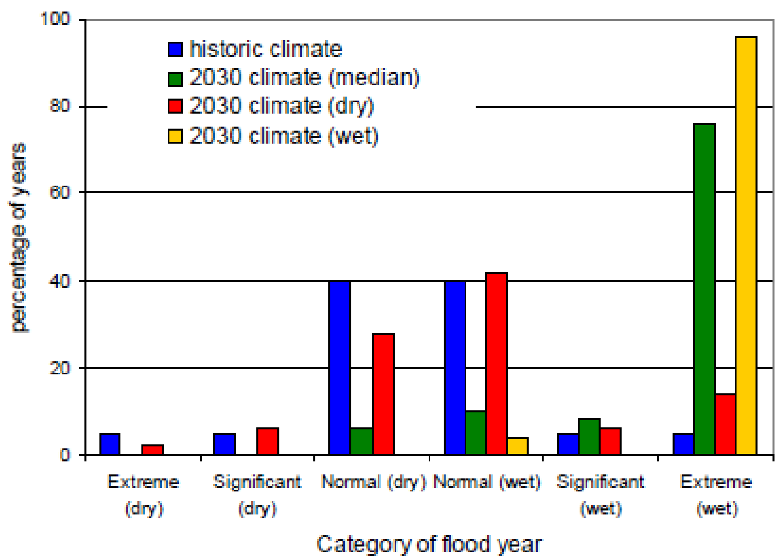


Figure 6.3. Historical (1951-2000) and future (2030) frequency of floods of different magnitude at Kratie.

CONCLUSIONS FOR EXTREME EVENTS

In order to explore the implications of climate change for extreme events, the SEA has used the above conclusions from the CSIRO study to explore the magnitude of change that could be likely with climate change. To do this it has been assumed that the predicted 31% increase in wet season flood volumes is concentrated in an increase of extreme events.

B. PURPOSE & APPROACH

The purpose of this calculation is to explore the implications of climate change on extreme weather in the LMB and to quantify the changes to the return periods for the events which have been used to design the

[1] A 'normal' flood corresponds to the mean annual discharge (~13,600m3/s at Kratie) (Eastham et al, 2008).

spillways. This is an important consideration for the SEA because the risks associated with dam failure could be catastrophic for downstream reaches of the river which are some of the most densely populated regions of the basin and also play an important role in sustaining the livelihoods of riverine populations.

Precedence at Yali project on the Sekong River have shown that large unannounced releases of water (in this case for provision of storage capacity for the imminent flood season) can result in loss of life and destruction of property and livelihoods.

The approach taken is as follows:

i. rank annual maximum series and calculate the 10yr, 100yr , 1,000yr and 10,000 yr events using the frequency factor approach as defined by Chow (1988) for the extreme value method and log pearson III method. Then compare with Adamson's estimates for validity of the method
ii. predict the impacts of CC on the annual maxima series by taking the last twenty years of historical data and projecting this data to 2030 with a 31% increase in the mean of the annual maxima between 2009-2030 – as summarised in table 4.

Figure 4: Annual maxima Series for Kratie: *the blue series represents actual historical records between 1924 – 2009; the red series takes the 1990-2009 historic data increases the value by 31% and projects it forward as the indicative 2010-2030 series.*

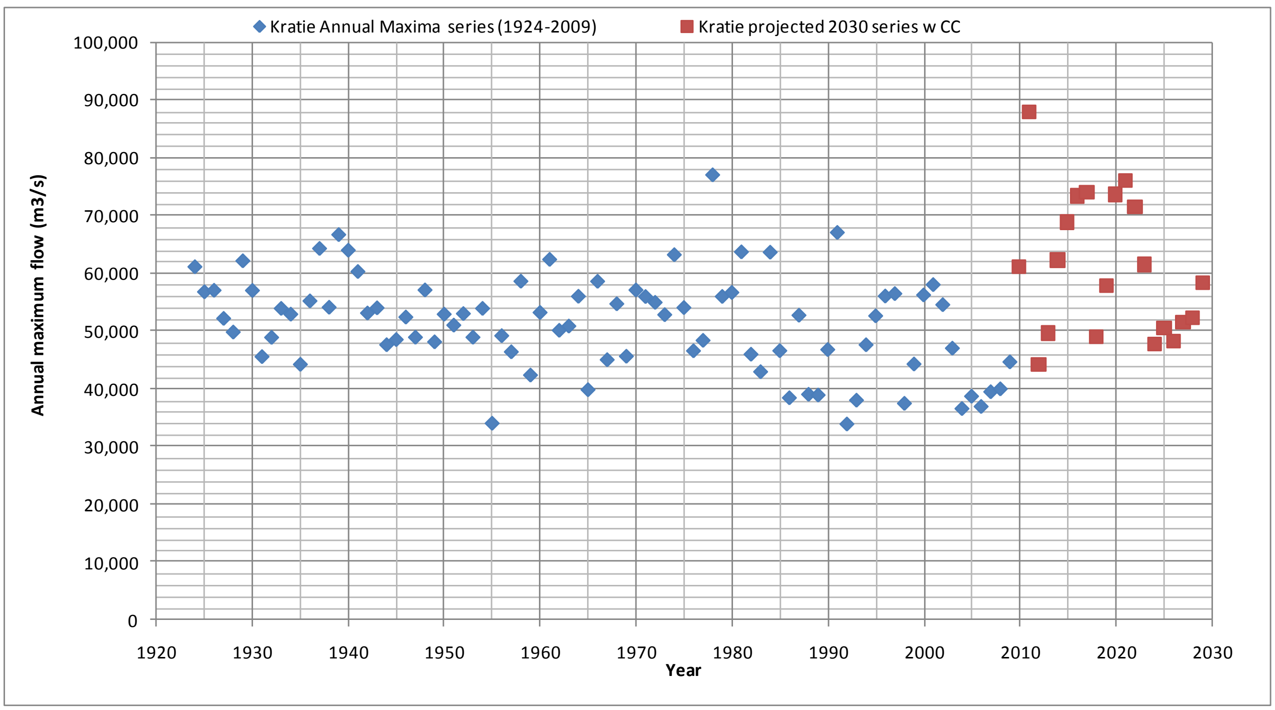


Table 4: summary of historic and projected statistics for the annual maxima series at mainstream stations: *the mean of the entire series from the beginning of the historical record to 2030 typical increases by 3-8%. The standard deviation increases by 10-30%.*

Station	Time period	Data record	Average (m3/s)	standard deviation (m3/s)
Chiang Saen	Historical 1960-2009	1960-2009	10,535	2,889
	CC projected 1960 – 2030	1990-2009 + 31% increase in mean	11,297 (+7.2%)	3,217 (+11.3%)
Luang Prabang	Historical 1939-2009	1939-2009	15,161	3,424
	CC projected 1939-2009	1990-2009 + 31% increase in mean	16,109 (+6.3%)	4,498 (+31.3%)
Vientiane	Historical: 1913-2009	1913-2009	16,717	3,286
	CC projected 1913 - 2030	1990-2009 + 31% increase in mean	17,411 (+4.2%)	3,837 (+16.8)
Pakse	Historical: 1923-2009	Historical: 1923-2009	37,479	5,658
	CC projected 1923-2030	1990-2009 + 31% increase in mean	39,209 (+4.6%)	7,150 (+26.4%)
Kratie	Historical: 1924-2009	1924-2009	51,264	8,395
	CC projected 1924-2030	1990-2009 + 31% increase in mean	53,109 (+3.6%)	9,911 (+18.0%)

iii. The next step is to estimate the 10yr, 100yr, 1,000yr and 10,000yr flows using the entire time series available projected forward to 2030

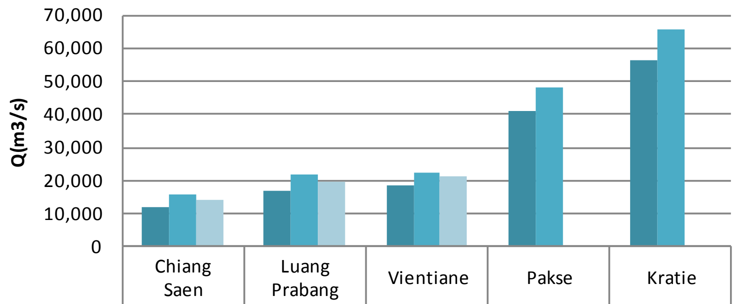
iv. for convenience I have assumed that a similar increase is reflected at the other mainstream stations in a warming climate

COMPARISON OF HISTORICAL EXTREMES

The EV frequency factor method under-estimates the size of the return flood when compared to Adamson's estimates and those provided by dam operators, while the LPIII is comparable to Adamson's estimates. This becomes more of a problem for larger events, with good correlation for the one in 10yr event, while the 1 in 10,000 flood at Luang Prabang was estimated as 25,357m3/s compared to the developer estimate of 44,838m3/s.

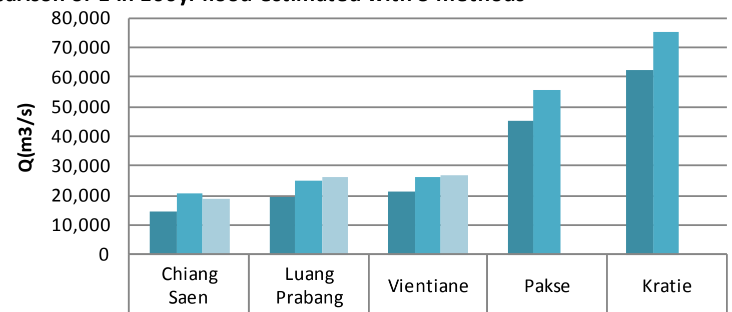
The frequency factor method is likely to be an acceptable approximation for return periods of 1,000years or less.

Comparison of 1 in 10yr flood estimated with 3 methods



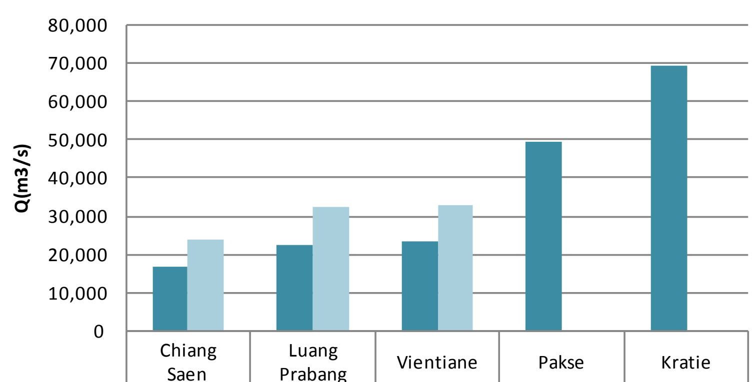
	Chiang Saen	Luang Prabang	Vientiane	Pakse	Kratie
EV - 10yr	12,252	17,137	18,670	40,842	56,254
LPIII - 10yr	15,625	21,614	22,287	48,226	65,602
GV - 10yr	14,000	19,800	21,100	0	0

Comparison of 1 in 100yr flood estimated with 3 methods



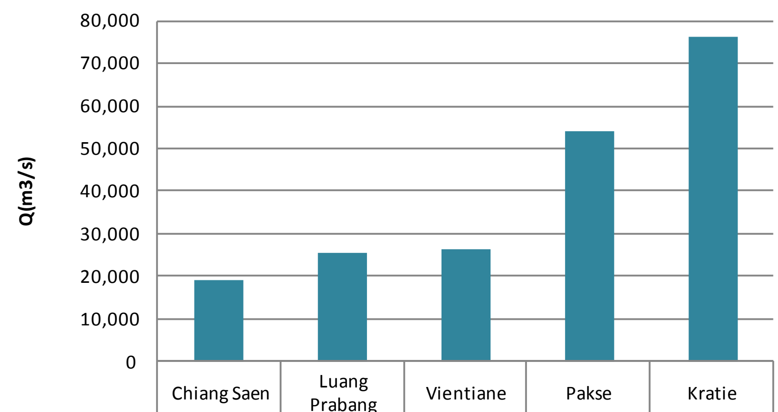
	Chiang Saen	Luang Prabang	Vientiane	Pakse	Kratie
EV - 100yr	14,551	19,912	21,285	45,344	62,934
LPIII - 100yr	21,018	25,412	26,547	56,246	75,995
GV - 100yr	19,000	26,500	27,200	0	0

Comparison of 1 in 1,000yr flood estimated with 3 methods



	Chiang Saen	Luang Prabang	Vientiane	Pakse	Kratie
EV - 1,000yr	16,808	22,637	23,852	49,765	69,493
GV - 1,000yr	24,000	32,800	33,000	0	0

Comparison of 1 in 10,000yr flood estimated with 3 methods



	Chiang Saen	Luang Prabang	Vientiane	Pakse	Kratie
EV - 10,000yr	19,061	25,357	26,414	54,177	76,040

IMPACTS OF CLIMATE CHANGE

Comparing the historic and future climates the following conclusions can be drawn:

- The historic 100yr event is smaller than the 1 in 10yr event with the projected climate change at each station analysed. This means that an event which occurred every 100years is likely to occur more than once every 10years.
- The historic 1,000yr event is comparable in size to the 1 in 100yr event at each station with climate change. This means that the 1 in 1,000yr event will become ~ 1 in 100year event.
- The historic 1 in 10,000yr event is comparable to the 1 in 1,000year event with project climate at each station. This is more pronounced for downstream stations

Table 5: comparison of changes to the magnitude of extreme events for the same return period

	EXTREME VALUE DISTRIBUTION Historic Return period flow (EV dist)				EXTREME VALUE DISTRIBUTION Projected 2030 Return period flow (EV dist) with CC			
Station	*10yr*	*100yr*	*1,000yr*	*10,000*	*10yr*	*100yr*	*1,000yr*	*10,000*
Chiang Saen	12,252	14,551	16,808	19,061	13,209	15,769	18,282	20,790
Luang Prabang	17,137	19,912	22,637	25,357	18,783	22,362	25,876	29,384
Vientiane	18,670	21,285	23,852	26,414	19,692	22,745	25,742	28,734
Pakse	40,842	45,344	49,765	54,177	43,459	49,149	54,734	60,311
Kratie	56,254	62,934	69,493	76,040	59,000	66,886	74,629	82,358

Assuming a project design life of 100years:

- Project structures designed for a 1 in 1,00 year event will see the probability of this event occurring over the design life increase from 63% to ~100%
- Project structures designed for a 1 in 1,000 year event will see the probability of this event occurring over the design life increase from 10% to 63%
- Project structures designed for a 1 in 10,000yr event will see the probability of this event occurring over the design life increase from 1% to 10%

Table 6: Risk of failure associated with return periods for an assumed project life of 100yrs

T	1	5	10	50	100	500	1,000	2,000	5,000	10,000	50,000
RISK	100.00%	100.00%	100.00%	86.74%	63.40%	18.14%	9.52%	4.88%	1.98%	1.00%	0.20%

THE PROBABLE MAXIMUM FLOOD & PRECIPITATION

The PMP and PMF are generally used to design large water control infrastructure. The PMP provides a maximum depth of duration based on regional weather and ground cover characteristics, when coupled with a time distribution indicating the length of the storm event, this can then provide an estimate of the PMF using a rainfall-runoff model (Chow et al, 1988). The PMF can be defined as the largest flood which could be expected assuming the complete coincidence of all factors that would produce the heaviest rainfall and maximum run-off (Chow et al, 1988). The PMF method represents a deterministic approximation to extreme events compared with the probabilistic method of the return periods. The probability of occurrence for the PMP is typically not known and is often interpreted as the 1 in 500,000 year event as well as the 1 in 10,000yr event. Both the PMP and PMF methods do not take into account long term climate change, and changes to the weather pattern (e.g. increasing severity of storm events) will affect the PMP and PMF.

ANNEX VIII: SEDIMENT TRANSPORT CAPACITY OF THE MEKONG DELTA CHANNELS

PURPOSE & APPROACH

The purpose of this calculation is to provide an order of magnitude estimation of the range of sediment grain sizes which can be successfully entrained in the Mekong River as it flattens and enters the delta. This can be taken as a measure of stream competence for the delta and is driven by the turbulent flow velocity of the channel. In general the larger the velocity, the greater the size of sediment which can remain entrained and be transported with the flow.

There are two approaches:

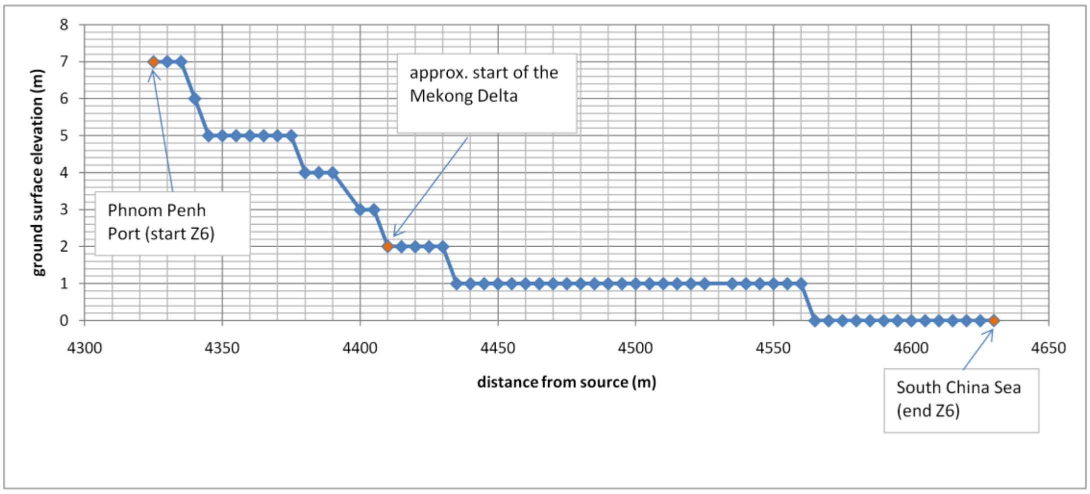
1. Look at bed movement threshold velocity (slope and depth dependent) and test the size that can be resuspended (see for e.g. Carling's (2009) application of the Shield's formula
2. Turbulent fluctuations: compare turbulence with settling velocities for particles of different size, by applying Stokes' Law.

The approach used in this calculation is to use observed WLs from the 2000 flood at Chau Doc and Can Tho gauging stations to determine water slope, then to use Manning's equation for open channel flow to estimate flow velocity, shear velocity and then turbulent flow velocity to determine what is the largest size particle which could be expected to remain in suspension through the delta.

B. BACKGROUND

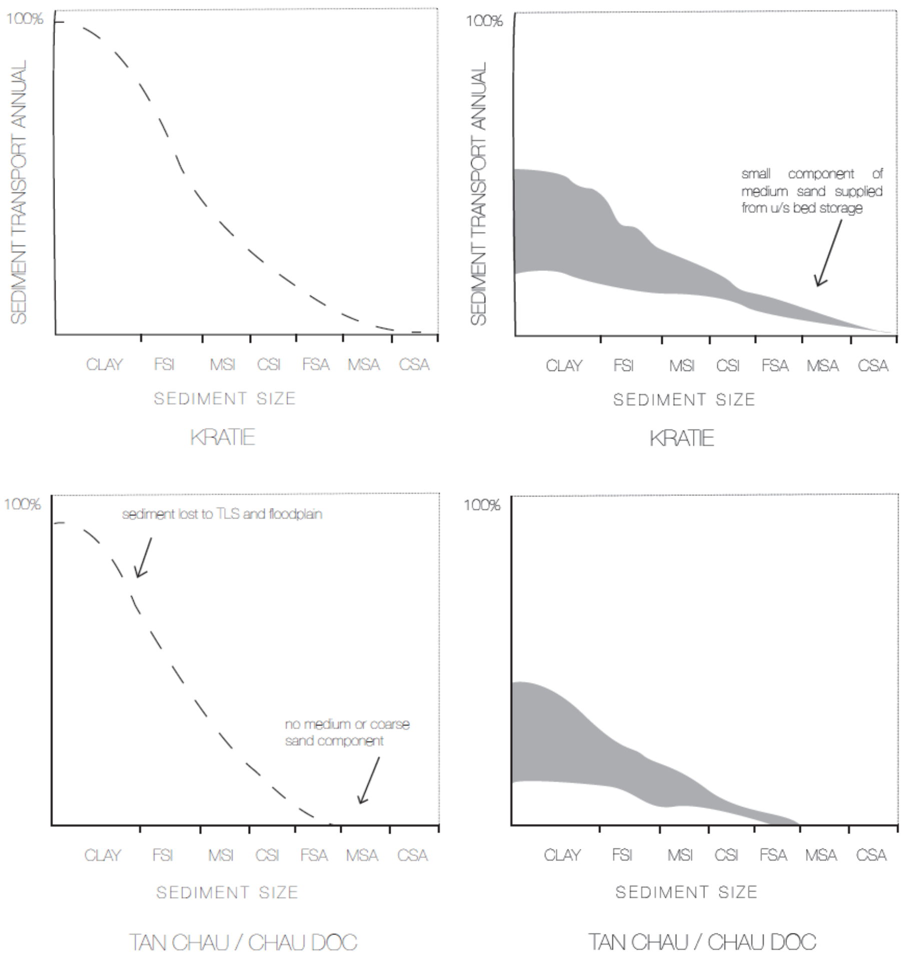
As the Mekong River enters the delta is splits into two main channels before fanning into a network of distributaries on approach to the sea. The longitudinal profile based on elevations extracted from the MRC hydrographic atlas at 5km interval gives a rough indication of the change in surface gradient. The upper part of Zone 6 (Phnom Penh to the Vietnamese border) has a longitudinal fall of ~ 0.06, which is an order of magnitude steeper than the Vietnamese delta with a fall of ~0.009.

Figure 1: Longitudinal profile of Zone 6 (note this profile is for the Tien River channel of the Mekong, not the Hau River Channel, though it is expected to be representative of both)



This is the basis of the hypothesis presented in the SEA baseline working paper(Figure 2) that there is insufficient energy in the delta channels to transport medium and fine sized sand particles.

Figure 2: Indicative changes to the sediment load composition for Kratie and Tan Chau/Chau Doc.The left hand figure represent the current and past situation, while the right hand figures present the best estimate of the 2015 situation



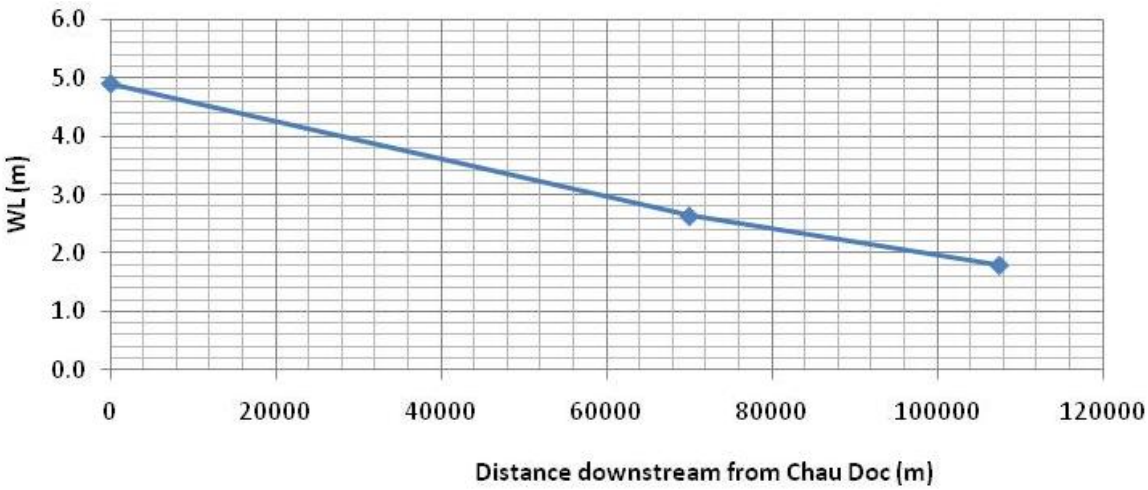
C. RESULTS

Chau Doc and Can Tho both lie on the Hau River and are separated by ~108km. WL readings were taken during the 2000 flood at both these stations as part of the feasibility study for the Vam Cong Bridge (TEDI, 2009). The 2000 flood water levels and station chainage are presented in table 1 and used to calculate and average water surface slope between Chau Doc and Can Tho of 0.0289.

Table 1: Chau Doc and Can Tho: WLs and slope during the 2000 flood (based on: TEDI, 2009)

	Chau Doc (CD)	Long Xuyen (LX)	Can Tho (CT)
dist to bridge	62500	7500	45000
X	0	70000	107500
WL (1%)	5.1	2.75	2.01
WL (2%)	2.75	2.58	1.86
WL (5%)	2.01	2.49	1.79
WL (2000)	4.9	2.63	1.79
slope		3.24286E-05	2.2E-05
slope (CD - CT)			2.9E-05

Figure 3: indicative water surface slope between Chau Doc and Can Tho



Manning's equation was then used to compute the flow velocity in this river reach based on the following assumptions:

1. The Mekong channel between Chau Doc and Can Tho is sufficiently wide that the hydraulic radius can be approximated by the water depth
2. The Manning's *n* number is taken as n = 0.029 based on an estimate for the Mekong mainstream channel derived near Khong Chiam[2] (just south of the Mun confluence) (Nawarathna et al, 2005).

In order to test whether these assumptions were accurate, Henderson's criteria for fully turbulent flow was used:

[2] The study found average Manning's coefficients for the mainstream (0.029) and tributaries (0.034). The mainstream value is assumed for this calc

It is reasonable to assume that the Hau River channel would undergo fully turbulent flow during the flood season, therefore Henderson's criteria(above) should be satisfied based on the *n,* R and S values obtained. Putting the estimates from table 1 and the above assumptions into the above criteria gives a value between 1.35 – 2.24 $x10^{-10}$ which is larger than the criteria and an indication of turbulent flow. Therefore the values assumed for *n*, the use of depth to estimate the hydraulic Radius and the water slope estimated are of the right order of magnitude to represent the flood season flow dynamics of the Hau River. The Manning's equation is:

–

Table 2: Mean flow velocity

	CH	velocity	n	R	S	u*
	m	m/s		m		m/s
Chau Doc	0	0.53	0.029	4.9	2.9E-05	0.03
Long Xuyen	70	0.35	0.029	2.63	2.9E-05	0.02
Can Tho	107.5	0.27	0.029	1.79	2.9E-05	0.01

Table 2 shows that changes to channel dimensions and water levels reduce the mean flow velocity by ~50% between Chau Doc and Can Tho. The relationship between velocity and stream competence is a power relationship, such that halving the velocity more than halves the stream competence. This gives an indication of the scale in reduction of stream competence between the Cambodian floodplain (upstream of Chau Doc) and the Mekong Delta (downstream of Chau Doc).

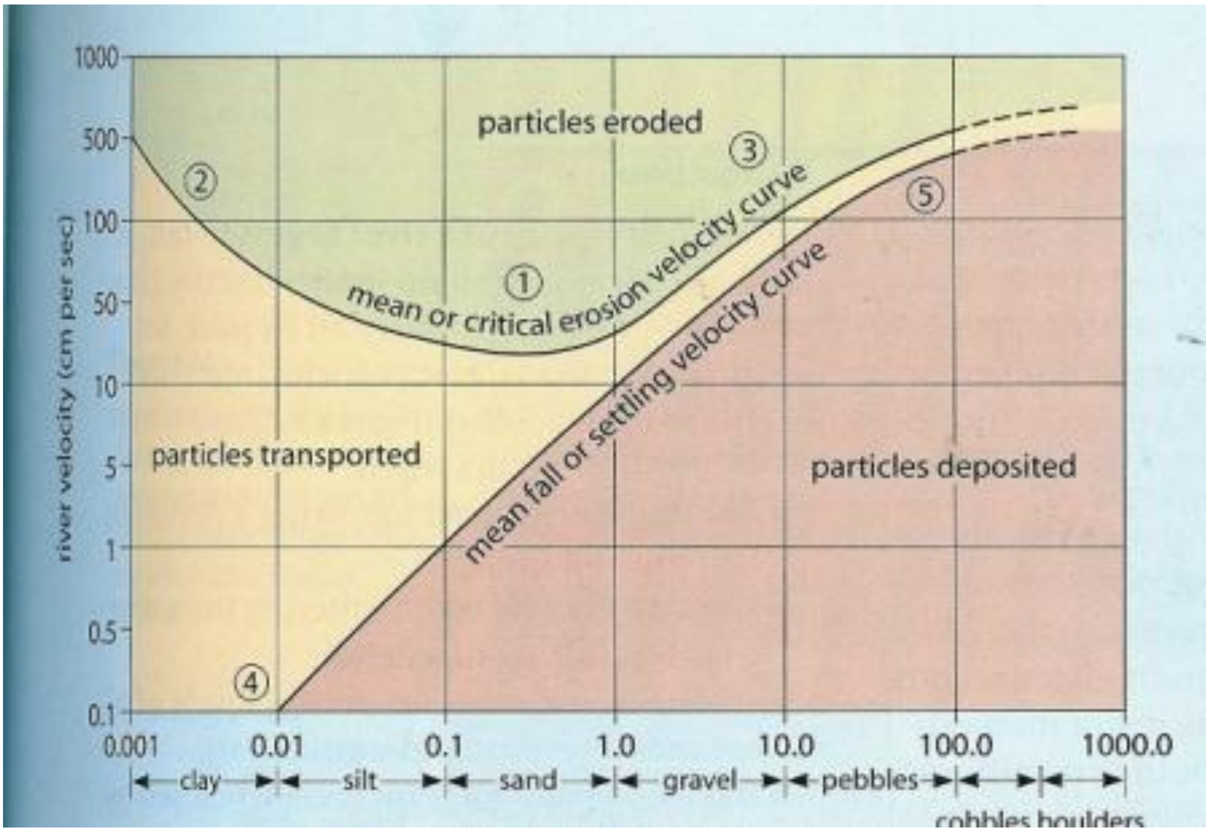
To further quantify stream competence, the shear velocity, (*u**) was calculated as ~ 1/20 times the mean flow velocity (see table2). Turbulent fluctuations in the water column are closely related to the shear stress in the boundary layer. As an order of magnitude estimate, the turbulent velocity of transport is assumed as 3-times the shear velocity (table 3).

Table 3: estimated settling velocities for the Mekong Delta

Station	V
	cm/s
Chau Doc	0.001
Long Xuyen	0.001
Can Tho	0.000

Comparing these velocities with the Hjulestron diagram presented below (Figure 4), it can be seen that downstream from Chau Doc there is only competence to transport clays and fine silts (< 0.01mm).

Figure 4: Hjulestron diagram: Settling velocities calculated in Table xx are used to determine the max size of transported particles



D. CONCLUSIONS

- Under the baseline, only clay size particles are likely to be transported through the Mekong Delta.
- During extreme events there may also be some capacity for silts to be transported
- Stream competence increases as a power of velocity, so transport is likely to be focused on the wet season, when flow velocities are higher and also when most of the sediment load enters the Mekong.
- The Definite future scenario will see a reduction in wet season flow (-4-5%) and increase in dry season flow (+20-30%) which will act to reduce the stream competence of the channel reaches through the delta
- Any shift in the composition of the sediment load towards larger size materials will not compensate for the transport load through the Mekong Delta if the material is larger than clay/silt size.