World Bank

Mekong Regional Water Resources Assistance Strategy

Modelled Observations on Development Scenarios in the Lower Mekong Basin

November 2004

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Executive Summary

Introduction

The World Bank is in the process of developing a Mekong Regional Water Resources Assistance Strategy that will set out the scope for potential assistance to both regional and national projects in the basin over the next 10 years.

A comprehensive Decision Support System is under development. The hydrological component is already in place, and has been calibrated, tested, approved and adopted by the Mekong River Commission (MRC). It comprises a suite of models that make it possible to simulate major hydrological aspects of river basin behaviour, which can in turn support and inform the negotiations that are now addressing the water-sharing issues.

The MRC models have the capacity to test and evaluate development scenarios defined generically in terms of hydropower development, irrigation development and inter-basin diversions. The output of the models is quite narrowly hydrological - water utilised for irrigation and power generation; river flow and stage at key locations; volumes; inundated areas, depths and duration of inundation; and salinity levels. These parameters can in turn provide insights into possible impacts on fisheries, flood management, saline intrusion, navigation, and the environment.

The Review Process

In this report, the results of modelled scenarios are summarised on the basis of agreed key indicators. The scenarios have been selected to represent feasible development scenarios - some balanced, others unbalanced - thus providing a range of possible outcomes.

The Scenarios: A range of development scenarios has been selected to provide a perspective on development opportunities and their impacts. The inclusion of a project within any development scenario does not imply any endorsement from the panel, the countries or the MRCS. The panel is confident, however, that the range of scenarios tested is sufficient to illustrate the range of likely impacts for the next twenty years.

All scenarios reflect the impact of some dams that are planned to be developed in China. China is not a party to the 1995 Agreement, and we have accepted for the purpose of these scenarios that some of these dams will be in place. The two run-of-river dams already built have negligible impact on flow redistribution. The two largest dams proposed are likely to cause the most significant seasonal redistribution of flow of any the development scenarios evaluated.

Six scenarios were evaluated:

- Baseline: Representing the development conditions that existed in the basin in the year 2000.
- China dams: Identical to the baseline scenario but including all the proposed Chinese dams.
- Low development: Representing a minimum level of development based on population growth to 2020, and including water usage growth in line with population trends and irrigation constraints, dams in Laos and likely dams in China.
- Embankments: Similar to the low development scenario but including 130,000 ha isolated from the Cambodian floodplain.
- Agriculture: Including a substantial amount of growth in water usage and likely hydropower dams in China and the lower basin. This includes maximum likely levels of water usage growth to 2020, constrained by irrigable land availability and water access. The growth in water usage also includes inter- and intra-basin transfers. The hydropower development is similar to the low development scenario.
- High development: Similar to the agriculture development scenario but has including a substantial amount of hydropower growth. It includes all proposed Chinese dams and a large number of proposed dams in Laos, Vietnam and a mainstream dam in Cambodia.

A summary of the key model parameters for all of the scenarios are shown in Table 1 below.

Table.1 Scenarios modelled

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas (‘000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area (‘000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

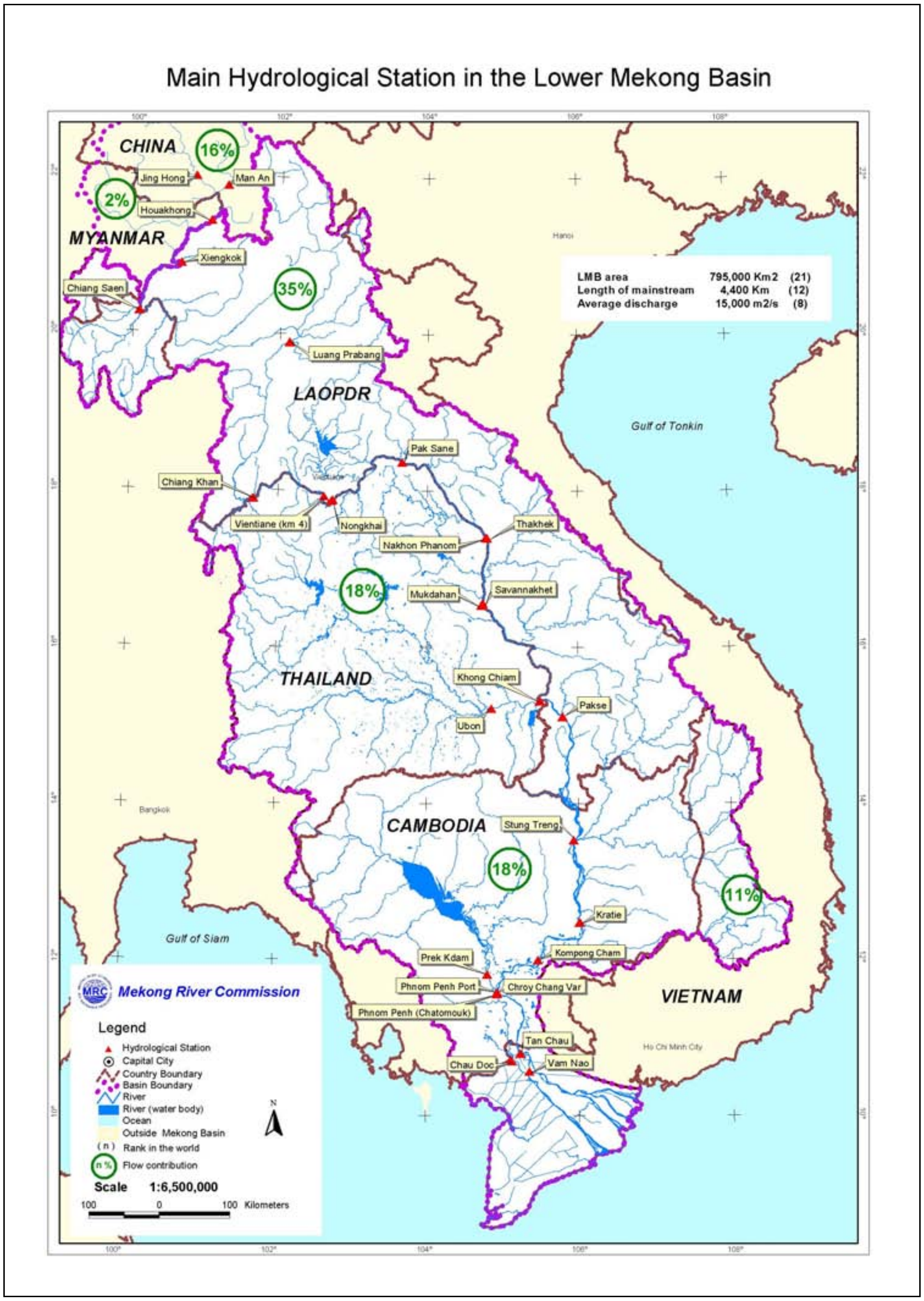

Figure 1 Mainstream hydrographic stations and country flow contributions for the LMB

The Indicators: A range of indicators has been selected to show the impacts of flow and salinity changes at key locations throughout the LMB (Figure). The indicators can be grouped into five broad categories

- Mainstream flow indicators
- Great Lake and floodplain indicators
- Delta indicators
- Irrigation production

- Hydropower generated

The mainstream flow indicators have been selected to look at changes in flow. These indicators are also used to investigate changes in duration of low flow to assess impacts on navigation.

The Great Lake and floodplain indicators have been used to look at changes in lake area and durations of inundation. This has a dual purpose for indicating flooding impacts as well as impacts on fish production. A Fish Feeding Opportunity indicator was developed as an initial basis for assessing possible impacts on fish production.

The delta indicators are concerned with salinity intrusion. The indicators show three classes of salinity durations. These can be used to assess the impacts of changes in salinity intrusion on rice production.

The irrigation indicators are based on irrigable areas, taking into consideration water availability. These data, in combination with yield estimates can be used to assess food production.

Hydropower generated is the average annual total power produced over the 16 year modelling period at each hydropower station.

Conclusions and Observations

Conclusions on modelling capacity

The MRC has developed, tested and formally adopted a comprehensive, modern suite of hydrological models. Development will continue, however the studies underlying this report indicate that the models are robust and provide important insights into the hydrological impacts of a wide range of basin development scenarios on river flow, floodplain inundation, flooding, navigation, hydropower production, and salt water intrusion on the delta.

An overall check of the MRC models was carried out. The checks covered the overall mass balance of the model as well as verifying the demands. The tests confirmed that the models preserved mass balance for all scenarios. The magnitude and change in demands was consistent with simple estimates, and in line with the level of development. The distribution of flow and usage within the models was also consistent with the level of development.

Use and maintenance of such modelling capacity is an essential asset for a basin of this size. Ongoing quality assurance is an important responsibility for the MRC.

The information provided by the models will allow specification of key parameters in the inter-country agreements that are required for coordinated basin development. The models can subsequently be used as a part of the monitoring, auditing and reporting program that the MRC will be responsible for as development proceeds.

The models have the capacity to report on a range of environmental indicators once the relationship between flow, water level and area inundated and the particular environmental issue (e.g. fish production/wetland health) is established. During this exercise, we have developed a basic fish indicator to demonstrate what is possible.

The Basin

As stated in the 1995 Basin Agreement, the countries require a set of operating rules that provides scope for national development while protecting the shared resources that they collectively rely on. Such rules define the key, monitorable indicators – in terms of times, locations, flow rates, levels, quantities, water quality or other variables – that are sufficient to define each country's opportunities and responsibilities in the Mekong Basin.

The Countries

The development path chosen by each country will reflect its national policies, investment potential, and investment capacity. The resulting priorities may vary sharply between countries, and within countries over time. The rules set boundaries to the nature and scope of the development such that the interests of other basin states are protected while each state pursues its legitimate goals.

The Commission

The role of the river commission is threefold:

(i) Information: to provide and maintain the information base and analytical capacity to determine fundamental elements of the 1995 agreement, and, as required for additional future agreements;

(ii) Monitoring: to monitor, audit and report on the conformity of ongoing basin management to the terms and conditions agreed by the countries and contained within the agreement.

(iii) Shared Asset Management: to own and manage assets which have been created by joint investment and have been agreed to be best managed centrally.

The Studies

These studies do not (and were not intended to) compare or evaluate the merits of alternative development scenarios, but rather to demonstrate the likely impacts of a credible variety of single- and multi-sectoral development scenarios. The studies confirm that there is scope for significant levels of co-ordinated development with associated benefits to all basin countries.

Key findings are summarised below.

Hydrological impacts

All development will have an impact and the models reflect the change in the hydrology of the river that would result from that development. Decisions on what is the reasonable balance of development is a matter that can be informed by the model outputs but requires the economic, environmental and socio-political inputs by the country concerned to determine the appropriateness and priority of each investment.

Current development of the Mekong river is very limited compared to almost all large river basins in the world. The natural flow pattern is essentially intact, as are the highly productive natural fisheries in the river.

Existing storage corresponds to less than 2% of average annual flows at Kratie and does not significantly redistribute water between seasons. Diversions in the Lower Mekong Basin are 10% of annual flow at Kratie. Diversions in the Mekong Delta constitute some 60% of this total. In consequence, the Mekong retains most of its natural flow characteristics upstream of the delta, and the major environmental impact of water-related development to date is to increase the local problem of salt water intrusion in the delta areas.

However, it is critical to realise when evaluating the results that ongoing and committed developments in the upper basin will result in significant transfers of water from the wet to the dry season. The hydrological implications of this are broadly reflected in the "China Dams" scenario. Any lower Mekong scenario must therefore be evaluated in relation to the expected future situation – independent of lower Mekong development – as well as the historic "Baseline" scenario.

The main body of the report contains details of the scenario analysis, reported against a broad range of indicators. An indication of the change in flow regime between the baseline and the High Development scenarios for Nong Khai and Kratie are presented below.

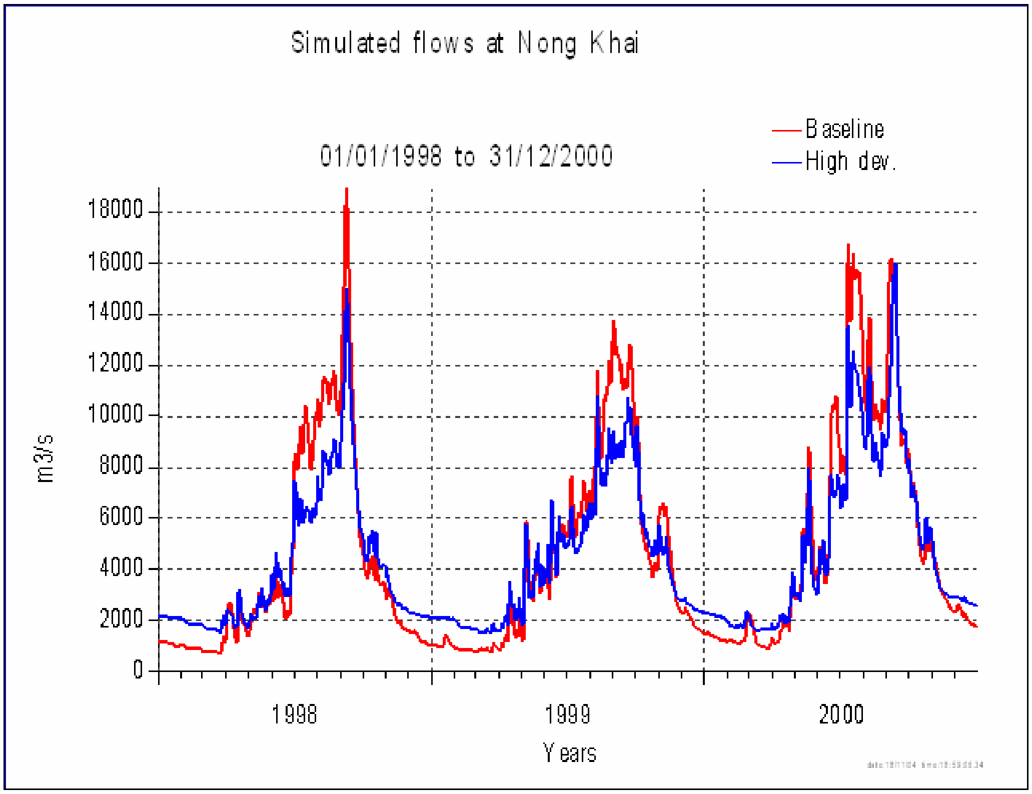

Figure 2 Simulated flows at Nong Khai

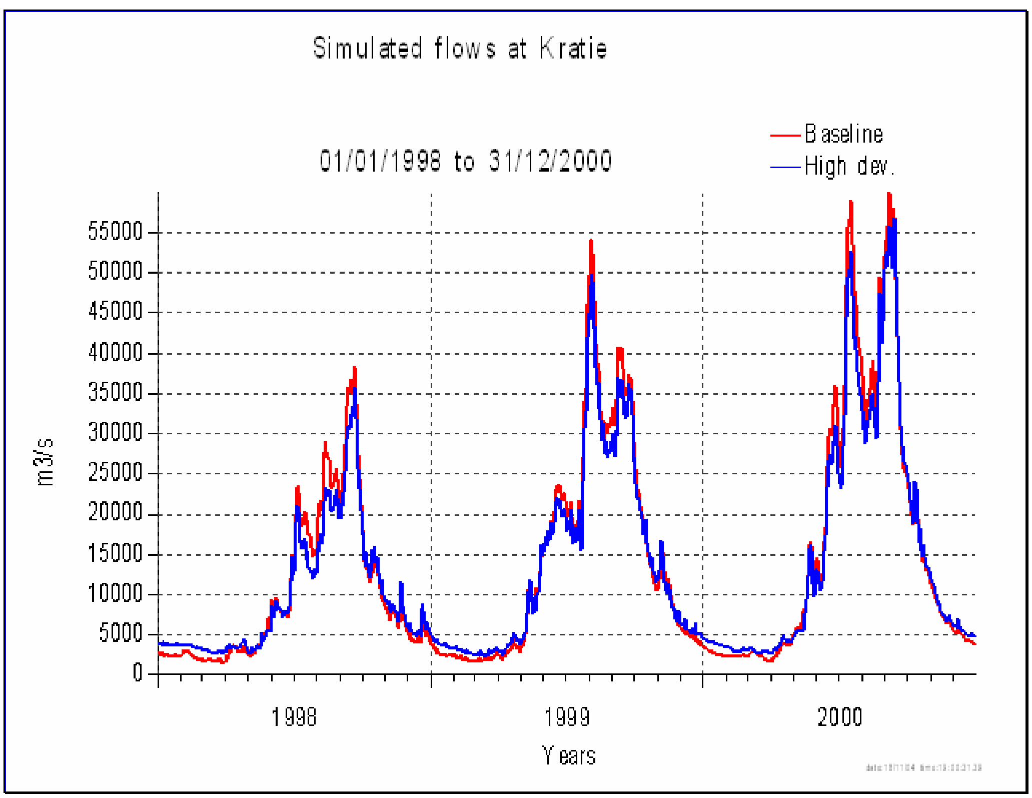

Figure 3 Simulated flows at Kratie

Summary observations are:

- The overall character of the hydrograph is maintained
- Low flows are significantly increased and are higher than the historically observed range
- High flows are marginally reduced, but within the historically observed range

Future development must be properly co-ordinated, and managed, to preserve the environmental flows that support the existing Ramsar wetland sites upstream of the delta and the highly productive natural fisheries – which represent 2% of total world fish production. These objectives are consistent with objectives set out in the Mekong River Agreement.

The results confirm the importance of a balanced and coordinated approach to water management. The results set out here confirm that agreement on access to the waters of the Mekong river is a necessary precondition to provide development security at a country level, ensuring that the benefits of development in one country are not eroded by development in another. Only a coordinated approach provides assurance of sustainable development opportunities.

Fisheries

Potential impacts on the fisheries sector are a major concern, because fisheries are a primary source of income to the poor and nutrition to the population more generally. A complicating factor in assessing the impact of potential developments within the basin on the fisheries sector is the difficulty of projecting the future of fisheries: quite separately from any impacts of dams and irrigation facilities, fish production is threatened by over-fishing, pollution from chemicals and habitat destruction due to pressure on land. It can be argued that the best basis for intervening in these "common property" problems is provided by the existence of alternative sources of income (as provided by irrigated agriculture) and development generally (as facilitated by the availability of power).

The models produce data on flow, height, and area inundated, from which a preliminary indicator of fish production has been developed, based on fish feeding opportunities. This should be a forerunner of more sophisticated indicators, but it does correlate well with available fish catch data from Tonle Sap. All scenarios tested show a small decline in fish feeding opportunities, the most pronounced reduction occurring in years of low flow.

Nevertheless, any development which directly impedes fish migration in the mid and lower reaches of the river will have significant negative impacts on fish production. Mainstream dams or weirs in the mid and lower Mekong are therefore most unlikely to be a part of any balanced development scenario that complies with the objectives of the Agreement. It is also clear that floodplain connectivity is fundamental to fisheries production and river health and must be protected.

Hydropower

The realistic estimate for hydropower is much lower than the figure generally quoted of 30,000MW because this includes 13,000MW on or near the main stream in the lower basin. It is likely that this figure will be further reduced when individual projects have been evaluated for local environmental and social impacts. However, even after these qualifications there is still a very large hydro power potential that could be developed as part of a well structured and integrated program.

The projected hydro-power in the Lower Mekong Basin in the various scenarios ranges is summarised below:

Table.2 Projected hydropower in the Mekong Basin

	Capacity (MW)		Energy (GWh)	
Location	**Lower Mekong**	**China**	**Lower Mekong**	**China**
Minimum	1,290	0	7,500	0
Maximum	6,084	12,550	43,000	68,000

Irrigation

To support national objectives of basic food security and crop diversification an increase in irrigated area is inevitable. There is currently 7.4Mha irrigated, of which 4.1Mha is in the Mekong Delta. The high development scenario increases the total area to 11.3 Mha, with most of the increase located in Cambodia – where irrigation is planned to triple. This increases the amount of water diverted for irrigation by 15.5 Gm^3/y to 55.8 Gm^3/y. This is a 40% increase in diversions and will in total represent 12 % of annual flows.

As modelled, the high development areas in Cambodia did not have fully reliable access to water for irrigation, resulting in some understatement of potential withdrawals. This is not seen as a significant issue in interpreting the results because any higher demands would not coincide with periods of major impact in the Mekong Delta.

The high Development Scenario has included an average inter-basin transfer in the wet season of 1.9 Gm^3/y.

Navigation

All the scenarios generally show substantially improved opportunities for navigation. This is a result of the redistribution of flow from wet to dry season as a result of hydro-power dams, and is particularly significant in the higher reaches of the river, where navigation access that is currently only experienced for 2-3 months each year on average will in future be virtually year-round.

Flood Damage

While there will be some redistribution of flood peaks, the developments – even those in the high scenarios – will not significantly mitigate major floods in the Lower Mekong Basin.

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1 Introduction

The World Bank is in the process of developing a Mekong Regional Water Resources Assistance Strategy that will set out the scope for potential assistance to both regional and national projects in the basin over the next 10 years.

Currently, under the "Water Utilisation Project" the Bank is supporting the Mekong River Commission to develop models and analyses to assist in meeting the requirements of the Mekong River Agreement in respect of water sharing, water quality and environmental flows. As part of this effort, a Decision Support System is now in place that has been calibrated, tested, approved and adopted by the MRC. It comprises a suite of models that make it possible to simulate major hydrological aspects of river basin behaviour, which can in turn support and inform the negotiations that are now addressing the water-sharing issues.

While the Mekong Basin is currently relatively underdeveloped, the scope for physical and management-based development is enormous. However, the capacity of the riparian states to finance infrastructural development is uneven, and their priorities and opportunities are varied. Thus while it is certain that development will occur, the nature of the development path is uncertain unless guided by the principles set out in the 1995 Agreement. The commitment of the countries to those principles is not in doubt, but moving from data collection, studies and discussions to actual implementation of projects with cross-boundary implications, governed by defined operational rules, is a major step. Similarly, for donors, the confirmation that there are investment scenarios with clear positive outcomes for all riparians is a prerequisite to support for a development program.

This report explores these concerns, noting at the outset that the potential for some states to experience a "future without project" scenario that is environmentally or socio-economically substantially worse than the present situation is a real risk in the absence of a jointly agreed basis for development and management.

The models referenced above have the capacity to test and evaluate development scenarios defined generically in terms of hydropower development, irrigation development and inter-basin diversions. The output of the models is quite narrowly hydrological - water utilised for irrigation and power generation; river flow and stage at key locations; volumes; inundated areas, depths and duration of inundation, as well as salinity levels and locations. These parameters can in turn provide insights into possible impacts on fisheries, flood management, saline intrusion, navigation, and the environment. The status of knowledge and major sensitivities in these areas are summarised in the Appendices on the basis of current views of the MRC.

In this report, the results of modelled scenarios are summarised on the basis of agreed key indicators, interpreted with the benefit of the insights of the Appendices. The scenarios have been selected to represent feasible development scenarios - some balanced, others unbalanced - thus providing a range of possible outcomes.

1.1 Intent of this report

The intent of this report is to;

- Report on the application of the MRCS DSF to evaluate development scenarios.
- Utilise the tested models to assess a range of development scenarios.
- Report on key indicators generated by the model.
- Comment on the range of indicators that inform countries as they pursue a shared development pathway.

2 Description of simulation models

The simulation models used to evaluate the scenarios in this study are SWAT, IQQM and iSIS. These models are part of the MRC Decision Support Framework (DSF). The DSF is a state-of-the-art computer based system designed to investigate impacts of changes in the quantity and the quality of flows in the Lower Mekong river system brought about by changing circumstances within the river basin.

The DSF was developed during the period 2001 to 2004 through a participatory process with the four member countries. It provides a powerful analytical basis to understanding the behaviour of the river basin and thus to making appropriate planning decisions on how best to manage its water and related natural resources. The DSF has been set up to assist planners to assess the magnitude of biophysical changes brought about through natural and man-made interventions in the Lower Mekong Basin. This information provided through the DSF can then be used to assess associated impacts on the natural environment and people's livelihoods.

2.1 DSF Components

The DSF has three main elements accessed through a single user-interface (Figure 2-1):

(iv) A Knowledge Base containing information on the historical and existing biophysical resources and, when fully populated, socio-economic and environmental conditions, as well as predictions of how these may change in the future.

(v) A suite of Simulation Models that enable the prediction of impacts of changes in conditions within the basin on the river system.

(vi) A set of Impact **Analysis Tools** that enable the prediction of environmental and socio-economic impacts in response to changes in condition of the river system.

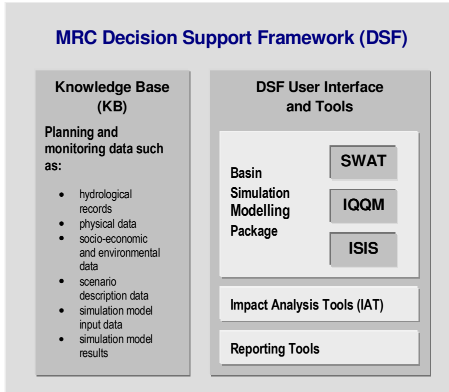

Figure 2-1. MRC Decision Support Framework

2.2 Simulation Models

2.2.1 SWAT

A series of hydrological models, based on the SWAT software of US Department of Agriculture, have been set up to simulate catchment runoff based on estimates of daily rainfall, potential evapotranspiration (PET), the topography, soils and land cover of sub-basin within the Lower Mekong Basin (LMB). The SWAT software also has the technical capability to investigate nutrient and sediment loads. The SWAT model was used to estimate inflows to the other simulation models. These inflows were the same for all scenarios.

2.2.2 IQQM

The hydrological models provide input of runoff to a basin simulation model that use the IQQM software developed in Australia. The basin simulation models route sub-basin flows through the river system, making allowance for diversions for irrigation and other consumptive demands, and for control structures such as dams. Estimates of dam releases, diversions, and daily flows are generated at any pre-defined point in the river system.

The main basin simulation model covers tributaries and the mainstream of the Mekong River down to Kratie. Simulation models were also set up to estimate irrigation demands for the Great Lake and Mekong Delta regions.

2.2.3 ISIS

A hydrodynamic model, based on ISIS software developed by HR Wallingford and Halcrow, is used to simulate the river system downstream of Kratie, including the Ton le Sap and the East Vaico in Viet Nam where wet season flooding extends beyond the LMB boundary. The hydrodynamic model represents the complex interactions caused by tidal influences, flow reversal in the Tonal Sap River and over-bank flow in the flood season with the varying inflows from upstream. Typically it generates hourly data for water levels and discharges throughout the main channels and distributaries in the delta. A salinity intrusion model was also set up with the ISIS software using results of the hydrodynamic model.

2.3 Model review and calibration

The DSF was reviewed in August 2003 by an international expert review panel. The expert panel's aide-memoire recommended a set of calibration criteria that were subsequently adopted. The criteria for the IQQM and SWAT models focused on overall mass balance, mass balance in the dry and wet seasons, preservation of flow distribution and Nash-Sutcliff criteria (Table 2.1).

Table 2.1. Thresholds for model calibration

Performance measure	Main stream			Tributaries		
	Daily	*Monthly*	*Total*	*Daily*	*Monthly*	*Total*
Vr			± 1%			± 5%
Vr high			± 1%			± 5%
Vr low			± 1%			± 5%
$Q_{\%}$	±2-3%			±10%		
CE	0.85	0.90		0.40	0.60	

The models were subsequently calibrated to meet these criteria and the results of this calibration are presented in (MRC 2004c). The final acceptance and handover of the model to MRC was in March 2004.

2.4 Representativeness of modelling period

The current modelling period used in the DSF is from 1985-2000. This 16 year record of the hydrological regime is a relatively short sample of data. However, as has been already discussed at length during the process of DSF development, the data deficiencies prior to 1985 rapidly become unacceptable for accurate hydrological model development and calibration. Therefore, the use of such a small sample is unavoidable.

Integrated Basin Flow Management (IBFM) as developed under the MRC Water Utilization Program (WUP) is addressing important requirements of the 1995 Agreement – that of determination of acceptable flows in relation to the provisions of Article 6. A key milestone for the WUP and the MRC is to achieve agreement of Rules for the Maintenance of Flows on the Mainstream (RMFM) by the end of 2004. Phase 1 of this work has looked in detail at the representativeness of this 16 year modelling period.

IBFM Report No 2 (MRC 2004d) used a statistical approach to address this issue in some detail and concluded that the 16 years between 1985 and 2000 experienced overall hydrological conditions that in most respects were typical and representative of the longer term hydrology of the Basin. IBFM Report No. 3 (MRC 2004f) independently confirmed this conclusion.

3 Setting

3.1 Overview of the Mekong

The Mekong is one of a group of some of the world's largest rivers that have their origins among the snowfields of the Tibetan plateau. The Mekong maintains a southerly course from the Tibetan plateau for some 4,500 km to the South China Sea, draining a total catchment of some 795,000 km^2 within six countries (Table 3.1).

Table 3.1. Territory of the six Mekong River Basin countries within the catchment

Country	Area (km^2)	Area % of Basin	Flow % of Basin
China	165,000	21	16
Myanmar	24,000	3	2
Lao PDR	202,000	25	235
Thailand	184,000	23	18
Cambodia	155,000	20	18
Vietnam	65,000	8	11
TOTAL	**795,000**	**100**	**100**

This Mekong Basin is widely perceived as divisible into two parts:

(i) the Upper Basin in Tibet and China, where the river is referred to as the Lancang Jiang, and

(ii) the Lower Mekong Basin (LMB) downstream of the China.

Major tributary systems only really begin to develop in the Lower Basin and these can be separated between those which contribute the major wet season flows and those that drain low relief regions of lower rainfall. The former are the left bank tributaries that drain the high rainfall regions of Laos and the Central Highlands region in Vietnam and eastern Cambodia, and the latter those on the right bank, most notably the Mun and Chi Rivers that drain NE Thailand.

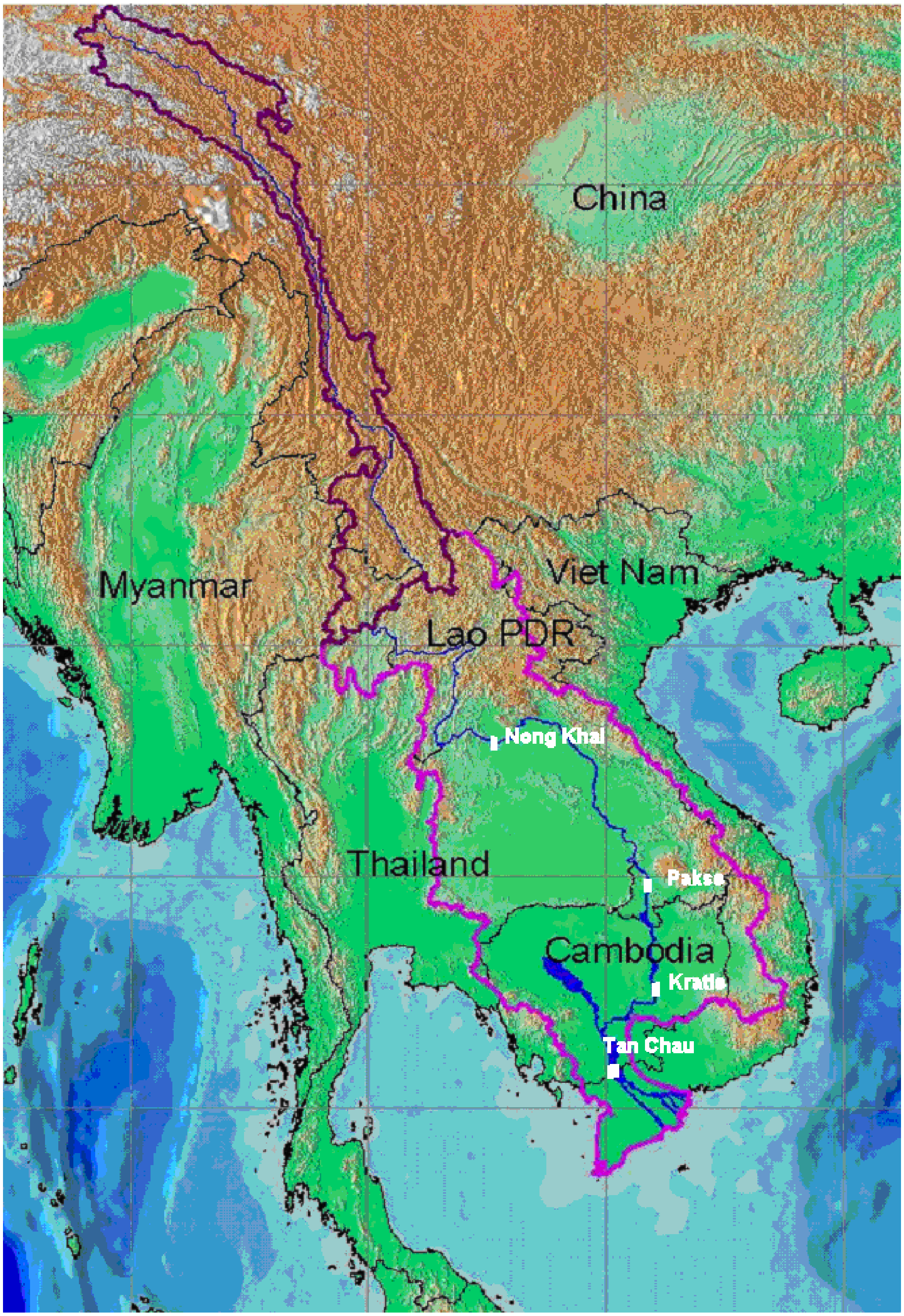

Figure 3-1. Mekong Basin.

3.2 Characteristics of the Lower Mekong Basin

3.2.1 Population

The distribution of the 55 million people living in the LMB varies considerably (Table 3.2). Projected growth also varies considerably between countries with higher growth rates in the developing countries.

Table 3.2. Population in the Lower Mekong Basin

Country	National population 2000 (million)	Rural (%)	Growth rate (%)	LMB Population (million)	
				2000	2020
Cambodia	13.1	84	2.3	9.8	16.5
Lao PDR	5.3	76	2.6	4.9	7.6
Thailand	62.8	78	1.0	23.1	28.2
Viet Nam	78.1	80	1.4	16.9	21.8
TOTAL	**159.3**			**54.7**	**74.1**

3.2.2 Rainfall

The rainfall climate throughout the LMB is dominated by the SW monsoon, which usually commences in May and lasts for about five months. Geographically, the distribution of precipitation is largely controlled by relief, with the upland and plateau regions of Lao PDR receiving up to 3,000 mm annually, thus comprising the major source of runoff in the Lower Basin. The low relief right bank regions in Thailand and Cambodia receive much less rainfall on the average with figures of between 1,000 and 1,500 mm being typical.

3.2.3 Flows in the mainstream and major tributaries

The mean annual discharge of the Mekong is approximately 475,000 million cubic metres (mcm), of which about 16% originates in China and only 2% in Myanmar. Table 3.3 indicates the dominance of the flow contributions from the major left bank tributaries in Lao PDR and particularly those that enter the mainstream downstream of Vientiane / Nong Khai and downstream of Pakse.

Table 3.3 Flow contributions for mainstream reaches (MRC, 2004e)

River reach	Percent conribution		
	Left Bank	Right Bank	Total %
China	16		
China - Chiang Saen	1	4	5
Chiang Saen – Luang Prabang	6	3	9
Luang Prabang - Chiang Khan	1	2	2

Chiang Khan - Vientiane	0	0	0
Vientiane - Nong Khai	0	1	1
Nong Khai - Nakhon Phanom	19	4	24
Nakhon Phanom - Mukdahan	3	1	4
Mukdahan - Pakse	5	6	11
Pakse - Stung Treng	23	3	26
Stung Treng – Kratie	1	0	1
TOTAL	**60**	**24**	**100**

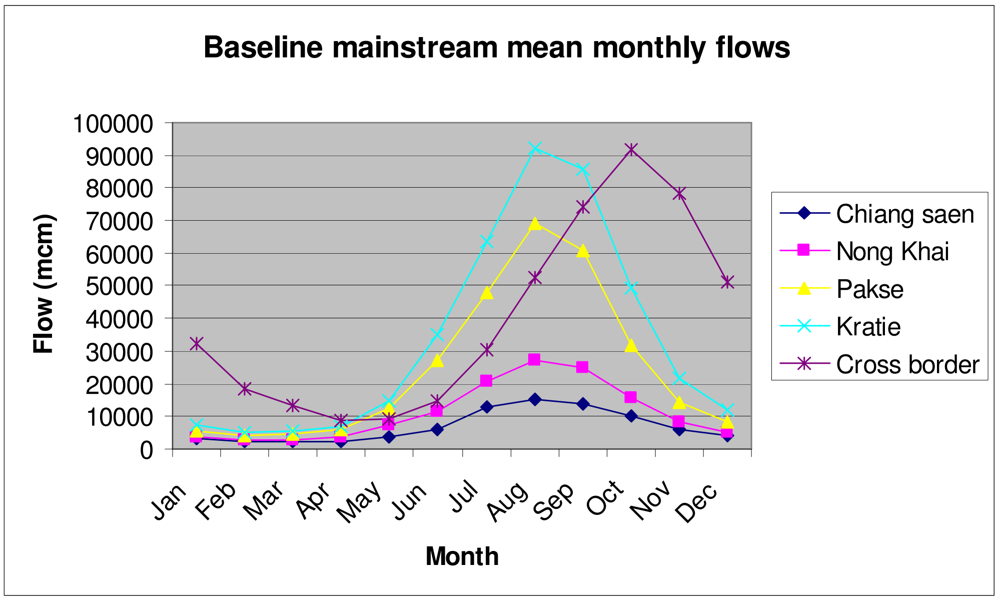

Figure 3-2. Mean monthly discharges at Mekong mainstream stations

3.2.4 Water Use

(a) Fisheries

Although not a consumptive user, fisheries are a significant water user in the Mekong Basin. There are more than 1,200 different freshwater species in the Mekong. Current estimates are that almost 2 million tonnes are harvested each year from the Lancang/Mekong fisheary and 1.5 million tonnes caught and 0.5 million tonnes from aquaculture. The annual fish catch from Ton le Sap Great Lake is estimated between 0.2-0.4 million tonnes (MRC 2003a).

(b) Irrigation

There is a considerable amount of irrigation development in the LMB with rice as the main crop under irrigation. Major wet and dry season areas exist in the Mekong delta and major wet season areas in Thailand and Cambodia (Table 3.4). Rice yields for the LMB are shown in Table 3.5.

Table 3.4. Irrigated areas in the Mekong Basin, 2000 (MRC, 2004c)

Country	Area irrigated ('000 ha)		
	Wet Season	Dry Season	Total
Cambodia	3,320	751	4,071
Lao PDR	500	483	983
Thailand	1,423	469	1,892
Vietnam	3,697	1,702	4,399
TOTAL	8,940	3,405	11,345

Table 3.5. Rice Yield, 2000 (MRC, 2003a)

Country		Yield (tonnes / ha)			
		Wet season	Dry season	3rd Season	Average
Cambodia		1.8	3.0	-	1.9
Lao PDR	***Upland***	1.5	-	-	1.5
	Lowland	3.1	4.1	-	2.9
Thailand (NE region)		1.9	3.3	-	2.0
Vietnam	***Central Highlands***	3.0	4.6	-	3.1
	Mekong Delta	2.6	5.0	3.7	4.1

3.2.5 Domestic and industrial

There is a considerable population in the LMB and associated with the population is domestic and industrial water usage. This usage, although small compared to flows in the mainstream (<0.5%) is a considerable volume of water. Table 3.6 shows the urban and industrial demands in the LMB based on year 2000 population estimates.

Table 3.6. Domestic and industrial water usage, year 2000 estimates (MRC, 2004c)

Country	Demand per person (l/day)	Annual demand (mcm)
Cambodia	32	126
Lao PDR	64	116
Thailand	115	935
Viet Nam	67	443
TOTAL		**1,620**

3.3 Hydropower

The published total potential for feasible hydropower projects in the four LMB countries is 30,000 MW(MRC, 2003a). Of this, 13,000 MW is on the Mekong's mainstream and remaining potential is on the tributaries (Lao PDR 13,000 MW, Cambodia 2,200 MW and Vietnam 2,000 MW). Only 5% of the Lower Mekong's hydro potential has been developed (Table 3.7). The year 2000 electricity consumption and peak demands are shown in Table 3.8.

Table 3.7. Existing major hydropower reservoirs of the Lower Mekong basin (MRC 2003)

Country and dam name	Total storage (mcm)	Installed capacity (MW)	Annual energy (GWh)	Date built
Laos PDR				
Nam Ngum	7,010	150	900	1971-85
Xeset		45	150	1991
Theun Hinboun	20	210	1,645	1998
Huay Ho	620	150	600	1999
Nam Leuk	185	60	184	2000
Thailand				
Sirindhorn	1,967	36	115	1968
Chulabhorn	188	15	62	1971
Ubolratana	2,263	25	75	1966
Pak Mun		136	462	1997
Dray Ling		13	70	1995
Vietnam				
Yali	1,037	720	3,642	2000
TOTAL	13,290	1,560	7,905	

Table 3.8. Country energy demand, annual growth rate and peak load (MRC, 2003a)

Country	Energy demand (GWh)	Annual growth rate (%)	Peak Load (MW)
Cambodia	381	21.7	114
Lao PDR	865	12.0	167
Thailand	96,781	7.0	14,918
Viet Nam	26,722	12.6	4,890

4 Development opportunities and impacts

4.1 Sustainable Development in the Mekong Basin

The MRC has been working for many years to prepare the necessary knowledge technical information to assist the countries meet their shared goals stated in the 1995 Agreement for sustainable development.

Mekong River is relatively unregulated compared to other major rivers in South and East Asia. Of a total average annual flow of 470,000 mcm, about 16 mcm diverted upstream of the Delta, with a further 24 million cubic metres being used for irrigation on the Delta. The diversions above the Delta are less than 4% of the total flow.

Each of the key sectors is discussed below.

4.1.1 Navigation

The MRC Navigation Strategy promotes the role of navigation in the LMB, with the view that it can attract investments and realise trade potential thereby creating better livelihoods for future generations. The Navigation Strategy recognises the unmet potential for greater operating efficiency and lower cost of navigation as part of a multi-modal transport network in the LMB. In addition to these efficiencies, there are strong equity reasons for strengthening the role of navigation, as it offers the only trade and communication lifeline for remote communities, especially during the wet season.

One of the most important water resource related issues is the influence of flow rate on navigability. The depth of water restricts the size of vessel that can pass, particularly during the dry season.

Changes in dry season flows, either increases by regulation or decreases by intra-basin diversions and irrigation extractions can be expected to influence these. Future navigation would benefit from forecasting of river levels during dry season, and possibly also consideration in the operation of hydropower dams.

There are also environmental issues that need to be addressed in developing the role of navigation, particularly the potential for pollutant spillage, and the increases in riverbank erosion.

4.1.2 Hydro power generation

All the LMB countries are forecasting increases of the order of 300% in demand for electricity by the year 2020 compared with year 2000 levels. Non-structural measures such as pricing policy and demand management can be used to minimise future demand for electricity. However, other than fossil fuels, hydropower is the only major source of energy.

There is significant potential for hydropower development in the LMB. Associated with this development will be a range of basin-wide impacts, adverse as well as beneficial. This development is already taking place, or plans significantly advanced for several significant hydropower dams in Laos and Vietnam.

In addition to this is the cascade of eight dams proposed by China in the Upper Mekong Basin. Two of the smaller dams, Manwan Dam and Dachaoshan Dam, have been completed, and construction has started on Xiaowan Dam. When completed, Xiaowan Dam will have almost twenty times more active storage capacity than the combined existing dams.

Hydropower demand and potential are unequally distributed in the LMB. Thailand has the highest demand but the lowest potential for hydropower development. This distribution has created the opportunities for export of hydropower between the countries.

Obstructions to meeting this potential include a limited regional transmission network, and difficulties getting funding. Many of these hydropower sites are not currently cost competitive with fossil fuel alternatives, and hydropower dams also take longer to produce a return on investment. The significant resistance to hydropower development by downstream stakeholders and NGOs introduces a larger risk for investors. This community resistance is based on concern for the impacts of these dams.

These dams will change in-stream conditions. Regardless of whether a dam substantially regulates flow in the river, or is a run-of-river type, the dam wall will be a physical barrier to fish migration. Also, dams that substantially regulate flow will typically decrease wet season flows and increase dry season flows.

These changes in the hydrologic regime downstream of the dam will impact other sectors. Reduced wet season flows will decrease downstream flooding, which may, amongst other impacts decrease:

- flood damage,
- addition of sediment rich nutrients to floodplains, and
- fish production.

Whereas higher dry season flows may, amongst other impacts:

- Aid navigation
- Provide access to more flow for irrigation and water supply
- Decrease salinity intrusion in the Mekong Delta
- Reduce in-stream bio-diversity through habitat change.

The development objective for the MRC is that increasing demand for affordable electric energy in the MRC member countries is met with minimal negative impacts on the environment and local people, thereby promoting economic growth for the countries mutual benefit. To do this, hydropower resources of the Mekong mainstream and its tributaries need to be developed according to true least cost planning, taking full consideration of environmental and social impacts.

4.1.3 Irrigated agriculture

Agriculture across the LMB is still the single most important economic activity, providing food and livelihoods for the majority of the population. The agricultural sector's share of the GDP reflects the country's level of industrialisation. In Thailand this is lowest, and in Laos and Cambodia this is highest. This share has decreased in recent years in all LMB countries over the last decade. However, overall agricultural production will need to be higher in the future to meet food needs for the population, as well as to provide additional income.

Issues related to water usage are discussed in an excellent review (MRC, 2003b). The review suggests that there is considerable scope to develop agriculture much further in all the LMB countries, but there are a number of issues to consider including land suitability, seasonal water availability compared with demand, farm profitability, risk and marketing.

Spatially, Thailand and Vietnam have already developed most of their irrigable land in the LMB, and use a significant part of available water resources, whereas Lao PDR and Cambodia have significantly more land available for development, and use only a small percentage of available water.

Irrigation for most of the LMB is either supplied by diverting water directly from natural water bodies, but run of river dams, and releases from dual purpose dams. Thailand is the exception with several large and many small irrigation dams in the North-East region. There are not known to be any proposals to develop large dams in the LMB solely for irrigation.

Water usage compared with availability is also unequally distributed across the year. During the wet season the availability is far in excess of the demand, whereas in the dry season water availability is a constraint, mainly in the Mun and Chi Basins in Thailand, the Central Highlands region of Vietnam, and the Mekong Delta.

River salinity in the Mekong Delta is related to the balance of water flowing into the Delta, water diverted within the Delta, and tide. Tidal water from the South China Sea mixes with the branches of the river branches and canals, increasing the salinity. Crop yields start to decline if the salinity of irrigation water exceeds certain levels for certain periods, e.g., 1 g/l for 4 weeks; 2 g/l for 2 weeks; or 4 g/l for 1 week. This condition happens during the dry season, and affects a greater area depending on the relative magnitude of the upstream flows to the tidal amplitude.

There are a number of constraints as well as opportunities to further develop the agricultural sector. Constraints include water usage, land suitability, labour availability, profitability, risk and marketability. Rice is the predominant crop in the

LMB, and is likely to remain so for a number of reasons, including: tradition, subsistence, land suitability, risk, ease of storage and marketability.

There is also an issue with the low availability of water compared with demand during the dry season. Possible solutions to this issue includes: selecting crops with lower water usage during critical periods, and improving the delivery efficiency of irrigation schemes, which tends to be quite low in the LMB.

The opportunities are that land and water is generally underutilised compared with their availability. However, the underlying reasons this is not already happening need to be addressed. Some of these issues will require some level of government intervention.

One key recommendation is that there crop water usage needs to be better estimated in the LMB. Estimates are based on standard methods, e.g., FAO (1998) with significant uncertainties on most of the factors that contribute to the estimate, e.g., crop types, crop areas, crop distributions, irrigation efficiencies, etc. Short term studies are needed to more accurately estimate water usage for representative farm types.

4.1.4 Fish production

Fish production is an enormously important sector for the economy of all the LMB countries, and is the principal form of income and animal protein for a large part of the population.

This level of production is at some risk from a range of factors, including unsustainable patterns of exploitation, population pressure, severe poverty, environmental degradation, poor management and inadequate enforcement of existing laws, allowing illegal and damaging practices to continue.

Maintaining the productivity of capture fisheries and aquaculture is crucial to the livelihood of a large part of the population of the LMB.

Development in this sector needs to be in the management of fisheries, including decentralising management to local communities, and eliminating destructive fishing practices. Capacity in management and governance also needs to be strengthened to link monitoring with management, and for enforcement of regulations.

Further development in this sector will also take place with aquaculture, both integrated with agricultural mixed farming, as well as more extensive and intensive production in in-land water bodies and the brackish reaches of the Mekong Delta.

4.1.5 Domestic and Industrial water supply

Supply of water for domestic and industrial demands is characteristic of urban centres in the LMB. Some regions already experience water shortages in the dry season. Increasing populations and urbanisation trends are going to result in increasing domestic and industrial demands. This use of water has a high value, and will require substantial investment in infrastructure to meet these demands, particularly in the regions with water shortages.

5 Development scenarios evaluated

A range of development scenarios have been selected to provide a perspective on development opportunities and their impacts. The inclusion of a project within the development scenario does not imply any endorsement from either the country or the MRCS. The panel is confident, however, that the range of scenarios tested is sufficient to illustrate the range of likely impacts for the next twenty years.

All scenarios reflect the impact of some dams that are planned to be developed in China. China is not a party to the 1995 Agreement, and we have accepted for the purpose of these scenarios that some of these dams will be in place. The two run of river dams already built have negligible impact on flow redistribution. The two largest dams proposed are likely to cause the most significant seasonal redistribution of flow of any the development scenarios evaluated.

The scenarios chose were principally about developing the hydropower sector and irrigation. The levels of development in each sector are shown graphically in Figure 2-1, summarised in Table 5.1 and described in the following sections.

We have not included particular scenarios that have incorporated land use change because capability, data impact Appendix D contains material on climate change. There is not sufficient information available within the MRC to realistically include climate change within the scenarios tested.

Figure 5-1. Levels of development in scenarios

5.1 Baseline Condition

A summary of the key model parameters for the Baseline scenario are shown in Table 5.1.

Table 5.1. Baseline scenario

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	**1,620**	**7,422**	**6,185**	**-**	**0**	**0**	**0**
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

5.1.1 Purpose of Scenario

A baseline is a reference state to compare other values against; e.g., mean sea level as a reference state for relative height of land surface. In the context of basin wide natural resource management, a baseline development condition is a reference state of the physical and management characteristics of the basin at a point in time. Examples of this include land use, irrigation areas, dams and their operational characteristics, and embankments.

A baseline condition can be specified in the hydrologic and hydraulic simulation models. A reference climatic data set is applied as input to these simulation models to produce a reference set of water related time series results. These results include flow and/or water height, irrigation diversions, hydropower generated, and salinity levels in the Mekong Delta. These and other results are used to calculate the indicators reported in Chapter 6.

The different development conditions in Sections 5.1-5.6 can also be specified in the simulation models. The same reference climate data set will produce a different set of results, and different indicators. By comparing these indicators against the baseline, the changes caused by the different scenarios can be compared. e.g., Scenario X increased Indicator A by 12%, whereas Scenario Y increased it by 15%, and Scenario Z decreased it by 4%.

5.1.2 Scenario Definition

A scenario is defined by a combination of physical and management characteristics. Physical characteristics include:

- Climate
- Land use
- Domestic and industrial demand;
- Irrigated crop type, area, and delivery infrastructure;
- Storage characteristics (location, size, shape and outlet structures).
- Hydraulic conveyance and flood storage

Management characteristics can include:

- Operating rule curves for storages.
- Operating rules for salinity barriers.
- Water allocation policies

Note water management characteristics are not varied for any of the scenarios, and will only be reported for the Baseline Development Condition.

(a) Climate

A benchmark climate period of 01/01/1985-31/12/2000 has been used for all scenarios. The reasons for selecting this period were discussed in Section 2.4. This data set includes rainfall, solar radiation, temperature, humidity, and wind speed. The rainfall data is used directly, whereas the other climate data is used to estimate Potential Evapotranspiration (PET) by the Penman-Monteith method. The climate data sets were derived from historical observations, and filled in time and space as described in MRC (2004).

(b) Land use

Land use is a physical characteristic that is defined in the SWAT rainfall runoff models. Specified changes in land use will results in a different runoff response from one or more of the 130 SWAT models used for the LMB. The changes in runoff would then replace the inflows in either or both of the IQQM and iSIS simulation models. The baseline land use is that used to calibrate the models as reported in Tables 33 and 34 of MRC (2004c).

(c) Domestic and Industrial demands

Water diverted to meet domestic and industrial demands was estimated as the product of population and per capita water demand. The per capita water demands reflect different levels of access of the population to clean water.

The total population in the LMB of the four member countries is 56.4 million people. The estimated total domestic and industrial water usage of 1,620 million cubic metres (mcm) is less than 0.4% of the average annual flow in the Mekong. Nevertheless, there are shortages in parts of the basin during the dry season.

Table 5.2. Baseline development condition Domestic and Industrial demands

Country	Population in basin (millions)	Demand per capita (litres/day)	Annual demand (mcm)
Thailand	22.3	115	935
Laos	5.0	64	116
Viet Nam	18.2	67	443
Cambodia	10.9	32	126

(d) Irrigation

Irrigation demands were estimated using climate and spatially distributed information on:

- Crop types;
- Crop areas;
- Irrigation efficiency and return flows.

Crop areas, types and distribution were estimated using the country's official statistics and ancillary information as reported in MRC (2004a). Irrigation efficiency is the ratio of the water the crop needs, to the volume that has to be taken out of the river to meet these needs. The 'inefficiency' is a measure of the amount of water that is lost along the way. An efficiency of 0.50 means that only half the water taken from a river is applied to the crop. Some of this water may find its way back to the river system. This volume returning is estimated as a ratio of the volume of water diverted.

Crop types, areas, efficiencies, and return flow ratios for the baseline models are reported for the LMB in Table 5.3.

Table 5.3. Baseline development, irrigated crops upstream of Kratie

Crop type	Efficiency	Return	Area ('000 ha)
Cambodia			
Wet season rice (Early season)	0.6	0.3	404
Wet season rice (Mid season)	0.6	0.3	704
Dry season rice	0.6	0.3	250
Laos			
Wet season rice	0.5	0.3	166
Dry season rice	0.5	0.1	127
Vegetables	0.5	0.1	37
Thailand			
Wet season rice	0.3-0.5	0.3	1,217
Dry season rice	0.5	0.2	156
Maize	0.5	0.2	15
Mung Beans	0.5	0.2	2
Soybean	0.5	0.2	7
Groundnut	0.5	0.2-0.3	9
Kenaf	0.5	0.2	16
Vietnam			
Wet season rice (Summer-Autumn)	0.5-0.8	0.0-0.3	1876
Wet season rice (Winter)	0.5-0.8	0.0-0.3	667
Wet season rice (Autumn Winter)	0.8	0.0	210
Dry season rice (Winter-Spring)	0.5-0.8	0.0-0.3	1559

(e) Hydropower

Key physical characteristics

The modelled hydropower dams in the baseline development scenario are listed in Table 5.4. No dams in China were modelled in the baseline development scenario. Although Manwan Dam was operating as early as 1993, analysis has shown it has only a small regulation capacity, and thus a negligible effect on flows entering the Lower Mekong Basin. No dams from the Thai part of the LMB were modelled as no information was made provided during the model development phase.

Installed capacity and active storage are reported for each dam in Table 5.4, and for subsequent scenarios. These are important for economic and hydrologic reasons. The installed capacity is a measure of how much power the dam can generate as a maximum, and can be used to estimate maximum release rate if the dam's operating head is known. Active storage is a measure of the dam's regulating capacity, and is a better indicator of hydrologic impact. Some of the hydropower projects are 'run-of-river' types, with a low active storage capacity. Because of this they have low regulating capacity, and low potential to change downstream flows.

Table 5.4. Baseline conditions modelled storages

Storage name	Installed capacity (MW)	Active Storage (mcm)
Laos		
Nam Ngum 1	150	4,714
Nam Leuk	60	154
Nam Song	-	11
Nam Theun-Hin Boun	210	0.02
Houay Ho	150	527
Vietnam		
Ya Li	720	779

Operating characteristics

Operating characteristics, that is decisions on how much water to release, were derived either from observed storage release data, or in the case of Ya Li Dam, from operational rule curves. Both sources showed similar patterns, characterised by:

- Release at maximum rates in the wet season, decreasing to a minimum rate in the dry season.
- Releases rates for any season decreasing as the storage level decreases.
- The storages fill during the wet season, and draw down during the dry season.

The first observation is consistent with the operators generating the maximum amount of power, rather than the water spilling. The second observation is the need to conserve water to be able to generate a minimum amount of power at the end of the dry season. The third observation is important shows that the hydropower dams store wet season flows and release during the dry season, thereby decreasing wet season flows and increasing dry season flows.

These release patterns determined by the first two observations are confirmed by official Ya Li Dam release curves. These are used to guide the derivation of operating characteristics for other hydropower dams.

(f) Hydraulic Conveyance and Storage

Hydraulic conditions in the area downstream of Kratie are as described in MRC (2004g).

5.2 China Dams

A summary of the key model parameters for the China dams scenario are shown in Table 5.5.

Table 5.5. China dams scenario

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	**1,620**	**7,422**	**6,185**	**22,700**	**0**	**0**	**0**
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

5.2.1 Purpose of scenario

A series of eight hydropower dams proposed for the Lancang part of the Mekong River in Yunnan Province in China is described in Plinston and Daming (2000). The dams, their installed capacity, and active storage volumes are listed in Table 5.6. Of these eight, Manwan Dam and Dachaoshan Dam are currently operating, and construction of Xiaowan Dam and Jinghong Dams has started. The construction of the other five, to our knowledge, has not yet begun.

Table 5.6. Characteristics of the hydropower cascade - Lancang River[i]

Dam name	Installed capacity (MW)	Active storage volume (mcm)
Gonguoqiao	750	120
Xiaowan	4,200	9,800
Manwan	1,500	258
Dachaoshan	1,350	240
Nuozhadu	5,500	12,400
Jinghong	1,500	230
Ganlanba	250	-
Mengsong	600	-

The two existing storages each have a regulating capacity equal to about one week's flow volume during the dry season, and effectively operate as run-of-river storages. Seasonal flow changes downstream of the Chinese border from the Manwan and Dachaoshan are negligible. Of the still to be constructed storages, only Xiaowan and Nuozhadu could significantly regulate flows in the LMB.

The decision to construct these storages is outside the scope of the Mekong River Agreement, as China is not a full MRC member. Given China's energy needs, it is reasonable to assume that these storages will be built, and that flows at the border of China will change significantly. The magnitude of the relative changes progressively reduces downstream as more tributaries contribute water to the Mekong. For example, Adamson (2000) estimates a 20-50% increase in dry season flow, and a 5% decrease in wet season flow at Kratie.

The changes to these flows will potentially effect development decisions in the LMB. More water will be available in the Mekong River for in-stream and consumptive uses, and will have ecological impacts. The increased flow, should it make it to the Mekong Delta after consumptive uses, will decrease intrusion of seawater in the Mekong Delta. The reduction in wet season flows will reduce the level of flooding along the whole length of the Mekong.

The purpose of this scenario is to isolate the impact of these dams on water related indicators. This change is modelled in this scenario by considering the two storages currently operating, and the two largest storages.

5.2.2 Scenario definition

The Lower Mekong Basin model was extended upstream into China, and the inflow at the China border was disaggregated to inflows at the location of all dams

[i] Adapted from Plinston and Daming (2000)

based on information in Plinston and Daming (1999). This scenario definition is identical to the Baseline except that the four dams and their associated operating rules were added.

Key physical characteristics

Table 5.7. Dams added to Baseline model for China Dams scenario

Storage name	Installed capacity (MW)	Active Storage (mcm)
China		
Xiaowan	4,200	9,800
Manwan	1,500	258
Dachaoshan	1,350	240
Nuozhadu	5,500	12,400

Operational characteristics

Rules for releasing water for hydropower generation were developed using information in Plinston and Daming (2000), and using the following criteria:

(i) Maintain firm power 100% of time, and

(ii) Maximise hydropower produced.

This resulted in similar release patterns to those observed in the hydropower storages in the LMB dams.

5.3 Low development

A summary of the key model parameters for the Low development scenario are shown in Table 5.8.

Table 5.8. Low development scenario

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	**3,109**	**8,316**	**12,443**	**10,300**	**0**	**0**	**0**
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

5.3.1 *Purpose of scenario*

A level of development assuming that at the very least, current levels of agricultural production will be maintained is proposed. Some increase in development in the other water usage sectors is also proposed in line with what is likely to happen to meet population growth.

Population is assumed to increase at a rate similar to current population growth rates. Programs are already in place by the four countries to increase access to safe water, so there will also be an increase in per capita demand. Domestic and Industrial uses will then increase. Agricultural production will also need to increase to feed the additional population. Some hydropower dams are also very likely to be built.

The purpose of this scenario is to assess the impacts of a moderate level of development, necessary to maintain current per capita agricultural production and power usage. A moderate increase in water usage, as well as some of the most currently feasible hydropower projects has been included.

5.3.2 Scenario definition

(a) Domestic and industrial demands

Population growth in the LMB varies by country, as described in Table 3.2. The resultant populations in the countries in the basin are reported in Table 5.9. The per capita water demand was increased based in part on information presented in MRC (2003a). This takes into consideration assumptions about improved access of the population to safe water, and assumptions on increase in water usage with increasing urbanisation.

The resultant total population in the LMB for the four MRC member countries is 73.4 million people, an increase of about 30% on the 2000 population. The total estimated domestic and industrial water demand increases to 3,108 mcm, slightly under double the estimated demand in 2000.

Table 5.9. Low development condition domestic and industrial demands

Country	Population in basin (millions)	Demand per capita (litres/day)	Annual demand (mcm)
Thailand	28.2	150	1,545
Laos	7.6	110	305
Viet Nam	21.1	111	855
Cambodia	16.5	67	404

(b) Irrigation demands

Projections and firm plans for agricultural changes by 2020 are not widely available, and have different qualities and detail of information for the four countries. The irrigation areas decided for the Low Development Scenario were based on maintaining the current per capita food production from irrigated crops. Where evidence is available, this has been adjusted for other known factors such as possible increases in yield, and constraints on water and land availability.

Laos

Production from irrigated crop needs to increase by 50% to match the per capita contribution from this source for the increased population. Published information for Laos show that the irrigated crops already have high yields, therefore no contribution from yield improvement is assumed. All additional production will come from additional areas developed for irrigation. Most of the irrigated agriculture in Laos is either around the main population centre in Vientiane, or in the Southern and Central provinces. A 50% increase in irrigated areas is assumed.

Thailand

Population is estimated to increase by 25% in the Thai part of the LMB (Table 3.2). It is not reasonable to assume that irrigated areas could increase by this substantial amount as this region is already reportedly short of water. Any area increases would need to be justified by increased water availability, and further production increases by improved yields.

There is some scope to increase wet season irrigation in the Mun and Chi Rivers by developing additional small to medium storages, and to otherwise increase water availability by improving irrigation efficiency. The likely development of hydropower dams in China and the Nam Ngum basin in Laos modelled in this scenario will increase dry season flows in the Mekong. This additional flow could be accessed by pumping from the provinces in Thailand that border the Mekong.

Wet Season irrigation areas will be increased by 150,000 ha in the Mun and Chi Basins, 30,000 ha in Northern Thailand, and 44,000 ha in North-East Thailand, along with a 10% improvement in irrigation efficiency. Dry season irrigation areas in Northern Thailand and along the Mekong River in North-East Thailand will be increased by 100% to take advantage of additional dry season flow in the Mekong River. These area increases alone will not maintain this sector's per contribution to food production. Increases in yield will also be necessary.

Cambodia

Population in Cambodia is estimated to increase by 50% by 2020 (Table 3.2). There are programs in place to improve yields from crops, which are low by regional standards. These are assumed to increase average productivity by 10%. An increase in irrigated areas of 37% is therefore needed to maintain the contribution of irrigated agriculture to food production.

Wet season rice areas are widely distributed across all provinces in Cambodia, whereas Dry Season rice is concentrated in the southern provinces of Cambodia, along the Mekong River. Increases in dry season rice can also access the additional dry season flow coming from the Chinese hydropower dams.

Vietnam

Population is estimated to increase by 16% in the parts of Vietnam in the LMB by 2020. The area of irrigated land is increased in the for the Central Highlands region to maintain the contribution of this sector to food production. No changes were made to cropping in the Mekong Delta region.

Table 5.10. Low development conditions irrigated crops

Crop type	Efficiency	Return	Area ('000 ha)
Cambodia			
Wet season rice (Early season)	0.6	0.3	579
Wet season rice (Mid season)	0.6	0.3	984
Dry season rice	0.6	0.3	350
Laos			
Wet season rice	0.5	0.3	250
Dry season rice	0.5	0.1	191
Vegetables	0.5	0.1	54
Thailand			
Wet season rice	0.55	0.3	1,423
Dry season rice	0.55	0.2	188
Maize	0.55	0.2	18
Mung Beans	0.55	0.2	2
Soybean	0.55	0.2	9
Groundnut	0.55	0.2	10
Kenaf	0.55	0.2	18
Vietnam			
Wet season rice (Summer-Autumn)	0.5-0.8	0.0-0.3	1877
Wet season rice (Winter)	0.5-0.8	0.0-0.3	687
Wet season rice (Autumn-Winter)	0.8	0.0	210
Dry season rice (Winter-Spring)	0.5-0.8	0.0-0.3	1566

(c) Hydropower

Key physical characteristics

Many sites have been proposed for building hydropower dams in the LMB (i.e., downstream of China). These proposed dams range in size from 12 MW to 1080 MW installed capacity, with a similar range in storage from around 100 mcm to 3,500 mcm.

Of these, only a few of the most economically feasible at this stage have been selected for inclusion in the Low Development Scenario. This development scenario also includes the six modelled storages in the Baseline Conditions model, one of the two large Chinese dams, and the two smaller dams in China that have been constructed. The hydropower dams modelled in addition to the baseline is reported in Table 5.11.

Table 5.11. Additional hydropower dams modelled in the Low Development scenario

Storage name	Installed capacity (MW)	Active Storage (mcm)
China		
Xiaowan	4,200	9,800
Manwan	1,500	258
Dachaoshan	1,350	240
Laos		
Nam Theun 2	1,088	2,970
Nam Ngum 2	615	1,113
Nam Ngum 3	444	983
Nam Ngiep 1	255	1,192
Vietnam		
Plei Krong	100	948
Se San 3	273	162

Operational characteristics

Similar principles were applied to developing operational rule curves as was the case for the Chinese Dams scenario. The operational rules for the existing Nam Ngum were modified as the inflows are regulated in part by Nam Ngum 2 and Nam Ngum 3.

5.4 Embankments

A summary of the key model parameters for the Embankments scenario are shown in Table 5.12.

Table 5.12. Embankments scenario

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	**3,109**	**8,316**	**12,443**	**10,300**	**130**	**0**	**0**
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

5.4.1 Purpose of scenario

To understand the impact of protecting approximately 130,000 ha of agricultural land between Kampong Cham and Phnom Penh on:

- changes in flood behaviour;
- changes in flows to Great Lake, and
- Fish production.

5.4.2 Scenario definition

A level of flood protection was included for 130,000 ha of agricultural land between Kampong Chan and Phnom Penh in the iSIS model. All other water resources development characteristics were exactly the same as in Scenario 3.

5.5 Agricultural development

A summary of the key model parameters for the Agriculture development scenario are shown in Table 5.13.

Table 5.13 Agriculture scenario summary

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	**4,194**	**11,349**	**12,443**	**10,300**	**0**	**2,200**	**3,262**
High Development	4,194	11,349	26,778	22,700	0	2,200	3,262

5.5.1 *Purpose of scenario*

This scenario is designed to assess the impact of large scale water diversion for irrigation without compensating releases from hydropower dams. This will test limits to water availability in different countries, as well as impacts on dry season flows and water levels, and salinity intrusion in the Mekong Delta.

5.5.2 *Scenario definition*

(a) Domestic and industrial demands

Population growth was assumed the same as the lower development scenario. Per capita demands were increased for Thailand more in line with developed countries. Per capita demands for the other countries were increased to Thailand levels for the Lower Level of development, assuming 100% access to water. The demands are reported in Table 5.14 for the LMB. The total water demand for the LMB is 4061 mcm, about two and a half times the baseline condition demand, or slightly less than 0.9 % of the total Mekong Flow

Table 5.14. Agriculture development condition domestic and industrial demands

Country	Population in basin (millions)	Demand per capita (litres/day)	Annual demand (mcm)
Thailand	28.2	170	1,750
Laos	7.6	140	388
Viet Nam	2.5	140	1,079
Cambodia	16.5	140	977

(b) Irrigation demands

The countries would be seeking to irrigate as much agricultural land as is possible under the High Development strategy. A robust estimate of this depends in part on land suitability, but also other factors, such as water availability, access to markets, and investment climate and priorities. This development scenario assumes that the additional flow in the Mekong River from regulation by hydropower dams can be used to irrigate dry season crops, and that intra-basin diversions are possible into the Mun-Chi Basins to alleviate dry season water shortages.

Laos

The National Sector Review indicated that as much as 400,000 ha of land can be irrigated in the dry season, and 800,000 ha wet season. This is approximately a 200% increase on baseline levels of irrigation. This was distributed in proportion to current irrigation areas.

Thailand

Historical proposals to divert water from the Mekong River near Nong Khai would create an opportunity to increase dry season irrigation in Thailand. Additional water in the Mekong River from the construction of the Chinese Dams would create an opportunity to irrigate dry season irrigation in the Thai provinces along the Mekong.

This scenario assumes the additional 224,000 ha of wet season irrigation with increased efficiencies, as in the low development scenario. Increased dry season irrigation areas along the Mekong are assumed to be similar to that in Laos of approximately 200%. The intra-basin diversions of 250 m^3/s in the dry season will be used to irrigate an additional 200,000 ha in the Mun and Chi Basins.

Cambodia

Only a small portion of the suitable land is irrigated in Cambodia, so land availability is not constrained to development in Cambodia. A similar increase of 200% is proposed for irrigation in Cambodia as for the upstream countries.

Vietnam

Projections for increases in water demands in the Central Highland are based on a 50% increase in irrigated areas, assumed for this Agriculture development scenario.

Land in the Mekong Delta is already highly developed. However, changes in crop mix in line with land suitability are proposed. The exact nature of this is reasonably complex, and would need special attention. This is not attempted in this scenario.

Table 5.15. Agriculture development conditions irrigated crops

Crop type	Efficiency	Return	Area ('000 ha)
Cambodia			
Wet season rice (Early season)	0.6	0.3	1212
Wet season rice (Mid season)	0.6	0.3	2111
Dry season rice	0.6	0.3	751
Laos			
Wet season rice	0.5	0.3	500
Dry season rice	0.5	0.1	382
Vegetables	0.5	0.1	101
Thailand			
Wet season rice	0.55	0.3	1,423
Dry season rice	0.55	0.2	412
Maize	0.55	0.2	18
Mung Beans	0.55	0.2	2
Soybean	0.55	0.2	9
Groundnut	0.55	0.2	10
Kenaf	0.55	0.2	18
Vietnam			
Wet season rice (Summer-Autumn)	0.5-0.8	0.0-0.3	1879
Wet season rice (Autumn-Winter)	0.5-0.8	0.0-0.3	730
Wet season rice (Autumn Winter)	0.8	0.0	210
Dry season rice (Winter-Spring)	0.5-0.8	0.0-0.3	1581

Table 5.16. Agriculture conditions irrigation for downstream of Kratie

Crop type	Efficiency	Return	Area (ha)
Cambodia			
Wet season rice (Early season)	0.6	0.3	1,164
Wet season rice (Mid season)	0.6	0.3	2,072
Dry season rice	0.6	0.3	738

(c) Inter-basin and Intra-basin diversions

Inter

Divert 140 m^3/s from the Kok River upstream of the confluence with the Mekong River during the months of June-November out of the LMB.

Intra

Divert 250 m^3/s from the Mekong River near Nong Khai during the months of December-April into the Chi and Mun basins.

5.6 High development

A summary of the key model parameters for the High level development scenario are shown in Table 5.13.

Table 5.17. High development scenario

Scenario	Domestic and Industrial usage (mcm)	Irrigated areas ('000 ha)	Hydropower Dams active storage volume (mcm)		Embankment area ('000 ha)	Basin diversions (mcm)	
			LMB	China		Intra	Inter
Baseline	1,620	7,422	6,185	-	0	0	0
China dams	1,620	7,422	6,185	22,700	0	0	0
Low development	3,109	8,316	12,443	10,300	0	0	0
Embankments	3,109	8,316	12,443	10,300	130	0	0
Agriculture	4,194	11,349	12,443	10,300	0	2,200	3,262
High Development	**4,194**	**11,349**	**26,778**	**22,700**	**0**	**2,200**	**3,262**

5.6.1 *Purpose of scenario*

This scenario represents the highest likely level of development by 2020. It includes the maximum likely hydropower and water use development. This is used to look at high level of impact of development on the basin.

5.6.2 *Scenario definition*

(a) Hydropower

The hydropower dams in this scenario include all of the dams in the China dams scenario, all the dams in the Low Development scenario, and additional dams in Laos, Vietnam, and Cambodia. The Lower Se San 2, Lower Sre Pok 2 and Sambor dams have surface areas exceeding 2000 km^2. This large surface area has a substantial evaporative loss of 150-200 m^3/s in the dry season.

Sambor, Lower Sre Pok and Lower Se San have been included because Cambodia has proposed these dams in recent times. However, their development would be subject to resolving complex issues, including their impacts on fish migration, navigation, resettlement, and large evaporative loss in the dry season.

Table 5.18. Additional hydropower dams modelled in High Development Scenario.

Storage name	Installed capacity (MW)	Active Storage (mcm)
China		
Xiaowan	4,200	9,800
Manwan	1,500	258
Dachaoshan	1,350	240
Nuozhadu	5,500	12,400
Laos		
Nam Theun 2	1,088	2,970
Nam Ngum 2	615	1,113
Nam Ngum 3	444	983
Nam Ngiep 1	255	1,192
Xe Kaman 1	310	3,350
Se Kong 4	290	3,150
Nam Theun 1	240	1,050
Nam Ou 2	575	4,200
Nam Tha 1	260	3,700
Vietnam		
Plei Krong	100	948
Se San 3	273	162
Se San 4	330	470
Cambodia		
Sambor	875	2050
Low Se San 2	207	1440
Lower Se Pok 2	222	

5.6.3 Operational characteristics

Operational characteristics for the dams in Laos and Vietnam were estimated using the same criteria described. The three dams in Cambodia operate as run of river dams, and the operating rules were derived differently.

The criteria for these operating rules was to maintain the water level at or near the maximum so as to maintain operating head for generating power. During times of high inflows this is not an issue as the water can be released through the turbines at the maximum rate. During periods of high flows the turbines should only release the maximum inflow, but reduced to allow for net evaporative losses from the water surface. Evaporation from the large surface areas of these storages during the dry season is in the range 70-100 m^3/s.

(a) Inter-basin and Intra-basin Diversions

Same as Agricultural Development Conditions scenario.

6 Indicators

A range of indicators have been selected to show the impacts of flow and salinity changes at key locations throughout the LMB. The indicators can be grouped into five broad categories:

- Mainstream flow indicators;
- Great Lake and floodplain indicators;
- Delta Indicators;
- Irrigation production;
- Hydropower generated.

The mainstream flow indicators have been selected to look at changes in flow and how this relates to Article 6 of the Mekong River agreement. These indicators are also used to investigate changes in duration of low flow that can be used to assess impacts on navigation.

The Great Lake and floodplain indicators have been used to look at changes in lake area and durations of inundation. This has a dual purpose for indicating flooding impacts as well as impacts on fish production. Changes in fish yields may be estimated by factoring changes in areas by fish production rates.

The delta indicators are concerned with salinity intrusion. The indicators show three classes of salinity durations. This can be used to assess the impacts of changes in salinity intrusion on rice production.

The irrigation production provides results on irrigated areas. This in combination with yield estimates can be used to assess food production. The irrigated areas take into consideration water access constraints and the areas represent the amount of area that could be grown with the water that is available.

Hydropower generated is the average annual total power produced over the 16 year modelling period at each hydropower station.

6.1 Mean monthly dry season flow

The mean monthly flow indicator is used to assess the impacts in changes in development as they might relate to Article 6A of the 1995 Mekong River Agreement. Article 6A states that the MRC members agree:

"To cooperate in the maintenance of the flows on the mainstream….

A. Of not less than the acceptable minimum monthly natural flow during each month of the dry season"

The acceptable minimum monthly natural flow:

"***Acceptable minimum monthly natural flow:*** *The acceptable minimum monthly natural flow during each month of the dry season.*"

It is understood that the intent of this clause and definition is that the member states agree to cooperate in maintaining the acceptable minimum monthly natural flow in a manner that is socially, environmentally and economically acceptable to all member states. It has also been agreed that the minimum months are from December to May. Deciding what is an acceptable minimum monthly flow is currently happening as part of WUP.

This indicator does not include information of the significance of change compared to the natural monthly variability of the system. The impact of this change on irrigation reliability, salinity intrusion, and navigation is discussed in Section 6.6, 6.7, and 6.9 respectively. Other potential impacts have not been evaluated.

The indicators are shown at four main stream locations; Nong Khai, Pakse, Kratie and trans-boundary flows to the Mekong Delta. These four locations were selected to represent key locations in the mainstream. The mean monthly flows for each of the low flow months at the four locations are shown in Figure 6-1 to Figure 6-4 for Nong Khai, Pakse, Kratie and cross-border respectively.

Note the period used to calculated mean monthly flows is different for the upstream of Kratie compared with downstream. This is because the iSIS model uses a shorter modelling period.

- Mean monthly flows at Nong Khai, Pakse and Kratie are calculated for the period 1986-2000 from IQQM results of simulated flow.
- Mean monthly flows crossing the Vietnamese border to the Mekong Delta are calculated for the period 1996-2000 from iSIS results of simulated flows.

6.1.1 Characteristics of changes in mean monthly dry season flows

(a) Nong Khai

- Mean monthly flows during dry season are higher for all scenarios compared with the baseline. These increases are all directly a result of regulation by large upstream storages in China, as well as on the Nam Ou and Nam Tha tributaries for the High Development Scenario.
- The increases are up to 700-800 m^3/s for the Chinese Dams Scenario and the High Development Scenario, and between 250-300 m^3/s for the other scenarios. This is on top of a flow rate of 1100-1500 m^3/s for the Baseline Scenario. The magnitude of the changes reduces by the end of the Dry Season in May.
- Irrigation removes about 40-50 m^3/s of the regulated flow for the Agriculture Scenario. The level of irrigation development upstream of Nong Khai is not as high as in other parts of the LMB.

(b) Pakse

- Mean monthly flows during dry season are higher for all scenarios during the core dry season months of January-April. The relative significance of these is less than at Nong Khai because the flow rate is 50-65% higher for the Baseline Scenario.
- The pattern and absolute magnitude of flow increases for the Chinese Dams Scenario does not vary significantly from the changes simulated at Nong Khai.
- The pattern and absolute magnitude of flow increases for the Low Development Scenario is greater than simulated at Nong Khai, because of the additional hydropower storages simulated on Laos tributaries downstream of Nong Khai.
- Mean monthly flows are lower during December for the Agriculture Scenario, because the large increases in irrigation, including the intra-basin diversion, is removing large volumes of water during these months
- Mean monthly flows decrease during May for the High Development Scenario. Reasons for this include the increases in irrigation and intra-basin diversion, as well as the reduced releases from hydropower storages towards the end of the dry season as they draw down to critical levels.

(c) Kratie

- The pattern and magnitude of changes is very similar to that of Pakse for the Chinese Dams Scenario and the Low Development Scenario. The relative significance of these is less than at Pakse because the flow rate is 15-40% higher for the Baseline Scenario. These increases in Baseline Scenario flow come mostly from the Se Kong, Se San, and Sre Pok tributaries.
- Mean monthly flows are significantly lower during December for the Agriculture Scenario, for the same reasons described for Pakse, and significant increases in irrigation areas along the Se Kong and Se San tributaries.
- Mean monthly flows decrease during May for the High Development Scenario, for the same reasons as described for Pakse, as well as increases in irrigation areas along the Se Kong and Se San tributaries, and reduced releases towards the end of the dry season from the additional hydropower dams in the Se Kong and Se San tributaries

(d) Cross-border flows to Mekong Delta

- The pattern and magnitude of changes is very similar to the upstream changes for the Chinese Dams Scenario and the Low Development Scenario. A notable characteristic of the mean monthly dry season flows is the influence of the reverse flow from the Great Lake augmenting the flow from Kratie during the early part of the dry season.
- Mean monthly flows increase by about 400-600 m^3/s during the dry season months of February to April for the Chinese Dams Scenario and High Development Scenario, and 100-200 m^3/s for the Low Development Scenario.
- Flow decreases by about 200-300 m^3/s for these months for the Agriculture Scenario. As well as the reasons described for the upstream stations, this increase is in part because of significant increases in irrigated areas modelled in Cambodia downstream of Kratie.

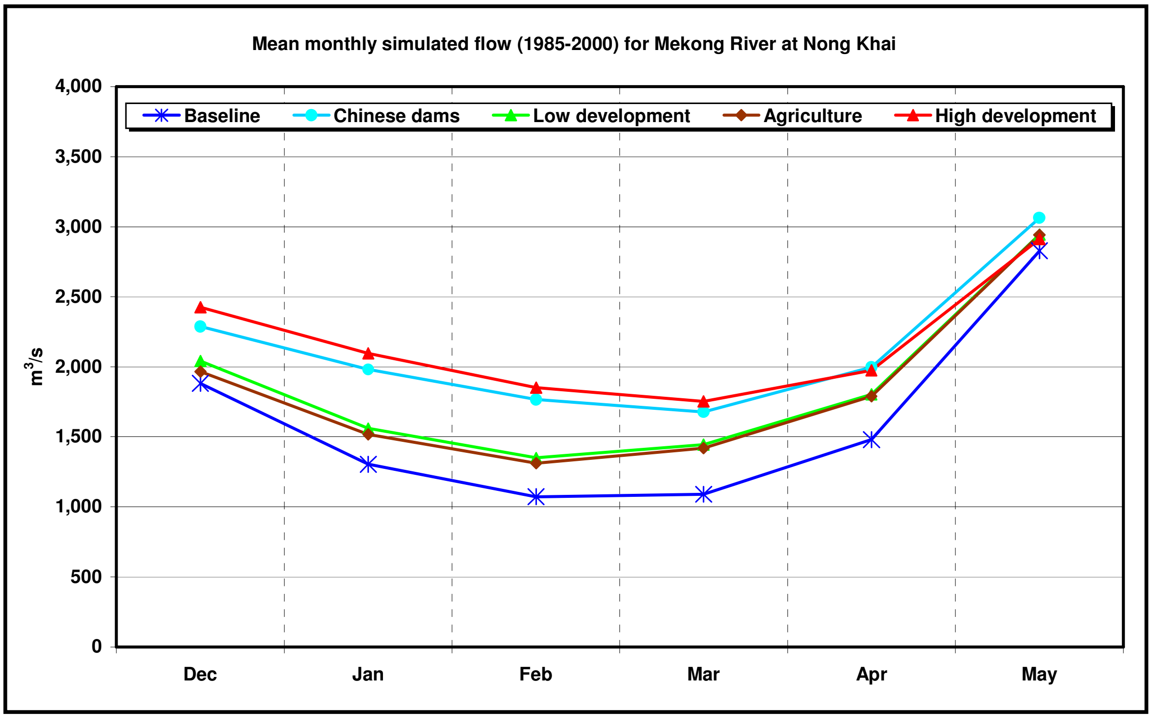

Figure 6-1. Mean monthly simulated flows at Nong Khai (1986-2000)

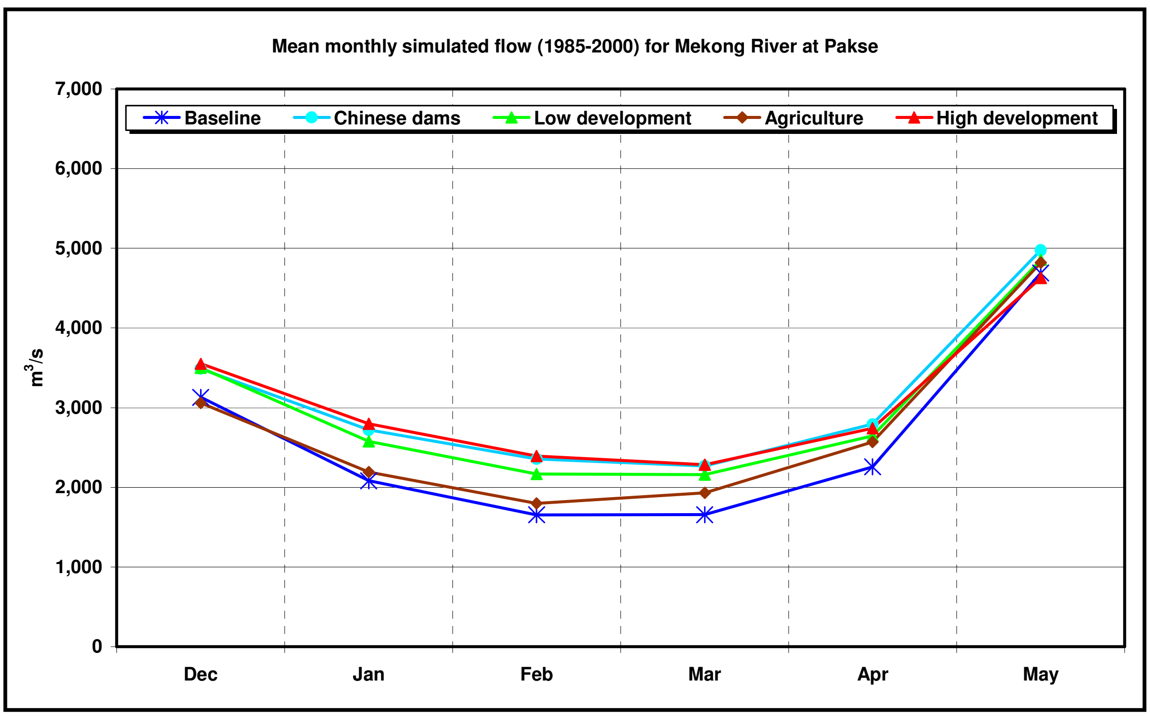

Figure 6-2. Mean monthly simulated flows at Pakse (1986-2000)

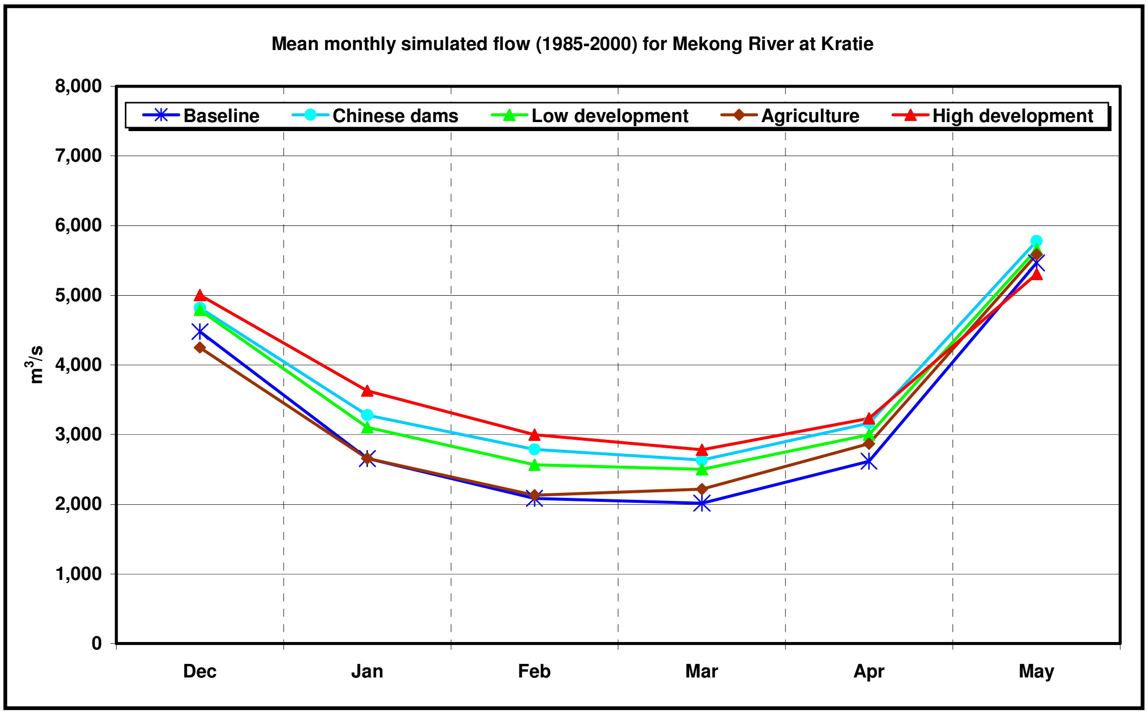

Figure 6-3. Mean monthly simulated flows at Kratie (1986-2000)

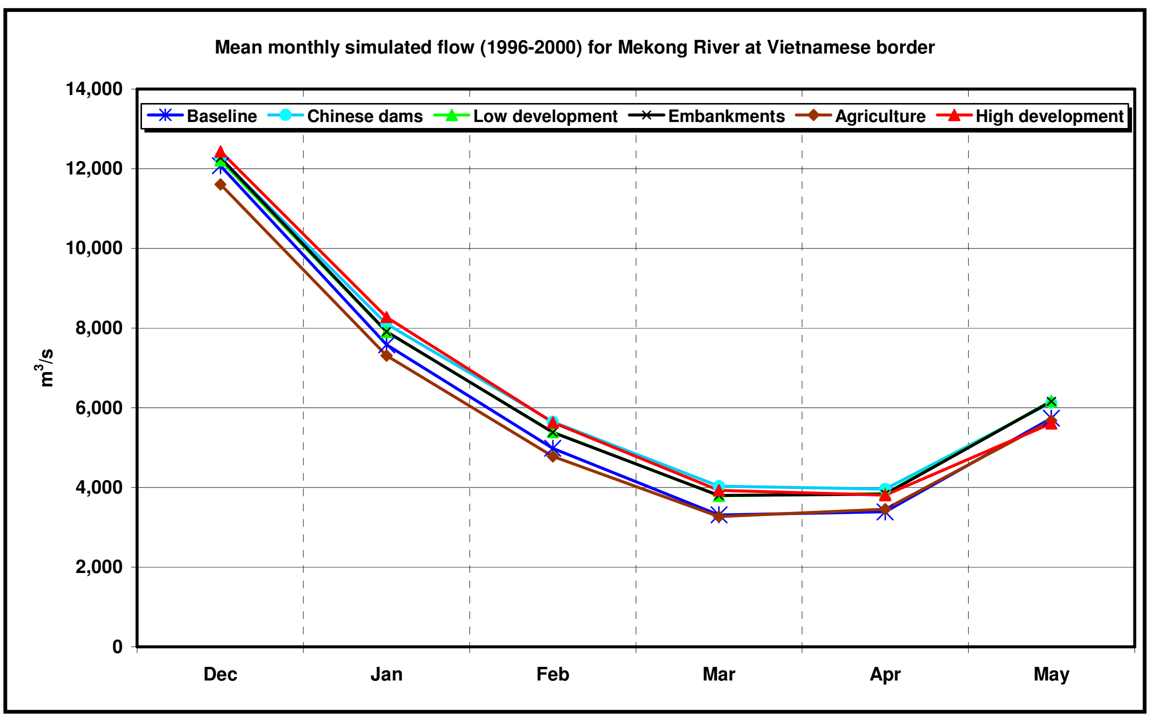

Figure 6-4. Mean minimum monthly cross boundary flows into the Mekong Delta (1996-2000)

6.2 Changes in mean water levels during wet season

The changes in wet season water levels is used here to indicate change in flood levels at the different locations. This is important not only for flood mitigation as an economic benefit, but also to indicate the environmental impact of the change in linkage between the main channel and wetlands in the floodplains.

The changes in simulated mean water levels is reported at the same locations as that for dry season mean monthly flows. The gauging station location at Tan Chau is used for the cross border impacts. The water levels are calculated by different methods, and for different simulation periods for the two upstream locations (Nong Khai and Pakse) and the two downstream locations (Kratie and at Tan Chau).

- Water levels at Nong Khai and Pakse were calculated using simulated flows from IQQM and the rating curves for the period 1/1/1986-31/12/2000.
- Water levels at Kratie and Tan Chau were taken directly from simulations results for the iSIS model for the period 1/1/1996-31/12/2000.

The differences in mean monthly water levels for each scenario compared with the Baseline Scenario for the wet season months of June to November are presented in Figure 6-5 to Figure 6-8 for Nong Khai, Pakse, Kratie and Tan Chau respectively.

6.2.1 Characteristics of changes in mean monthly wet season water levels

(a) Nong Khai

- There are significant changes, from 0.2-1.0 m, in the mean monthly water levels for all scenarios during the core wet season months of July to September for all scenarios.
- The changes in the early and late wet season are mixed, with less significant (± 0.20 m) increases in minimum monthly water levels. Where the water levels are higher is because the hydropower dams are releasing at a rate higher than the mean inflows.
- These changes are caused by the filling of the large hydropower storages upstream, particularly one or both of the largest Chinese Dams, as well as the two large dams on the Laos tributaries.
- Irrigation diversions do not contribute significantly to these changes.
- The inter-basin diversion reduces the mean monthly water levels by less than 0.10 m.

(b) Pakse

- A similar pattern is observed at Pakse compared with Nong Khai. The magnitude of the absolute changes ranges from 0.2-0.7 m, typically 0.30 m less than at Nong Khai.
- Part of the difference in water levels compared with Nong Khai is because the shape of the channel and floodplain is different.

- The relative magnitude of the water level changes for Scenario 3 is more significant here than at Nong Khai. This is because of the additional hydropower dams on the Laos tributaries between Nong Khai and Pakse.
- Wet season irrigation and the inter basin diversion contributes to the water level changes for the Agriculture Scenario and the High Development Scenario.

(c) Kratie

- A similar pattern is observed at Kratie compared with Pakse. The magnitude of the absolute changes for the main part of the wet season from July-September ranges from 0.2-0.8 m.
- Part of the difference in water levels compared with Pakse is because the shape of the channel and floodplain is different. There is also significant hydropower development downstream of Pakse for the High Development Scenario.
- The magnitude of changes during the early and late season is lower, (± 0.30 m).

(d) Tan Chau

- Water level changes have a similar pattern to Kratie, with the exception that these are still apparent through to October. The magnitude of the reduction in water levels us much lower, in the range of 0.05-0.29 m.
- The major part of the lower range of changes is because the water spreads out over quite a large area, including flowing up Ton le Sap into the Great Lake.
- These changes are typically of the range 0.10 m during the peak wet season months for most of the scenarios. The change for the High Development is quite significant, in the range 0.2-0.3 m. This is partly because of the hydropower development, but also because of large volumes of irrigation increases.
- The embankments scenario appears to have increased water levels relative to the low development scenario, even though it is some distance upstream. The physical reason for this may be that less of the flood water is stored, and therefore continues downstream. These phenomena should be investigated further.

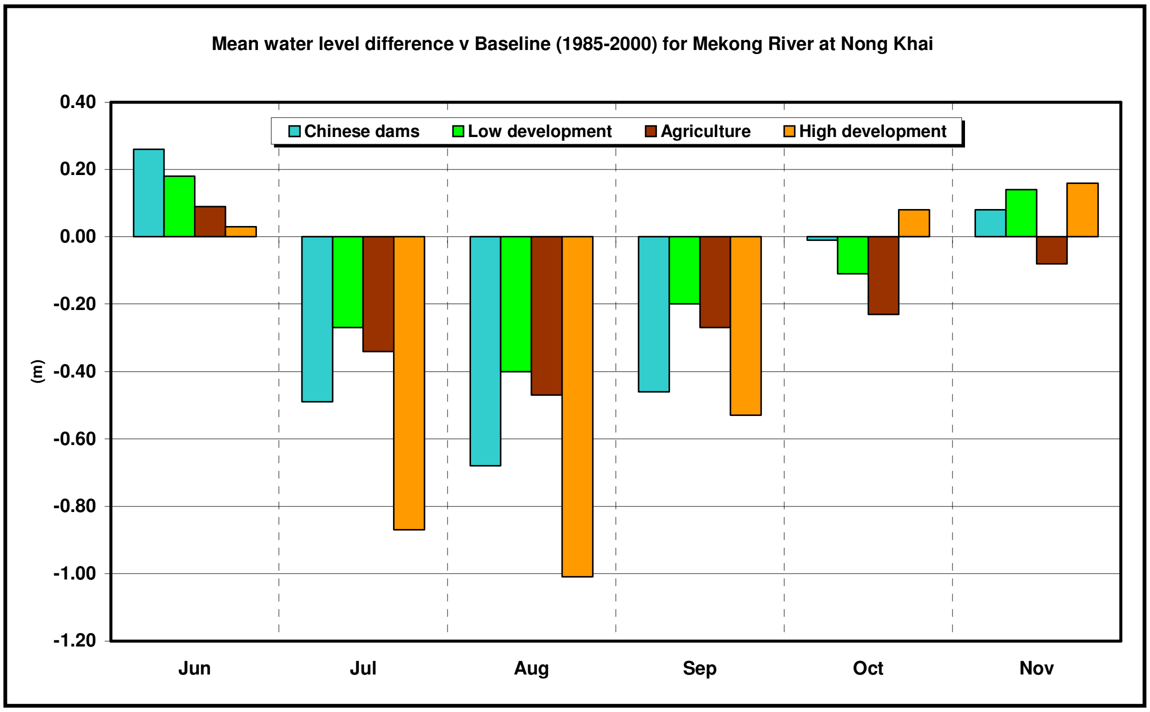

Figure 6-5. Change in mean monthly simulated water level at Nong Khai (1986-2000)

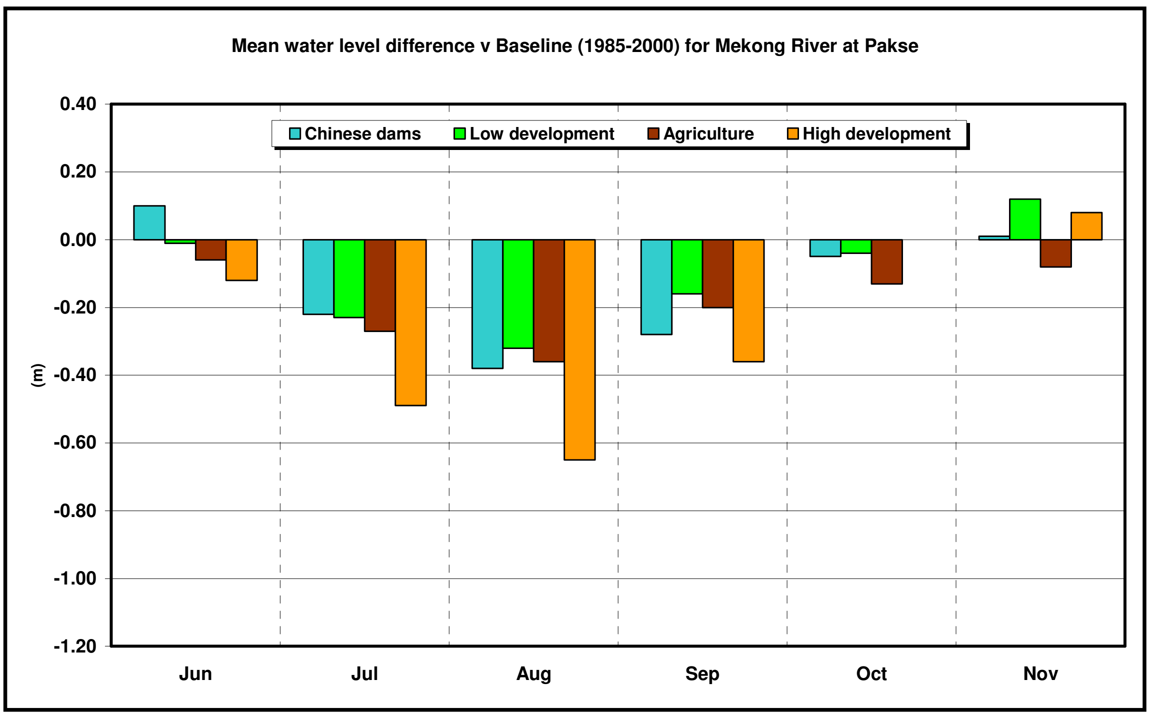

Figure 6-6. Change in mean monthly simulated water level at Pakse (1986-2000)

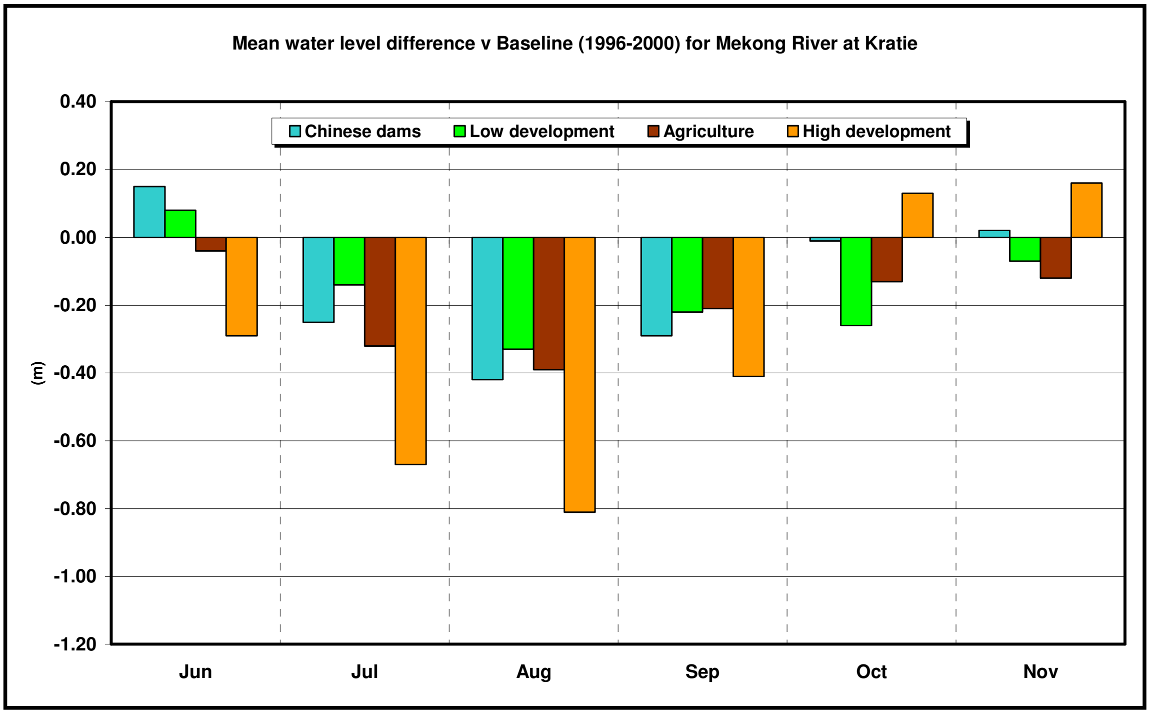

Figure 6-7. Change in mean monthly simulated water level at Kratie (1996-2000)

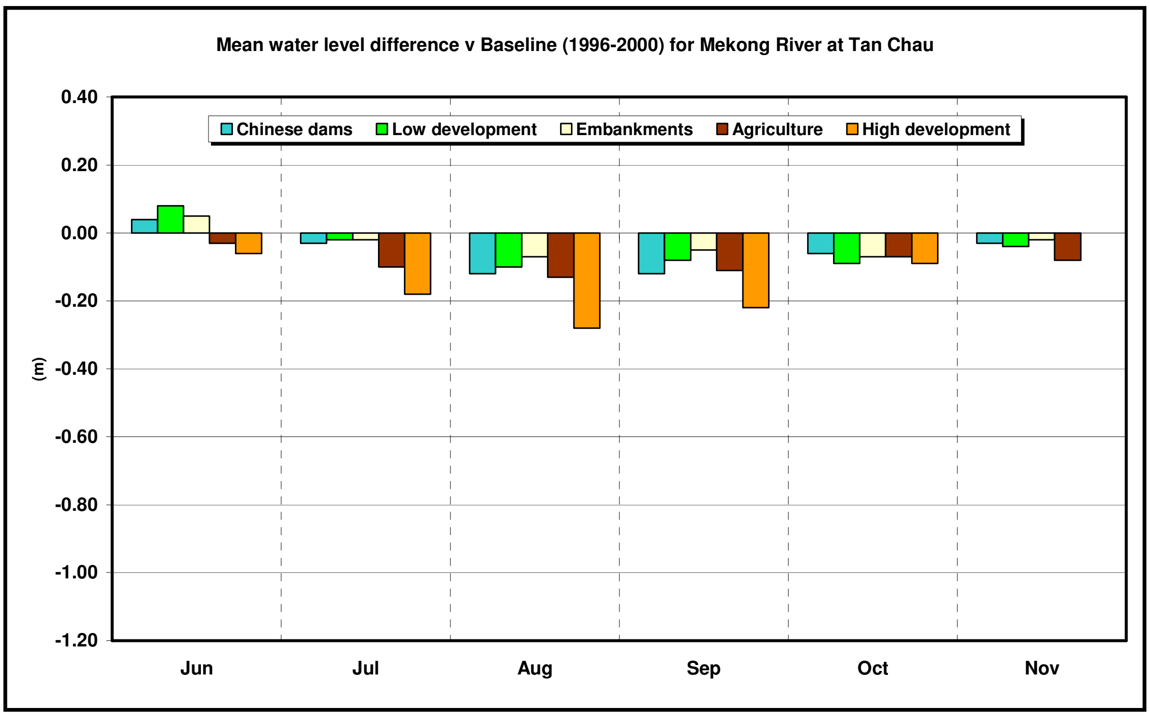

Figure 6-8. Change in mean monthly simulated water level at Tan Chau (1996-2000)

6.3 Mean annual range of water levels.

Seasonal variation in water levels is important for the river system ecology, as the wetting-drying cycle of the near channel areas are important for food production. The water level range over a year can be used as an indicator of this variation.

The water levels were calculated for the periods, and using the methods described in Section 6.2. The maximum and minimum water levels were calculated for each year to give a water level range for that year. The means of the range for all years was then calculated. The mean maximum and mean minimum for the four locations, Nong Khai, Pakse, Kratie, and Tan Chau are plotted for the six scenarios at Figure 6-9 to Figure 6-12 respectively.

6.3.1 Characteristics of changes in mean annual water level range

Reasons for the difference in mean minimum and mean maximum water levels are similar to the reasons discussed in Section 6.1 and Section 6.2 respectively. To avoid repetition, the observations for each location will focus on the results, and not the reasons for these results.

(a) Nong Khai

- Mean minimum water levels are 0.7-1.0 m higher, and mean maximum water levels 0.5-1.0 m lower. These combine to produce a change in range between 1.3 m and 2.8 m.
- The highest level of change in mean annual water range change occurs where there is significant upstream hydropower development.

(b) Pakse

- Mean minimum water levels are 0.15-0.5 m higher, and mean maximum water levels 0.3-0.56 m lower. These combine to produce a change in range between 0.5-1.0 m. The change in range is significantly less than at Nong Khai.
- The highest level of change in mean annual water range change occurs where there is significant upstream hydropower development.
- The diversion of water for irrigation has reduced the magnitude of the range change for the Agriculture Scenario compared with the Low Development Scenario.

(c) Kratie

- Mean minimum water levels are 0.3-0.7 m higher, and mean maximum water levels 0.1-0.5 m lower. These combine to produce a change in range between 0.4-1.2 m.
- The highest level of change in mean annual water range change occurs where there is significant upstream hydropower development. By comparison with the results at Pakse, large increases in agriculture do not appear to have influences the minimum water levels as much.

(d) Tan Chau

- Mean minimum water levels are less than 0.1 m higher, and mean maximum water levels between 0.03-0.19 m lower. The relative insensitivity of the water levels is because of the large surface area floodwater spread over for the maximum water levels, and of the dominance of the tidal influence for the minimum water levels.

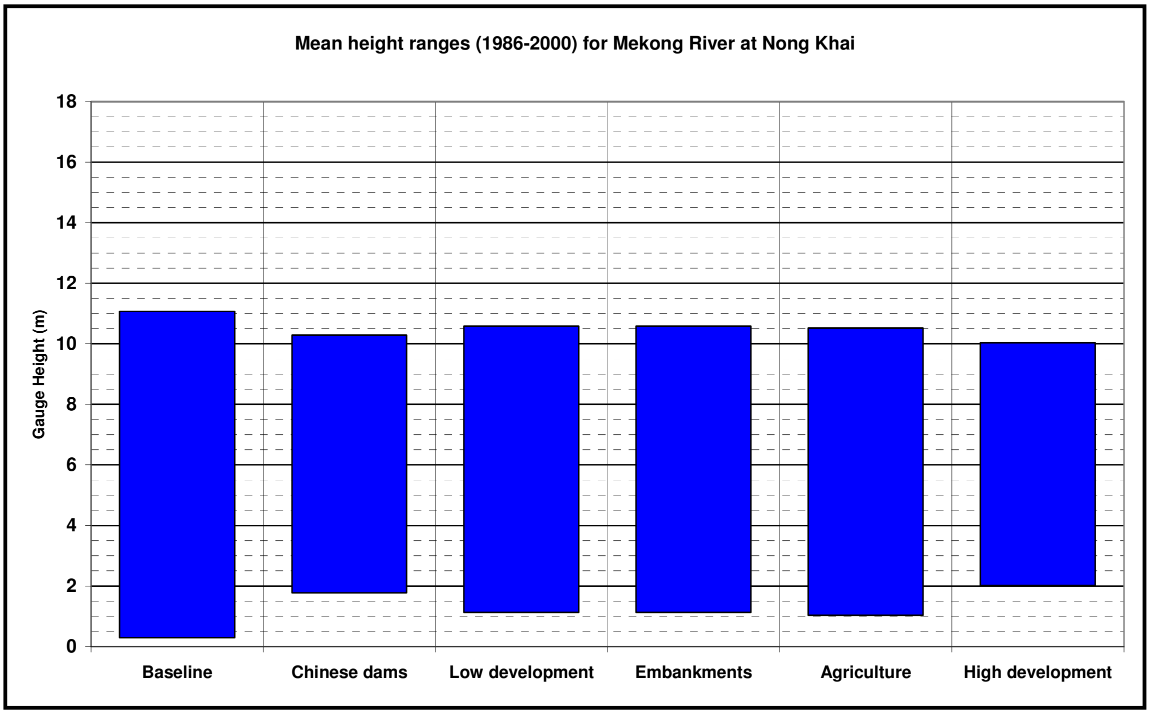

Figure 6-9. Mean maximum and minimum simulated water levels at Nong Khai (1986-2000)

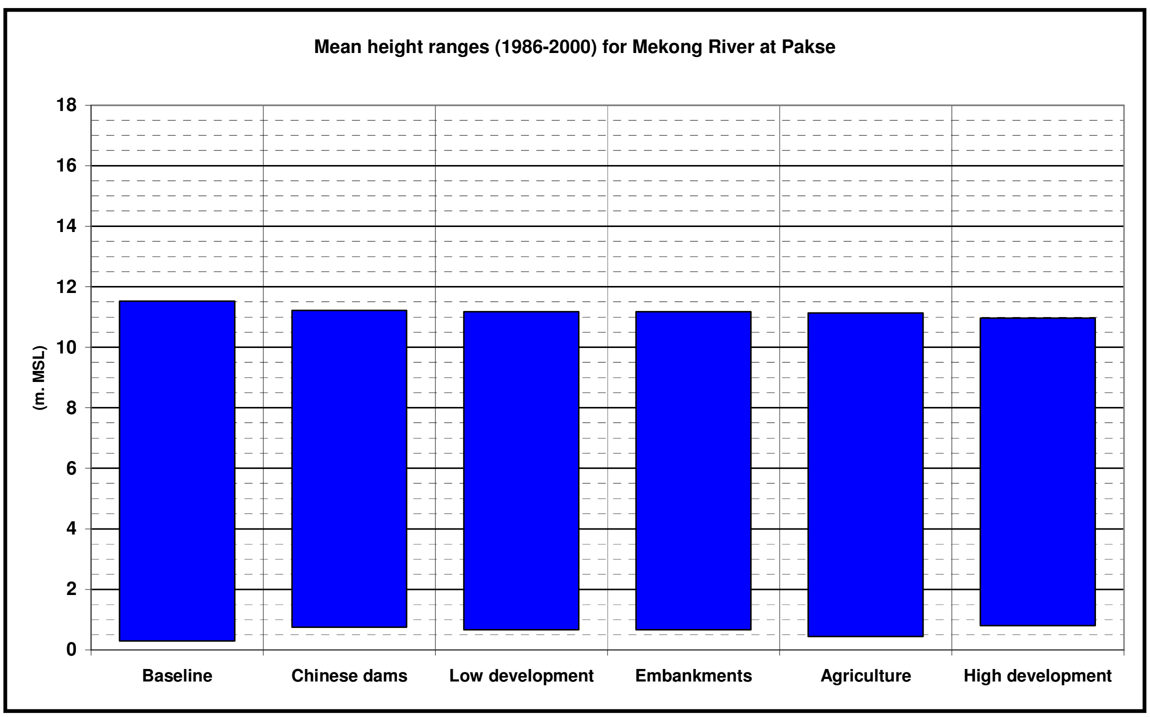

Figure 6-10. Mean maximum and minimum simulated water levels at Pakse (1986-2000)

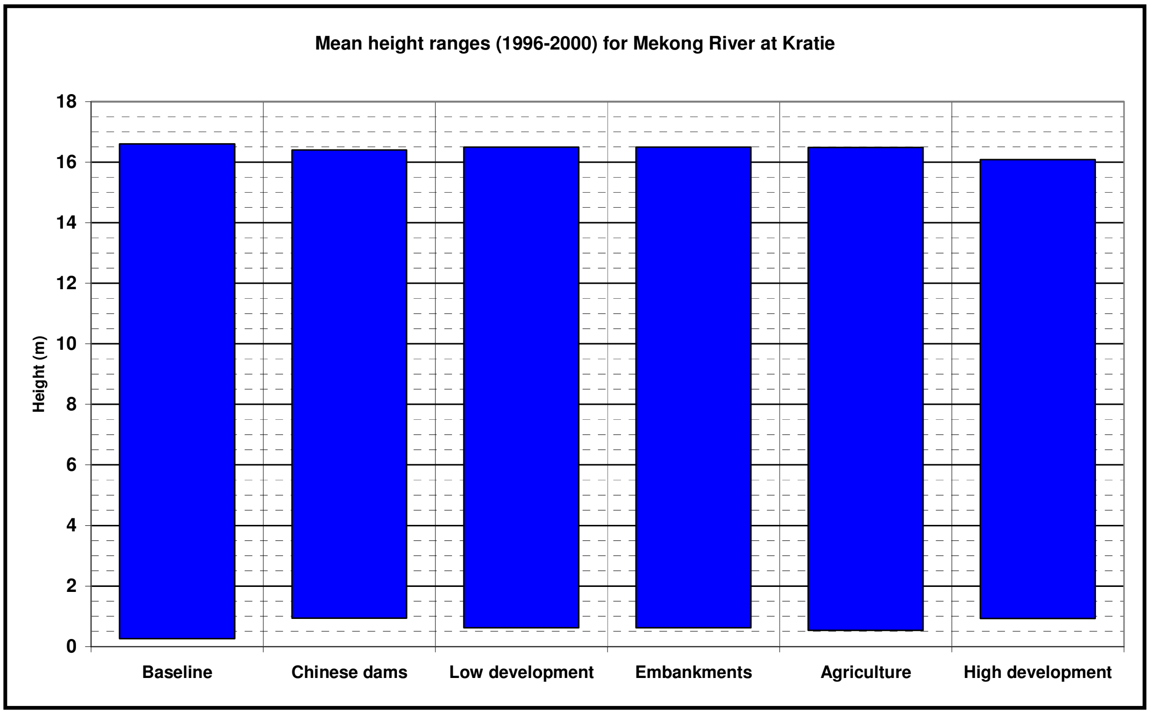

Figure 6-11. Mean maximum and minimum simulated water levels at Kratie (1996-2000)

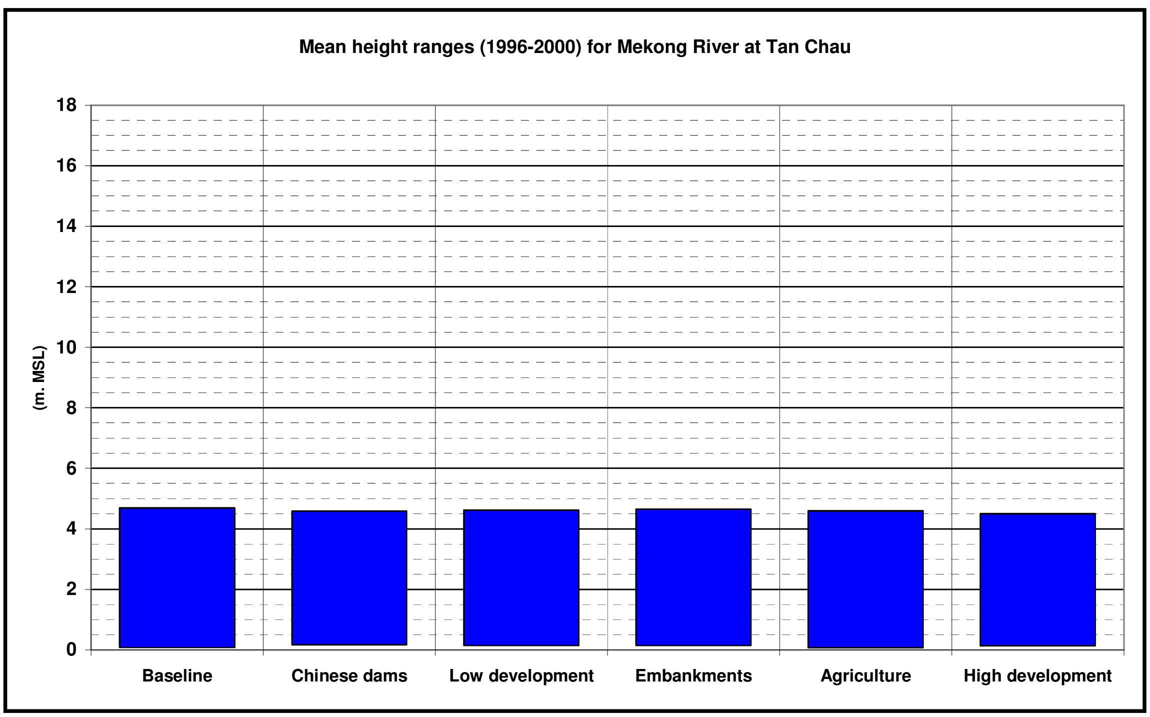

Figure 6-12. Mean and maximum simulated water levels at Tan Chau (1996-2000)

6.3.2 Change in mainstream flow hydrograph.

Plotting the mainstream hydrograph at daily time step for a representative period of time shows visually how each scenario compares against the baseline scenario.

The three year period 1998-200 was selected to show these changes clearly. This period includes both dry and wet years. Figure 6-13 and Figure 6-14 show the hydrographs for Nong Khai and Kratie respectively.

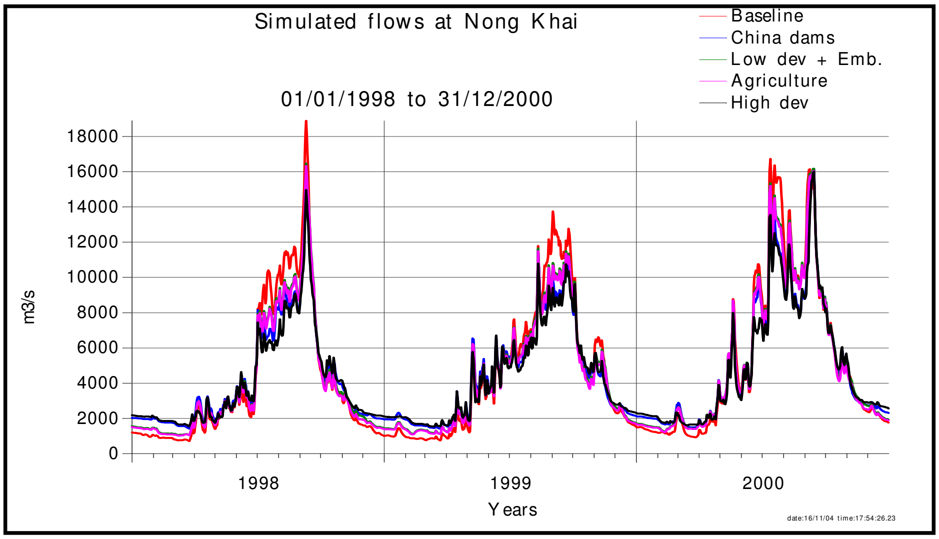

Figure 6-13. Simulated flows at Nong Khai 1998-2000

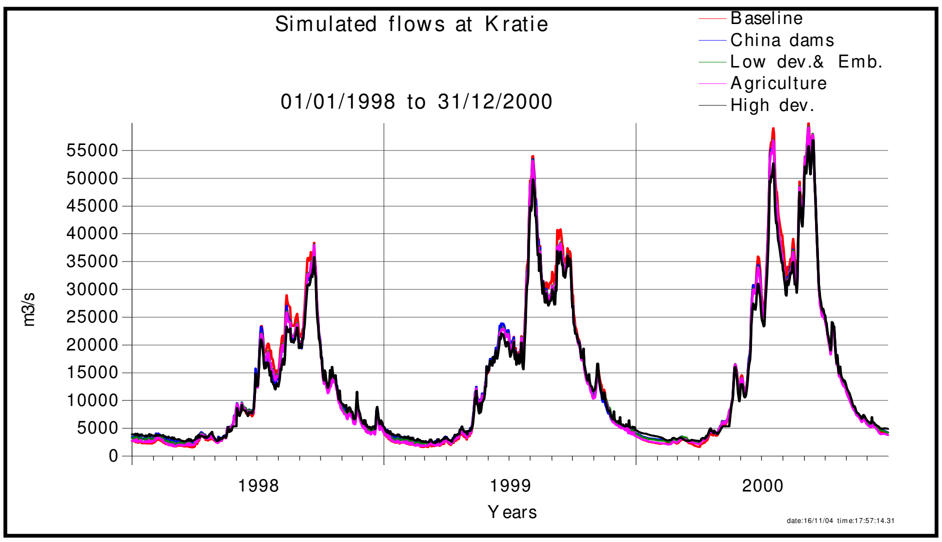

Figure 6-14. Simulated flows at Kratie 1998-2000

6.4 Duration of area inundated for > 0.5 m downstream of Kratie- 2000

Flooding is a significant issue in the lower reaches of the Mekong, particularly for Cambodia and for Vietnam in the Delta. Flooding height and duration are important, as the longer that areas are inundated affects access and peoples safety. The indicator of flooding used is the period that the water level is more than 0.5 m above ground level for the flood in the year 2000. Above this level, access and safety for the population decreases.

Flooding is also quite important for fish production, so reducing the extent and duration of flooding can decrease this. Aquatic species have good access to and from the floodplains with water at or above this level. The fish production is explored further in Section 6.8.

Results from the iSIS simulation were processed to produce the flood duration map shown in Figure 6-15. The flood durations have been mapped as categories of periods of weeks or months, as well as water-bodies defined as inundated more than eight months. These were analysed and compared using GIS to report areas in each category (Table 6.1). Changes to the period inundated for greater than 0.5 m is shown spatially in Figure 6-16 to Figure 6-20.

Table 6.1. Simulated areas inundated > 0.5 m for Baseline Scenario.

Period inundated	km²
Never	28,464
< 1 week	2,756
1 - 2 weeks	1,671
2 - 4 weeks	2,489
1 - 2 months	4,671
2 - 4 months	9,458
4 - 6 months	12,926
6 - 8 months	4,388
Always	6,277
TOTAL	**73,099**

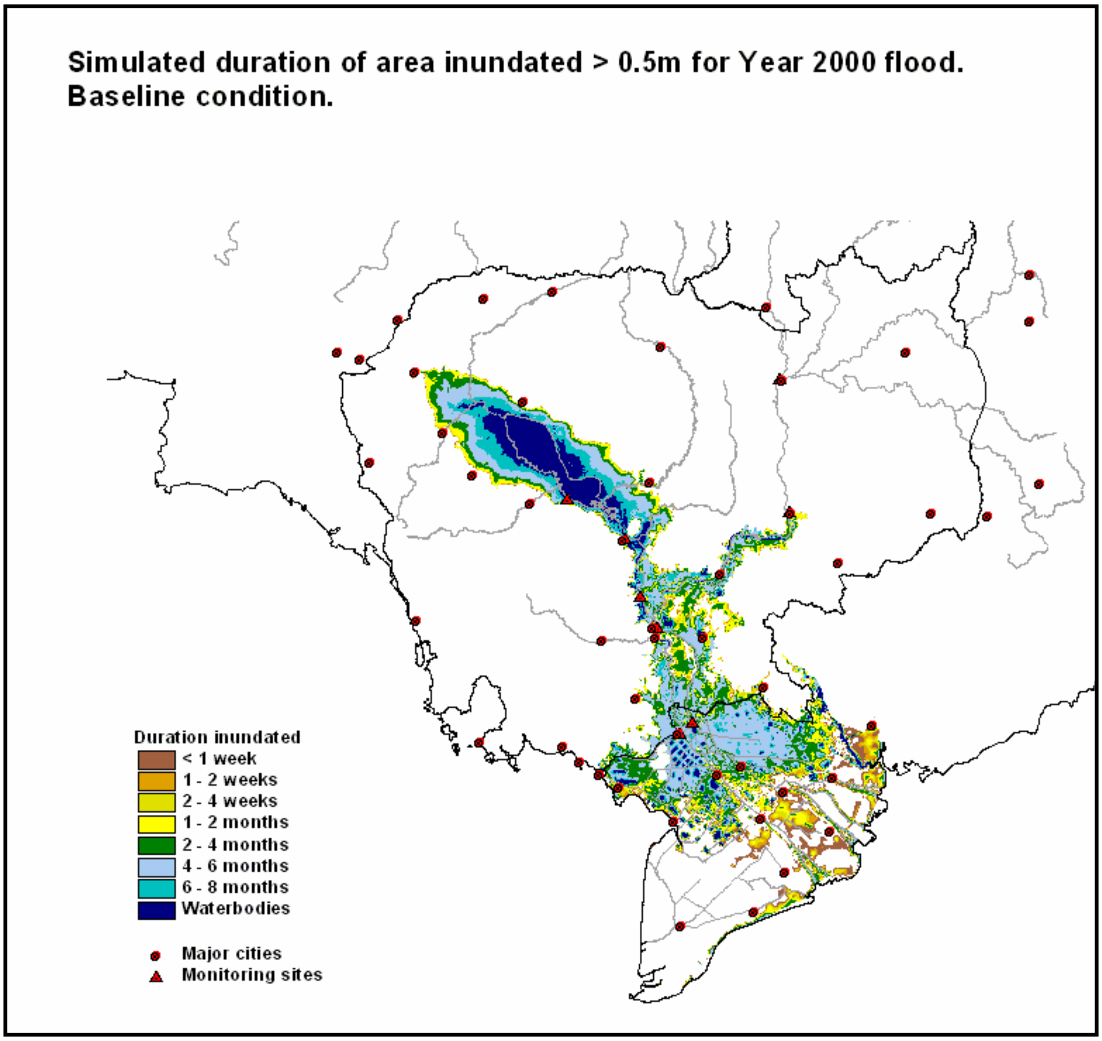

Figure 6-15. Simulated duration of area inundated > 0.5m for Year 2000 flood, Baseline conditions

6.4.1 Characteristics of changes in areas inundated more than 0.5 m

The duration of simulated areas inundated more than 0.5 m for the year 2000 flood is extensive, as was experienced in reality. The areas inundated for longer periods (the mid and light blues in the map) extend from north of Kampong Cham to below Long Xuyen, as well as significant areas of the Great Lake. Patchy short duration flooding (yellows and browns) are show downstream of Long Xuyen.

The long duration periods of 2-6 months are the dominant classes visually and as reported in Table 6.1. Most of these duration categories changed by less than 0.5%, with the maximum change being less than 2%. The contrary pattern of changes for the Embankments Scenario reflects the hydraulic changes caused by the embankments put in the model between Kampong Cham and Phnom Penh. The period inundated for 4-6 months decreases by a significant amount for the High Development Scenario.

The patterns of reduced period of inundation shown in Figure 6-16 to Figure 6-20 generally show extensive areas with less than one month shorter period of inundation. These are visually greater for the scenarios with more development. The Embankment Scenario actually maintains the area flooded compared with the Low Development Scenario. The only scenarios with any areas inundated for more than one month less are the Embankment Scenario, and the High Development Scenario. These are only darker areas on the difference maps.

There will not be a significant change in flooding and its impact on human habitation, and therefore it will continue to be a significant management issue in the LMB.

Under the High Development Scenario the modelling shows a maximum reduction in the peak flood height less than 0.3 m.

Difference in period inundated compared with Baseline

> 1 month less time

< 1 month less time

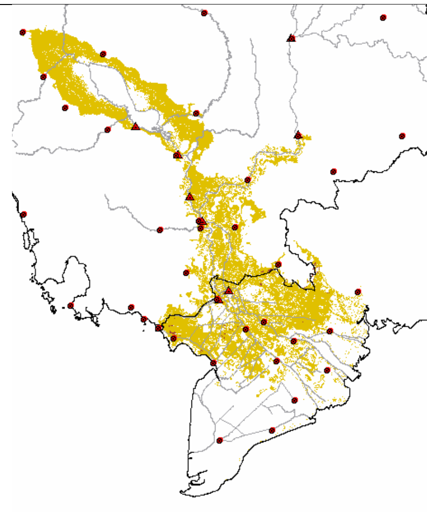

Figure 6-16. Difference Flood duration for Chinese Dams scenario v Baseline

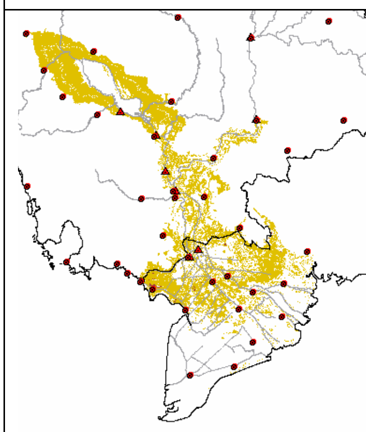

Figure 6-17. Difference flood duration for Low Development scenario v Baseline

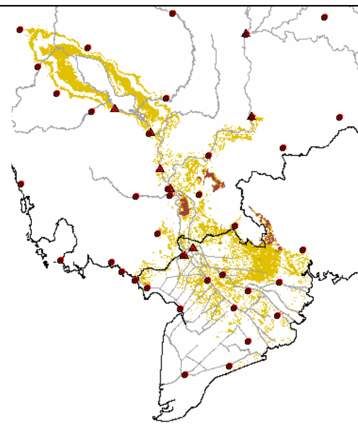

Figure 6-18. Difference flood duration for Embankments scenario v Baseline

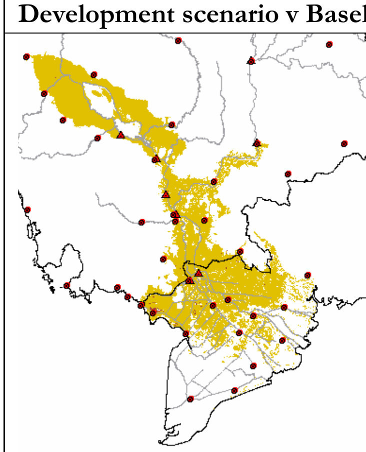

Figure 6-19. Difference flood duration for Agriculture Development scenario v Baseline

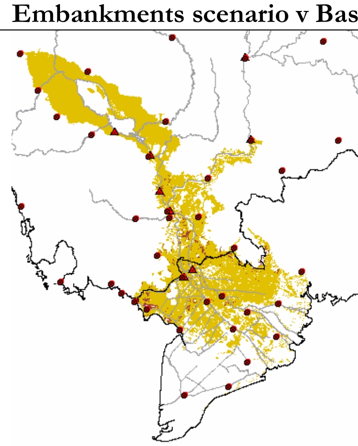

Figure 6-20. Difference flood duration for High Development scenario v Baseline

6.5 Hydropower generated

The average annual hydropower generated for each of the modelled dams for all scenarios is reported in Table 6.2. Note the results for the Low Development Scenario and the Embankment Scenario are the same.

6.5.1 Characteristics of changes in hydropower generated

The hydropower generated reported in Table 6.2 show that, if these major projects were to proceed, three to six times more hydropower would be generated in the Lower Mekong Basin. The amount of power that may be generated in the modelled China Dams exceeds the amount generated in the LMB.

One interesting outcome of the modelled results is the small decrease of hydropower in the Agriculture Scenario because of increased consumptive use.

The majority of the hydropower simulated in these scenarios in the LMB is in Laos, followed by Vietnam, and Cambodia has the least. Thailand has no detailed models of dams in the Baseline model, and no known plans for significant additional hydropower development within its national borders.

Table 6.2. Average annual hydropower generated

Country and storage name	Average annual energy production (GWh)				
	Baseline	China dams	Low development	Agriculture	High development
China					
Xiaowan	-	25,700	25,700	25,700	25,700
Manwan	-	7,300	7,300	7,300	7,300
Dachaoshan	-	5,700	5,700	5,700	5,700
Nuozhadu	-	29,300	-	-	29,300
Total China	**-**	**68,000**	**38,700**	**38,700**	**68,000**
Laos					
Nam Ngum 1	1,076	1,076	1,115	1,110	1,110
Nam Leuk	250	250	250	250	250
Nam Theun-Hin Boun	2,182	2,182	1,524	1,506	1,506
Houay Ho	650	650	650	650	650
Nam Theun 2	-	-	6,238	6,185	6,185
Nam Ngum 2	-	-	1,447	1,447	1,447
Nam Ngum 3	-	-	2,712	2,712	2,712
Nam Ngiep 1	-	-	1,142	1,142	1,142
Xe Kaman 1	-	-	-	-	2,092
Se Kong 4	-	-	-	-	2,200
Nam Theun 1	-	-	-	-	1,194
Nam Ou 2	-	-	-	-	2,786
Nam Tha 1	-	-	-	-	890
Total Laos	**4,158**	**4,158**	**15,078**	**15,002**	**24,164**
Vietnam					
Ya Li	3,352	3,352	3,432	3,410	3,410
Plei Krong	-	-	4,793	4,793	4,793
Se San 3	-	-	1,046	1,036	1,036
Se San 4	-	-	-	-	983
Total Vietnam	**3,352**	**3,352**	**9,271**	**9,239**	**10,222**
Cambodia					
Sambor	-	-	-	-	7,100
Low Se San 2	-	-	-	-	1,342
Lower Se Pok 2	-	-	-	-	
Total Cambodia	-	-	-	-	**8,442**
GRAND TOTAL Lower Mekong Basin	**7,510**	**7,510**	**24,349**	**24,241**	**42,828**

6.6 Irrigation reliability

The irrigation reliability is estimated from water availability for the irrigated area. Where there is sufficient water, irrigation reliability is 100%. Where there is insufficient water to meet crop requirements for more than ten days, the area that could have been reliably irrigated with the water available is estimated. The irrigation reliability as a percentage is then calculated by the ratio of the reliable area to the planted area. This calculation is done daily. The average reliability in April and October is used as an indicator of the reliability for the dry and wet season areas the respectively. The minimum dry season reliable area for Cambodia is based on February and an area weighted average used for the wet season based on the early rice in June and the mid season rice in November.

The irrigation reliabilities for dry and wet season areas for each country are shown in Table 6.3.

Table 6.3. Irrigation reliability for year with lowest water availability by season

Scenario	Thailand (%)		Laos (%)		Cambodia (%)		Vietnam (%)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Baseline	76	68	90	97	69	86	87	98
Chinese dams	76	68	90	97	69	86	87	98
Low Development	71	85	87	97	66	84	87	98
Embankments	71	85	87	97	66	84	87	98
Agriculture	81	85	85	97	65	81	87	98
High development	81	85	86	97	65	81	87	98

6.6.1 Characteristics of changes in irrigation reliability

(i) These reliabilities are based on the driest year. In wetter years at most locations the irrigation reliability is 100%.

(ii) The low reliabilities for Thailand are because of limitations on water access in the Mun and Chi basins.

(iii) The increase in reliability in Thailand in the wet season in the Low, Embankment, Agriculture and High development scenarios is due to the 10% increase in efficiency.

(iv) The increase in reliability in Thailand in the dry season in the Agriculture and High development scenarios is due to the intra basin transfers into the Mun and Chi basins.

(v) The reliabilities in Laos are reasonably high.

(vi) The decrease in reliability in Laos with increase in development is due to longer periods of limited water availability for the larger areas. Note that this is mainly in the dry season.

(vii) The low reliabilities in Cambodia are due to limited water availability in the irrigators in the tributaries surrounding the Great Lake. This has a significant impact on the dry season and early wet season rice crops. This is an area that requires further improvement in the model.

(viii) The reliability in Vietnam is high as irrigators in the delta are non constrained on access to water. Note this does not take into account any effects that salinity might have on access to water.

(ix) There are reliabilities similar to those in Laos for the Vietnam highlands. These reliabilities are dominated by the larger areas in the Mekong Delta region.

6.7 Area of Mekong Delta affected by salinity intrusion - 1998

Salinity intrusion in the Mekong Delta is a significant concern because of its potential impact on rice production. Salinity intrusion occurs as seawater travels up the river system during high tides. This seawater (salinity 35 g/l) mixes with freshwater from the Mekong, increasing salinity levels in the river water. The distance seawater moves upstream, and the resultant salinity level, all else being equal, is determined by the volume of water flowing from upstream. Lower upstream flow rates, as well as excessive diversions, result in lower salinity levels.

The level at which rice yields decline with the salinity levels varies from between species, but a rule of thumb used in the Mekong Delta is based on the salinity level and the length of time this water can be used for irrigation. These are:

(i) High salinity for short duration (4 g/l for up to 7 days).

(ii) Medium salinity and duration (2 g/l for up to 14 days).

(iii) Low salinity and long duration (1 g/l for up to 28 days).

Salinity levels were simulated in the iSIS model for the six scenarios for the year 1998. This year was selected as the model was calibrated on this year, and this year was the driest, therefore the salinity intrusion the most critical.

Maps were generated from these results showing salinity levels. The criteria (i)–(iii) above were used in GIS to map areas affected by these salinity levels for the Baseline Scenario (Figure 6-21). Maps were also generated for all other scenarios, and the differences between these areas compared with the Baseline Scenario calculated and reported in Table 6.4. The location of the changes in area affected for each development scenario area shown in Figure 6-22 to Figure 6-26.

6.7.1 Characteristics of changes in areas affected by salinity intrusion

In excess of 25,000 km² of area are affected by salinity intrusion as defined by the Baseline Condition simulation models combined with the threshold criteria for the defined indicator year, 1998.

The areas affected change for each scenario as the upstream flow in the dry season changes. These upstream mean monthly flow changes were reported in Section 6.1. The significant increase in flows for the China Dams scenario reduces the area affected by about 2,000 km² in the land affected, and the Low Development, Embankment, and High Development Scenario by between 700-1000 km².

Even though the High Development Scenario regulates more water, additional reduces it impact. The Agriculture Development Scenario, with a lower level of upstream regulated, increases the area affected by salinity intrusion by 1,250 km².

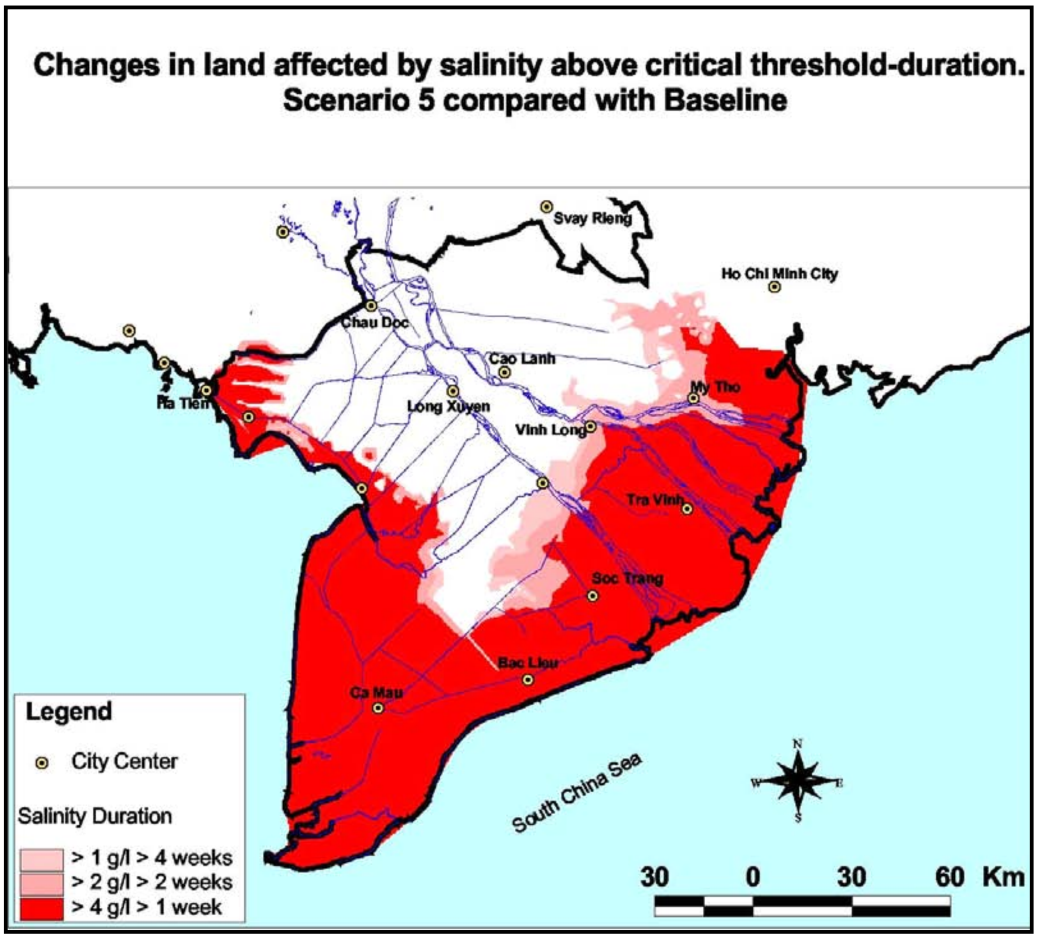

Figure 6-21. Maximum salinity intrusion for baseline condition scenario - lowest flow year 1998

Table 6.4. Change in areas affected by salinity intrusion.

Salinity intrusion	Development Scenario					
	Baseline	**Chinese Dams**	**Low Development**	**Embankments**	**Agriculture**	**High Development**
Area affected (km^2)	25,310	23,297	24,460	24,616	26,564	24,331
Change in area affected (km^2)	0	-2,013	-850	-694	**1,254**	-979

The areas affected are all in the same region of the Mekong Delta as would be expected. In the cases of the scenarios that reduce the area affected, these are shown in green in Figure 6-22, Figure 6-23, Figure 6-24, Figure 6-26, and extend downstream from the Baseline Scenario area affected. The scenario that increases the area affected is shown in red in Figure 6-25, and extends upstream from the Baseline Scenario areas affected.

Difference in areas with river salinity above critical threshold

Becomes available

Becomes unavailable

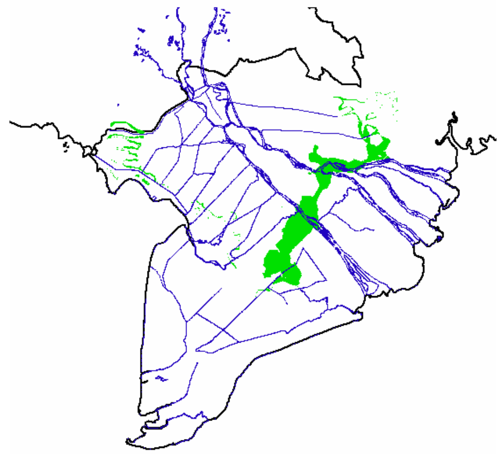

Figure 6-22. Change in area with critical salinity: Chinese Dams scenario v Baseline

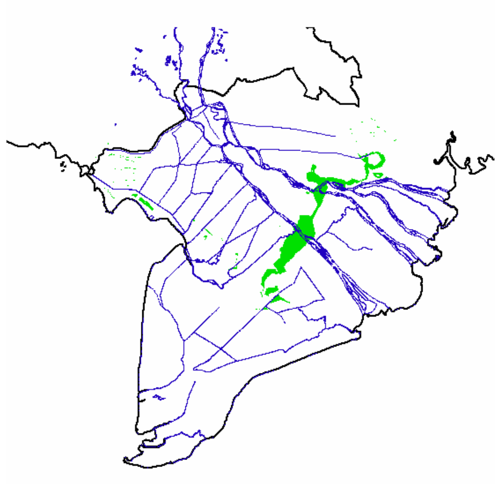

Figure 6-23. Change in area with critical salinity: Low Development scenario v Baseline

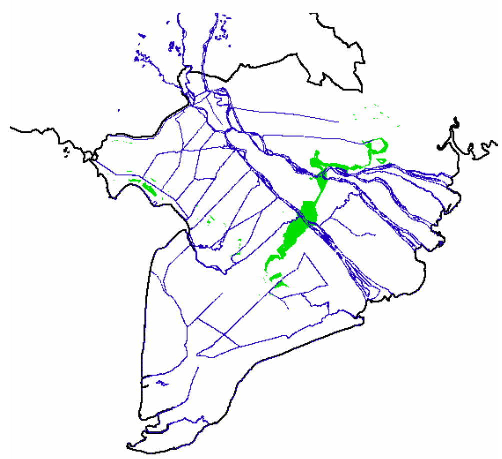

Figure 6-24. Change in area with critical salinity: Embankments scenario v Baseline

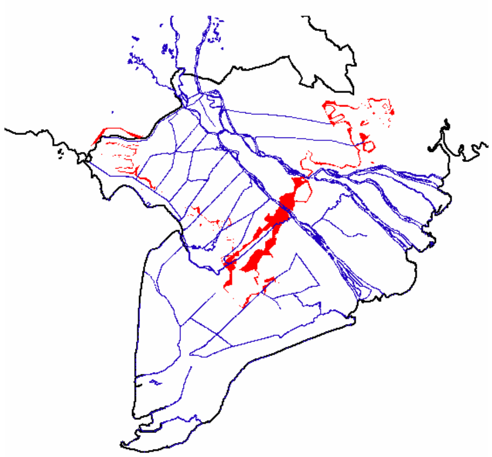

Figure 6-25. Change in area with critical salinity: Agriculture scenario v Baseline

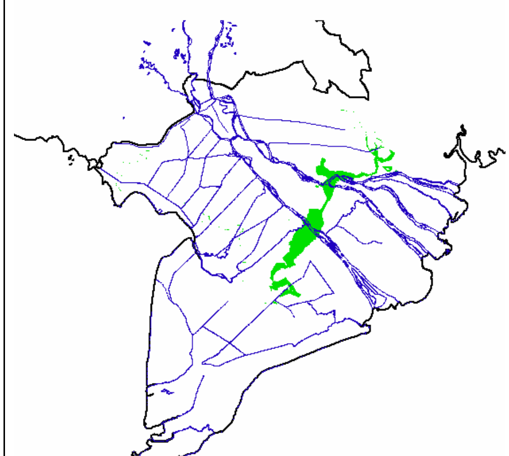

Figure 6-26. Change in area with critical salinity: High Development scenario v Baseline

6.8 Fish Production (Feeding Opportunity Index)

Fish production is affected by physical and management factors. Management factors relate to sustainable fishing practice, barriers to migration, and habitat changes. These factors are generally beyond the scope of a simple and accessible analysis with results from this model.

Baran and Coates (2000) conceptualised a fish production model that could potentially be applied to the Mekong Basin. Hydrologic issues considered included area inundated and the duration it is inundated for, timing, consistency of flooding, vegetation type, turbidity.

For the purpose of this report we developed a simple area-duration index as a surrogate for fish production. We would expect that the MRC will continue to develop flow versus environmental relationships and indicators to inform decision making.

The index is the product of area inundated and the number of days this area is inundated. This index is mean to represent the opportunity the aquatic species have for feeding on the floodplains. The greater the area, and the longer the fish have access to these areas, the more they can eat and therefore grow. The drying wetting cycle is understood to be of some importance, so areas always inundated for more than half the year were not included in the index.

The "Feeding Opportunity Index" was calculated using the same information as the Area inundated more that 0.5 m indicator, except five years (1996-2000) were analysed. Only areas inundated between four weeks and six months were used in the calculation. Areas inundated for less than four weeks are greatest in the near coastal parts of the Mekong Delta, and access to and from would be unreliable. Areas greater than this would not wet and dry, and therefore develop food.

The cumulative index for the periods inundated for five years of flood in for the period 1996-2000 is shown in Figure 6-27. This FOI was tested by comparing the relative magnitudes from year to year with fish catches from the Cambodian Dai fisheries (Hortel et al, 2004). This data is considered to be a good indicator of total production of migratory fish in this region. The relationship (Figure 6-28) shows that increases in FOI correspond to increases in catch. This catch was shown to also match well with peak water level in the Lake. However, the FOI should be a more robust estimate.

The percent changes in this index compared with the Baseline Scenario are shown in Table 6.5.

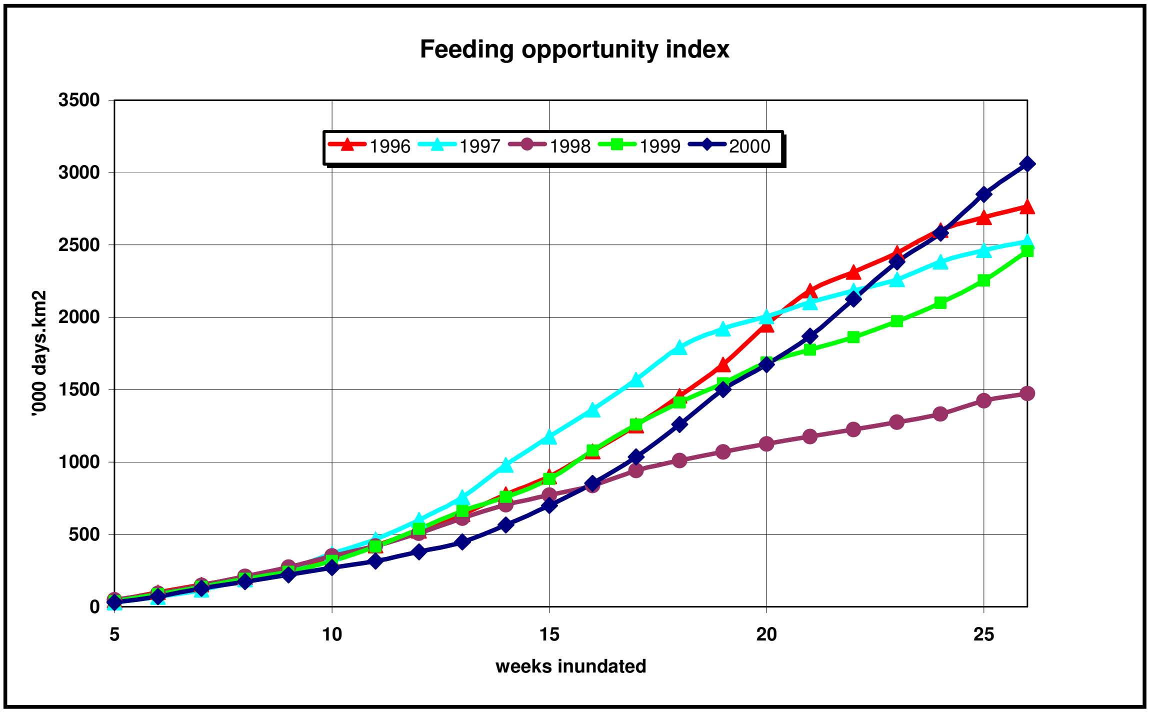

Figure 6-27. Feeding opportunity index for different periods inundated-Baseline Development scenario

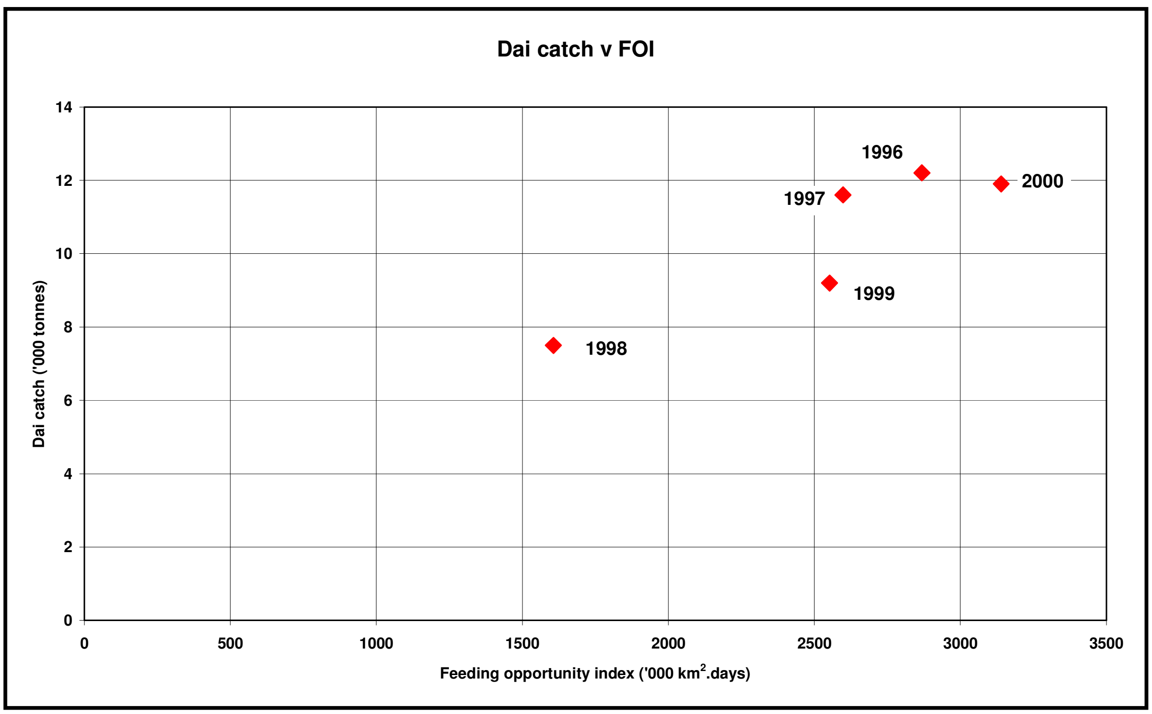

Figure 6-28. Relationship of Feeding Opportunity Index with Dai fish catch

Table 6.5. Changes in fish feeding opportunity index for all scenarios

Year	Baseline Condition FOI ('000 km^2.days)	Percent change compared with Baseline				
		China Dams	Low Development	Embank -ments	Agriculture	High Development
1996	**2,868**	-3.4	-2.7	-1.4	-3.7	-6.3
1997	**2,598**	-2.8	-2.7	-1.1	-3.4	-6.5
1998	**1,607**	-8.6	-6.2	-5.6	-8.3	-13.2
1999	**2,552**	-4.2	-3.7	-1.2	-3.7	-7.3
2000	**3,140**	-2.1	-0.9	-0.5	-1.4	-5.2

6.8.1 Characteristics of changes in of Feeding Opportunity Index

The absolute value of the index is not of great interest at this point, the relative values of the other indexes the Baseline Scenario are more important. The decreases for four of the five years is in the range 1-4 % for the Chinese Dams, Low Development, Embankments and Agriculture Development scenarios. The decreases for the High Development scenario is in the range 5-8 % for these same floods. Of particular note in these results is that the changes are greater for smaller floods, with changes in the range for 6-13% for all scenarios.

This result suggests that the access of aquatic fauna is not greatly restricted by the reduction in flooding caused by the scenarios. This is consistent with the conclusions from the area inundated analysis in Section 6.3.2.

The result that the FOI for the Embankments scenario is higher than for the corresponding Low Development scenario is not at first appearance logical. Alienating a significant area of the floodplain would be expected to decrease FOI. However, these embankments have increased the duration of areas inundated relative to the Low Development scenario. Some account may need to be taken in applying the FOI in these conditions.

Several caveats are necessary to the overall results. The index is no more than stated, a simple indicator of the opportunity for aquatic fauna to access food on the floodplain. Among the limitations are:

- It does not include quality of habitat, although there is an easily accessible capability to extend to this.
- It does not include barriers to migration that might occur. The Sambor, Lower Se San 2, and Lower Se Pok 2 Dams on the upstream of Kratie would be an insurpassable barrier to migration.
- The index also does not consider changes in flooding upstream of Kratie. The area inundated modelling capability is only easily available with the iSIS model. Upstream of Kratie, only flow changes are modelled. Areas inundated would need to be estimated by other means.

6.9 Navigation reliability

The duration of time that critical river levels are exceeded at key locations along the river affect the period that vessels of various tonnages my use the river. Figure 6-29 to Figure 6-32 shows the height exceedance probabilities during the dry season months of January-April for five key sites along the river.

6.9.1 Characteristics of changes in navigation reliability

The relationship between these tonnages and heights is not currently known. The opportunity for larger vessels to travel is increased in the reach down to Nong Khai, with water levels between 0.5 and 1.0 m higher. The water level increases at Stung Treng are between 0.2-0.3 m higher nearly all the time, showing the impacts of irrigation as well as hydropower releases. The water levels at the Kampong Cham are also higher nearly all the time. Water levels at Prek Dam site on the Ton le Sap between the Great Lake and Mekong River sites downstream of Kratie show that water levels are usually higher by up to 0.2 m, but there are some cases with Agricultural development that water levels are lower than the Baseline.

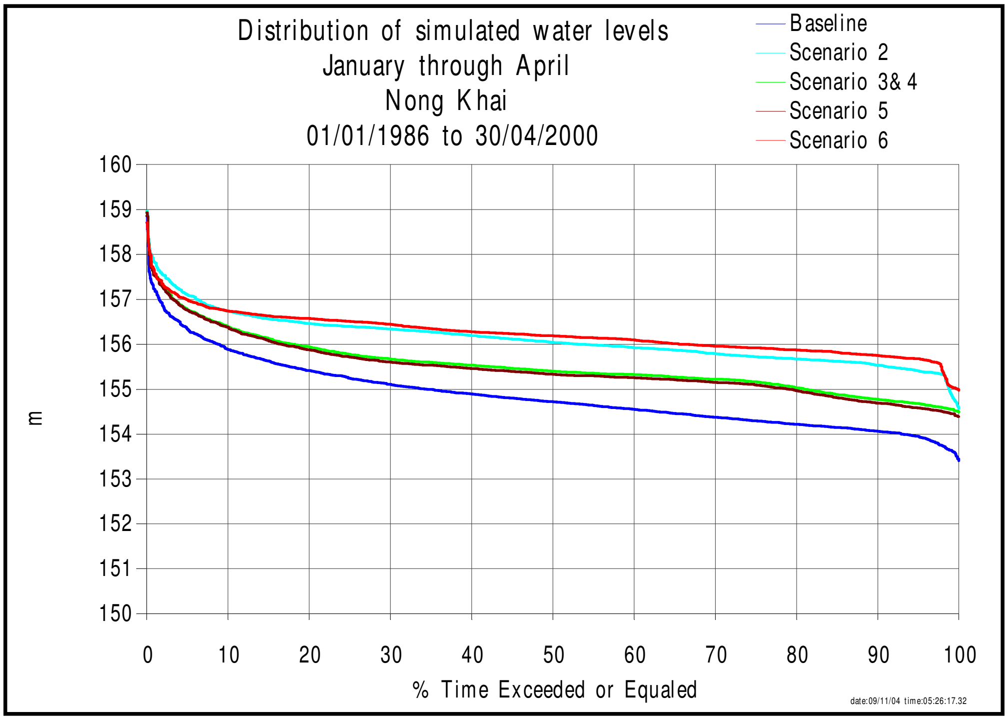

Figure 6-29. Height exceeded at Nong Khai (January-April)

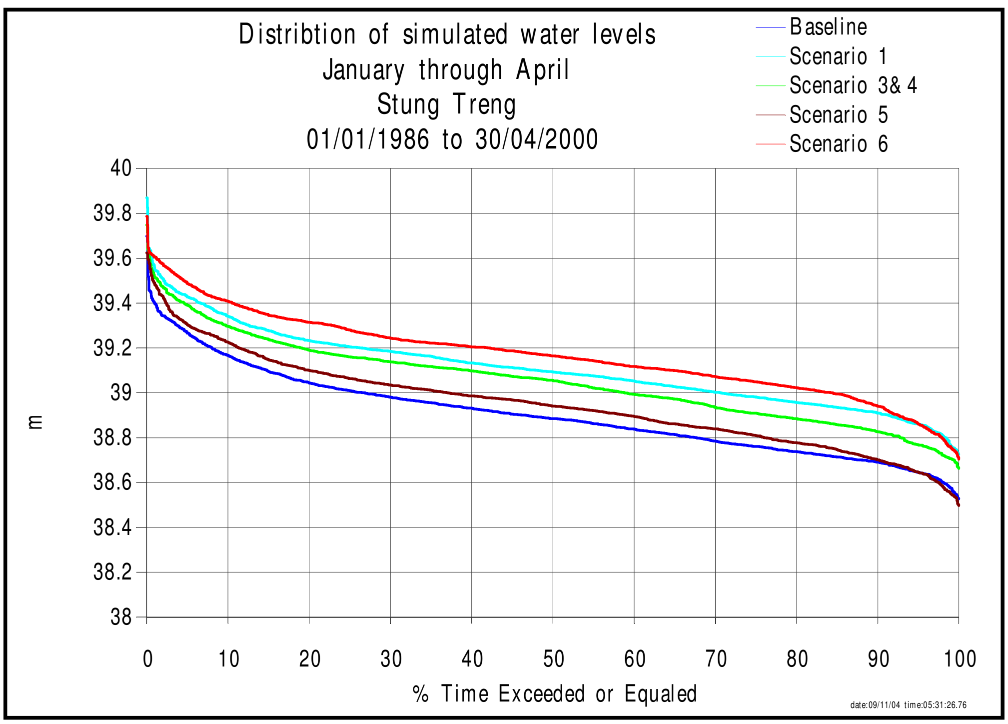

Figure 6-30. Height exceeded at Stung Treng (January-April)

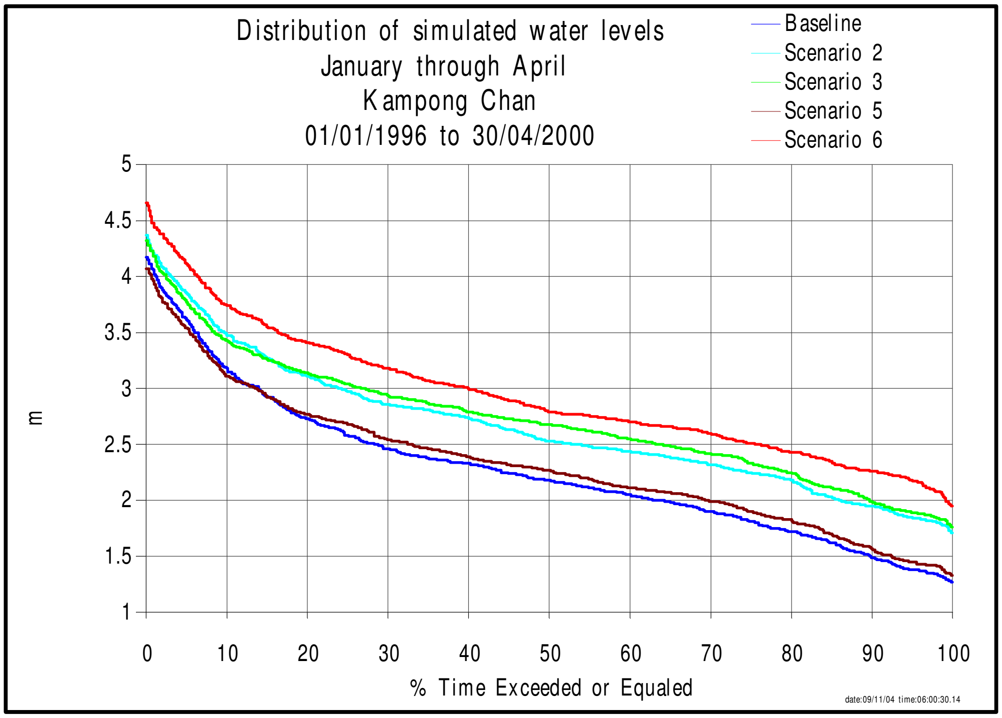

Figure 6-31. Height exceeded at Kompong Cham

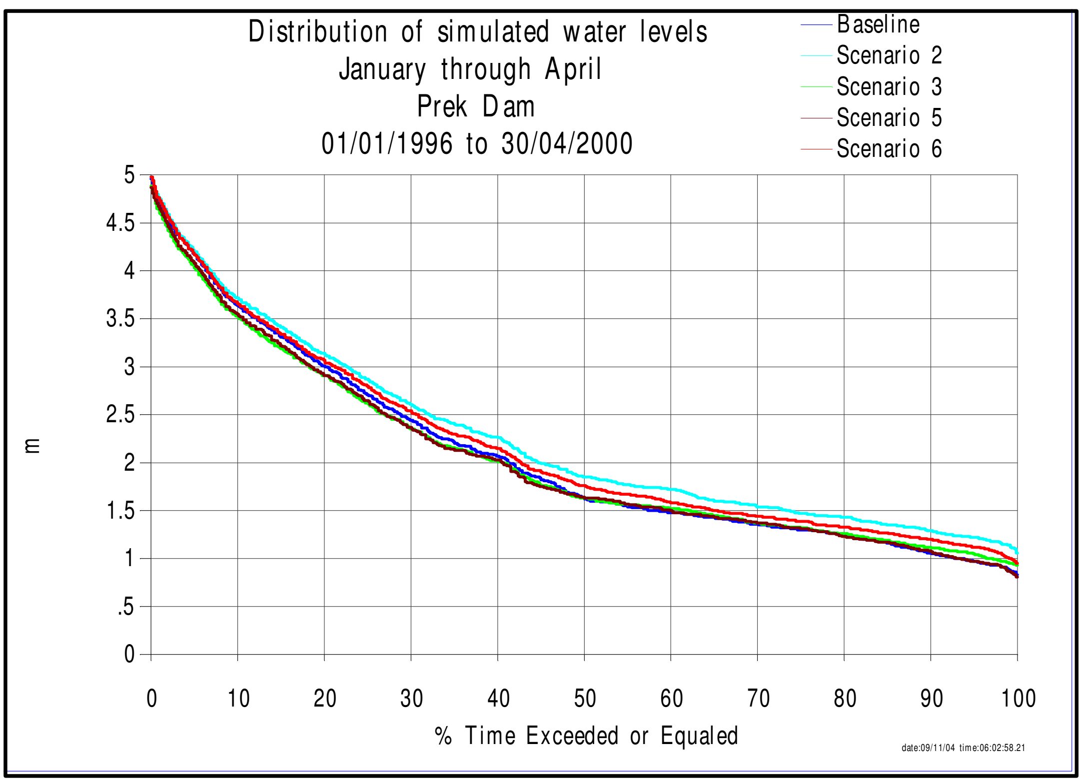

Figure 6-32. Height exceeded at Prek Dam

7 Observation

7.1 Conclusions on modelling capacity

The MRC has developed, tested and formally adopted a comprehensive, modern suite of hydrological models. Development will continue, however the studies underlying this report indicate that the models are robust and provide important insights into the hydrological impacts of a wide range of basin development scenarios on river flow, floodplain inundation, flooding, navigation, hydropower production, and salt water intrusion on the delta.

An overall check of the MRC models was carried out. The checks covered the overall mass balance of the model as well as verifying the demands. The tests confirmed that the models preserved mass balance for all scenarios. The magnitude and change in demands was consistent with simple estimates, and in line with the level of development. The distribution of flow and usage within the models was also consistent with the level of development.

Use and maintenance of such modelling capacity is an essential asset for a basin of this size. Ongoing quality assurance is an important responsibility for the MRC.

The information provided by the models will allow specification of key parameters in the inter-country agreements that are required for coordinated basin development. The models can subsequently be used as a part of the monitoring, auditing and reporting program that the MRC will be responsible for as development proceeds.

The models have the capacity to report on a range of environmental indicators once the relationship between flow, water level and area inundated and the particular environmental issue (e.g. fish production/wetland health) is established. During this exercise, we have developed a basic fish indicator to demonstrate what is possible.

7.2 The Basin

As stated in the 1995 Basin Agreement, the countries require a set of operating rules that provides scope for national development while protecting the shared resources that they collectively rely on. Such rules define the key, monitorable indicators – in terms of times, locations, flow rates, levels, quantities, water quality or other variables – that are sufficient to define each country's opportunities and responsibilities in the Mekong Basin.

7.3 The Countries

The development path chosen by each country will reflect its national policies, investment potential, and investment capacity. The resulting priorities may vary sharply between countries, and within countries over time. The rules set boundaries to the nature and scope of the development such that the interests of other basin states are protected while each state pursues its legitimate goals.

7.4 The Commission

The role of the river commission is threefold:

(i) Information: to provide and maintain the information base and analytical capacity to determine fundamental elements of the 1995 agreement, and, as required for additional future agreements;

(ii) Monitoring: to monitor, audit and report on the conformity of ongoing basin management to the terms and conditions agreed by the countries and contained within the agreement.

(iii) Shared asset management: to own and manage assets which have been created by joint investment and have been agreed to be best managed centrally.

7.5 The Studies

These studies do not (and were not intended to) compare or evaluate the merits of alternative development scenarios, but rather to demonstrate the likely impacts of a credible variety of single- and multi-sectoral development scenarios. The studies confirm that there is scope for significant levels of co-ordinated development with associated benefits to all basin countries.

Key findings are summarised below.

7.6 Hydrological impacts

All development will have an impact and the models reflect the change in the hydrology of the river that would result from that development. Decisions on what is the reasonable balance of development is a matter that can be informed by the model outputs but requires the economic, environmental and socio-political inputs by the country concerned to determine the appropriateness and priority of each investment.

Current development of the Mekong river is very limited compared to almost all large river basins in the world. The natural flow pattern is essentially intact, as are the highly productive natural fisheries in the river.

Existing storage corresponds to less than 2% of average annual flows at Kratie and does not significantly redistribute water between seasons. Diversions in the Lower Mekong Basin are 10% of annual flow at Kratie. Diversions in the Mekong Delta constitute some 60% of this total. In consequence, the Mekong retains most of its natural flow characteristics upstream of the delta, and the major environmental impact of water-related development to date is to increase the local problem of salt water intrusion in the delta areas.

However, it is critical to realise when evaluating the results that ongoing and committed developments in the upper basin will result in significant transfers of water from the wet to the dry season. The hydrological implications of this are broadly reflected in the "China Dams" scenario. Any lower Mekong scenario must therefore be evaluated in relation to the expected future situation – independent of lower Mekong development – as well as the historic "Baseline" scenario.

The main body of the report contains details of the scenario analysis, reported against a broad range of indicators. An indication of the change in flow regime between the baseline and the High Development scenarios for Nong Khai and Kratie are presented below.

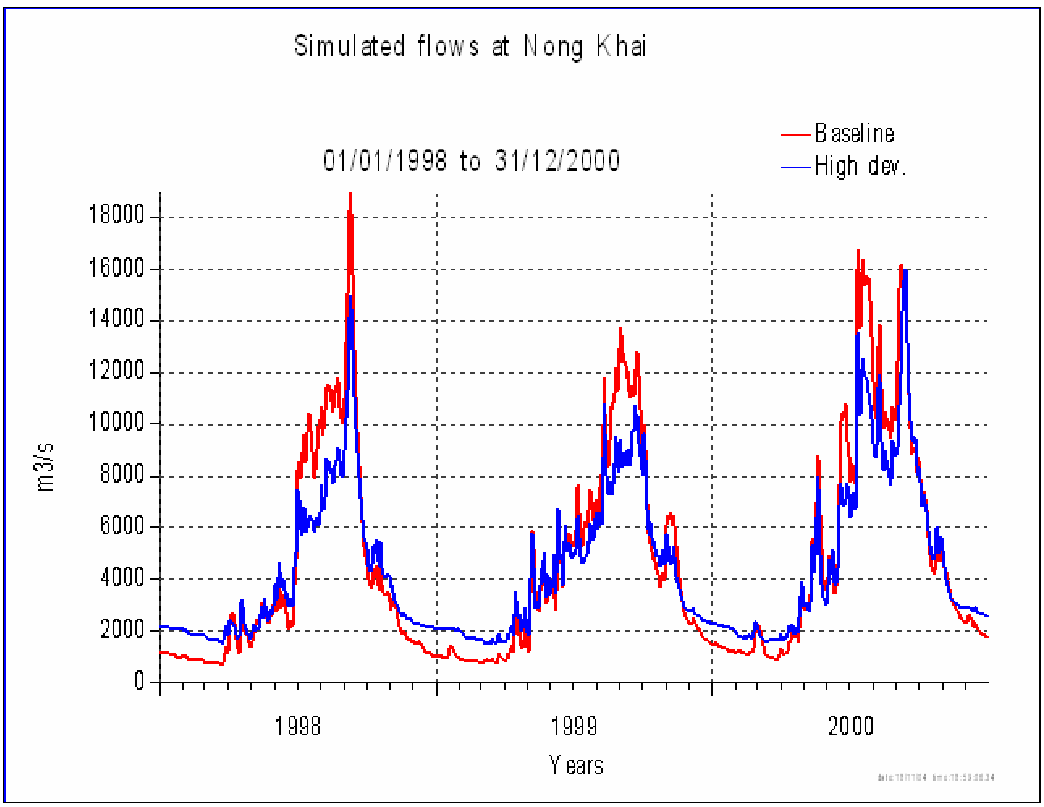

Figure 7-1 Simulated flows at Nong Khai

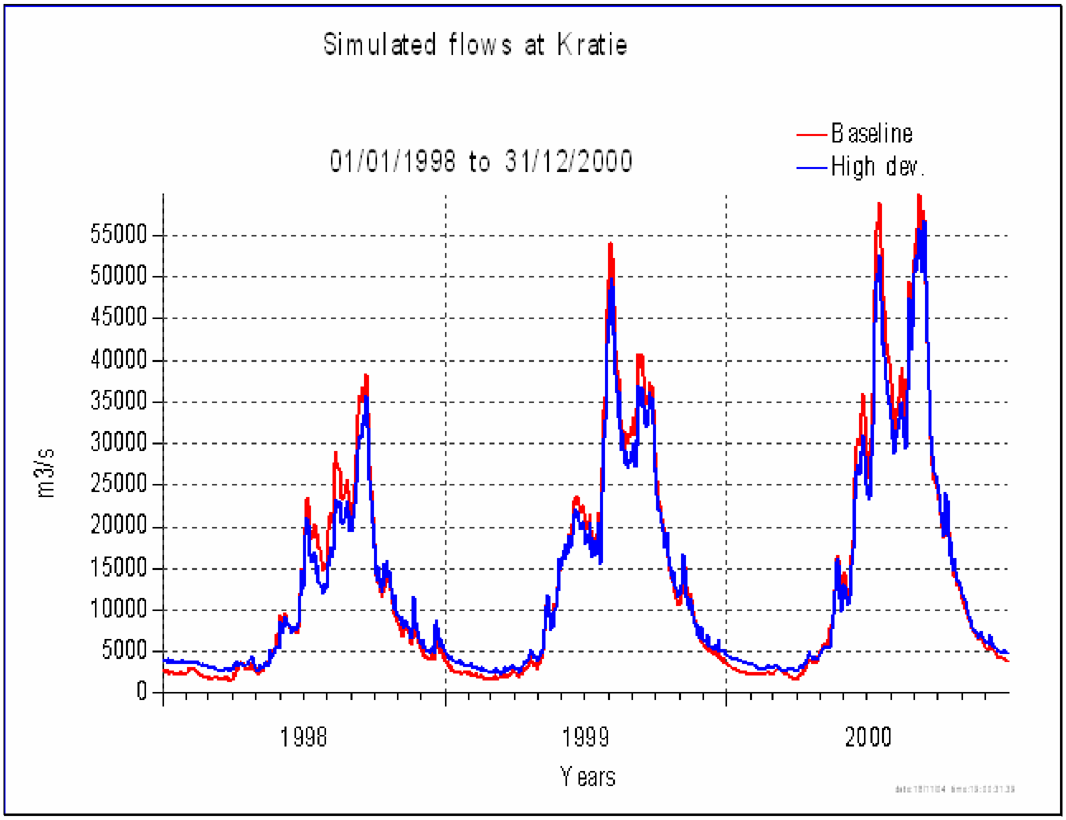

Figure 7-2 Simulated flows at Kratie

Summary observations are:

(i) The overall character of the hydrograph is maintained.

(ii) Low flows are significantly increased and are higher than the historically observed range.

(iii) High flows are marginally reduced, but within the historically observed range.

Future development must be properly co-ordinated, and managed, to preserve the environmental flows that support the existing Ramsar wetland sites upstream of the delta and the highly productive natural fisheries – which represent 2% of total world fish production. These objectives are consistent with objectives set out in the Mekong River Agreement.

The results confirm the importance of a balanced and coordinated approach to water management. The results set out here confirm that agreement on access to the waters of the Mekong river is a necessary precondition to provide development security at a country level, ensuring that the benefits of development in one country are not eroded by development in another. Only a coordinated approach provides assurance of sustainable development opportunities.

7.7 Fisheries

Potential impacts on the fisheries sector are a major concern, because fisheries are a primary source of income to the poor and nutrition to the population more generally. A complicating factor in assessing the impact of potential developments within the basin on the fisheries sector is the difficulty of projecting the future of fisheries: quite separately from any impacts of dams and irrigation facilities, fish production is threatened by over-fishing, pollution from chemicals and habitat destruction due to pressure on land. It can be argued that the best basis for intervening in these "common property" problems is provided by the existence of alternative sources of income (as provided by irrigated agriculture) and development generally (as facilitated by the availability of power).

The models produce data on flow, height, and area inundated, from which a preliminary indicator of fish production has been developed, based on fish feeding opportunities. This should be a forerunner of more sophisticated indicators, but it does correlate well with available fish catch data from Tonle Sap. All scenarios tested show a small decline in fish feeding opportunities, the most pronounced reduction occurring in years of low flow.

Nevertheless, any development which directly impedes fish migration in the mid and lower reaches of the river will have significant negative impacts on fish production. Mainstream dams or weirs in the mid and lower Mekong are therefore most unlikely to be a part of any balanced development scenario that complies with the objectives of the Agreement. It is also clear that floodplain connectivity is fundamental to fisheries production and river health and must be protected.

7.8 Hydropower

The realistic estimate for hydropower is much lower than the figure generally quoted of 30,000MW because this includes 13,000MW on or near the main stream in the lower basin. It is likely that this figure will be further reduced when individual projects have been evaluated for local environmental and social impacts. However, even after these qualifications there is still a very large hydro power potential that could be developed as part of a well structured and integrated program.

The projected hydro-power in the Lower Mekong Basin in the various scenarios ranges is summarised below:

Table 7.1 Projected hydropower in the Mekong Basin

	Capacity (MW)		Energy (GWh)	
Location	**Lower Mekong**	**China**	**Lower Mekong**	**China**
Minimum	1,290	0	7,500	0
Maximum	6,084	12,550	43,000	68,000

7.9 Irrigation

To support national objectives of basic food security and crop diversification an increase in irrigated area is inevitable. There is currently 7.4Mha irrigated, of which 4.1Mha is in the Mekong Delta. The high development scenario increases the total area to 11.3 Mha, with most of the increase located in Cambodia – where irrigation is planned to triple. This increases the amount of water diverted for irrigation by 15.5 Gm^3/y to 55.8 Gm^3/y. This is a 40% increase in diversions and will in total represent 12 % of annual flows.

As modelled, the high development areas in Cambodia did not have fully reliable access to water for irrigation, resulting in some understatement of potential withdrawals. This is not seen as a significant issue in interpreting the results because any higher demands would not coincide with periods of major impact in the Mekong Delta.

The high Development Scenario has included an average inter-basin transfer in the wet season of 1.9 Gm^3/y.

7.10 Navigation

All the scenarios generally show substantially improved opportunities for navigation. This is a result of the redistribution of flow from wet to dry season as a result of hydro-power dams, and is particularly significant in the higher reaches of the river, where navigation access that is currently only experienced for 2-3 months each year on average will in future be virtually year-round.

7.11 Flood Damage

While there will be some redistribution of flood peaks, the developments – even those in the high scenarios – will not significantly mitigate major floods in the Lower Mekong Basin.

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Attachment 1: Model Mass Balance

A preliminary check on the mass balance of the model gives a good sanity check on the numbers produced by the model. It provides at a glance an indication of the relative size of the numbers. Several tests are presented to check the overall mass balance of the model as well as verifying the demands. The following tests are considered:

1. Mass balance check upstream of Kratie
2. Domestic and Industrial demand
3. Irrigation demands

A.1 Mass balance upstream of Kratie

As the inflows to each of the scenarios are identical, by adding all of the diversion above a mainstream gauge onto the flow at the gauge should yield approximately the same answer in all scenarios. If the net inflow is fixed, to preserve mass balance, the net outflow should also be fixed. The numbers should be approximately equal, with small differences from changes in evaporation from additional storage water surfaces, and storage. Changes in storage are due to differences in initial and final storages in the model. Net outflows are compared to the storage in the model. The results of the mass balance check are presented in Table 8.1.

Table 8.1. Mass balance check u/s Kratie

Scenario	Average annual simulated volumes (mcm)					
	Flow at Kratie	D&I diversions	Net irrigation diversions	Inter-basin diversion	Total	% difference to Baseline
Baseline	398,877	1,003	11,306	0	411,186	0
China Dams	398,427	1,003	11,306	0	410,736	-0.11
Low dev.	395,996	1,753	13,482	0	411,231	0.01
Embankments	395,996	1,753	13,482	0	411,231	0.01
Agriculture	387,511	2,087	19,897	1,871	411,366	0.04
High dev.	387,750	2,088	19,911	1,871	411,620	0.11

The results of this test show a good agreement at Kratie. It also shows an expected increase in diversions. Note the larger error for the China dams and high development models is because of the change in storage volume of the dams between the start and end of the model run and the increase in evaporation loss on the dam surface areas.

The Vietnam border is the last gauging location where a total mass balance of the model can be made. This location gives a good indication of the overall mass balance of the model. The results of this check are presented in Table 8.3.

Table 8.2. Mass balance check at Vietnam border

Scenario	Average annual simulated volumes (mcm)					
	Flow at Kratie	D&I diversions	Net irrigation diversions	Inter-basin diversion	Total	% difference to Baseline
Baseline	475,132	1,121	15,355	0	491,609	0
China Dams	475,132	1,121	15,355	0	491,609	0
Low development	473,700	2,128	18,834	0	494,663	0.7
Embankments	475,827	2,128	18,834	0	496,790	1.3
Agriculture	460,791	2,862	30,779	1,871	496,304	1.1
High development	461,870	2,864	30,792	1,871	497,398	1.4

The results of this test show a reasonable agreement at the border. It also shows an expected increase in the diversions. The larger error for the high development scenarios is because of differences between initial and final lake storage volumes. Most significant in December when the model run finishes and the effect of development is reasonably large.

A.2 Domestic and industrial demands

The model was configured to look at the growth in domestic and industrial demands. A check was done that the model is diverting the required demand. The target demand and the simulated diversions are shown in Table 8.3. There are times when simulated diversions are less than the target demand, particularly in Thailand. This is due to limitations on the water user being able to extract water from a dry river.

Table 8.3 Simulated and maximum domestic and industrial demands upstream of Kratie

Scenario	Thailand	Laos	Cambodia	Vietnam
	Demand (mcm) Diversion (mcm)			
Baseline	**935** 817	**116** 115	**4** 4	**53** 51
China Dams	**935** 817	**116** 115	**4** 4	**53** 51
Low development	**1,546** 1,336	**305** 301	**13** 13	**101** 96
Embankments	**1,546** 1,336	**305** 301	**13** 13	**101** 96

Agriculture	**1,750** 1,537	**388** 383	**27** 27	**128** 122
High Development	**1,750** 1,537	**388** 383	**27** 27	**128** 122

A.3 Irrigation demands

The irrigation demands were checked by calculating the expected demand using crop area, crop watering depth (adjusted for effective rainfall), and irrigation efficiency and diversion proportion returned. The comparison between diversions estimated by this method and the modelled diversions for the Baseline Condition, Lowe Development Condition, and Agriculture Development scenarios are presented in Table 8.4 – Table 8.6 respectively.

Table 8.4 Comparison of estimated irrigation demands and simulated demands for baseline development

Country / Crop	Crop area ('000 ha)	Irrigation depth (m)	Irrigation volume (mcm)	Efficiency factor	Total diversions (mcm)	Return fraction	Return volume (mcm)	Net diversion (mcm)	Simulated diversion (mcm)
Thailand									
Dry Season Rice	156	0.8	1,250	0.5	2,500	0.2	500	2,000	
Groundnut	9	0.4	35	0.5	70	0.2	14	56	
Kenaf	16	0.2	31	0.5	62	0.2	12	50	
Maize	15	0.5	75	0.5	151	0.2	30	121	
Mung Bean	2	0.3	6	0.5	12	0.2	2	10	
Soybean	7	0.4	29	0.5	59	0.2	12	47	
Wet Season Rice	1,217	0.2	2,434	0.35	6,955	0.3	2,087	4,869	
Total	**1,422**		**3,862**		**9,810**		**2,657**	**7,152**	**7,855**
LAOS									
WS rice (N+C)	122	0.25	306	0.5	612	0.3	184	428	
WS rice (S)	44	0.25	111	0.5	222	0.3	67	155	
Dry rice	128	1.1	1,406	0.5	2,811	0.1	281	2,530	
DS early veg	10	0.4	39	0.5	77	0.1	8	69	
DS late veg	28	0.4	111	0.5	222	0.1	22	200	
Total	**332**		**1,972**		**3,944**		**561**	**3,383**	**2,590**
CAMBODIA									
Early WS rice	403	0.2	806	0.6	1,343	0.3	403	940	
Mid WS rice	703	0.4	2,814	0.6	4,690	0.3	1,407	3,283	
Dry rice	250	0.7	1,752	0.6	2,921	0.3	876	2,045	
Total	**1,357**		**5,372**		**8,954**		**2,686**	**6,268**	**4,248**
VIETNAM									
Highlands									
Win-Spr Rice	45	0.9	404	0.5	807	0.3	242	565	
Sum-Aut Rice	5	0.4	20	0.5	41	0.3	12	29	
Main Rice	125	0.4	501	0.5	1,002	0.3	301	701	
Mekong Delta									
D-Dry spring	1,514	0.7	10,597	0.8	13,246	0	-	13,246	
D-Wet Sum Aut	1,871	0.4	7,483	0.8	9,354	0	-	9,354	
D-Wet Aut-Win	210	0.3	629	0.8	786	0	-	786	
D-Wet main	542	0.1	542	0.8	678	0	-	678	
Total	**4,312**		**20,176**		**25,914**		**555**	**25,359**	**25,689**
Grand total	**7,423**		**31,255**		**48,367**		**6,434**	**41,932**	**40,372**

Table 8.5. Comparison of estimated irrigation demands and modelled demands for low level development

Country Crop	Crop area ('000 ha)	Irrigation depth (m)	Irrigation volume (mcm)	Efficiency factor	Total diversions (mcm)	Return fraction	Return volume (mcm)	Net diversion (mcm)	Simulated diversion (mcm)
Thailand									
Dry Season Rice	187	0.8	1,500	0.55	2,479	0.2	496	1,983	
Groundnut	10	0.4	40	0.55	67	0.2	13	53	
Kenaf	18	0.2	36	0.55	60	0.2	12	48	
Maize	18	0.5	89	0.55	146	0.2	29	117	
Mung Bean	2	0.3	7	0.55	11	0.2	2	9	
Soybean	9	0.4	34	0.55	56	0.2	11	45	
Wet Season Rice	1,423	0.2	2,846	0.35	7,350	0.3	2,205	5,145	
Total	**1,667**		**4,552**		**10,170**		**2,769**	**7,401**	**8,614**
Laos									
WS rice (N+C)	184	0.25	459	0.5	918	0.3	275	643	
WS rice (S)	67	0.25	166	0.5	333	0.3	100	233	
Dry rice	191	1	1,913	0.5	3,827	0.1	383	3,444	
DS early veg	14	0.4	58	0.5	116	0.1	12	104	
DS late veg	39	0.4	157	0.5	313	0.1	31	282	
Total	**495**		**2,753**		**5,506**		**801**	**4,706**	**3,820**
Cambodia									
Early WS rice	602	0.2	1,205	0.6	2,008	0.3	602	1,406	
Mid WS rice	1,054	0.4	4,214	0.6	7,024	0.3	2,107	4,917	
Dry rice	375	0.7	2,625	0.6	4,375	0.3	1,312	3,062	
Total	**2,031**		**8,044**		**13,407**		**4,022**	**9,385**	**5,624**
Vietnam									
Highlands									
Win-Spr Rice	52	0.9	468	0.5	936	0.3	281	655	
Sum-Aut Rice	6	0.4	24	0.5	48	0.3	14	33	
Main Rice	145	0.4	581	0.5	1,162	0.3	349	814	
Mekong Delta									
D-Dry spring	1,514	0.7	10,597	0.8	13,246	0	-	13,246	
D-Wet Sum Aut	1,871	0.4	7,483	0.8	9,354	0	-	9,354	
D-Wet Aut-Win	210	0.3	629	0.8	786	0	-	786	
D-Wet main	542	0.1	542	0.8	678	0	-	678	
Total	**4,340**		**20,324**		**26,210**		**644**	**25,566**	**25,793**
Grand total	**8,533**		**35,673**		**55,293**		**8,236**	**47,058**	**43,852**

Table 8.6. Comparison of estimated irrigation demands and modelled demands for high development

Country Crop	Crop area ('000 ha)	Irrigation depth (m)	Irrigation volume (mcm)	Efficiency factor	Total diversions (mcm)	Return fraction	Return volume (mcm)	Net diversion (mcm)	Simulated diversion (mcm)
Thailand									
Dry Season Rice	412	0.8	3,300	0.55	5,454	0.2	1,091	4,363	
Groundnut	10	0.4	40	0.55	67	0.2	13	53	
Kenaf	18	0.2	36	0.55	60	0.2	12	48	
Maize	18	0.5	89	0.55	146	0.2	29	117	
Mung Bean	2	0.3	7	0.55	11	0.2	2	9	
Soybean	9	0.4	34	0.55	56	0.2	11	45	
Wet Season Rice	1,423	0.2	2,846	0.35	7,350	0.3	2,205	5,145	
Total	**1,892**		**6,352**		**13,145**		**3,364**	**9,781**	**10,780**
Laos									
WS rice (N+C)	367	0.25	918	0.5	1,836	0.3	551	1,285	
WS rice (S)	133	0.25	333	0.5	665	0.3	200	466	
Dry rice	382	1	3,818	0.5	7,637	0.1	764	6,873	
DS early veg	29	0.4	116	0.5	231	0.1	23	208	
DS late veg	72	0.4	289	0.5	578	0.1	58	521	
Total	**983**		**5,474**		**10,948**		**1,595**	**9,353**	**7,539**
Cambodia									
Early WS rice	1,209	0.2	2,418	0.6	4,030	0.3	1,209	2,821	
Mid WS rice	2,110	0.4	8,442	0.6	14,069	0.3	4,221	9,849	
Dry rice	751	0.7	5,257	0.6	8,762	0.3	2,629	6,134	
Total	**4,071**		**16,117**		**26,862**		**8,059**	**18,804**	**11,478**
Vietnam									
Highlands									
Win-Spr Rice	67	0.9	605	0.5	1,211	0.3	363	847	
Sum-Aut Rice	8	0.4	31	0.5	61	0.3	18	43	
Main Rice	188	0.4	751	0.5	1,503	0.3	451	1,052	
Mekong Delta									
D-Dry spring	1,514	0.7	10,597	0.8	13,246	0	-	13,246	
D-Wet Sum Aut	1,871	0.4	7,483	0.8	9,354	0	-	9,354	
D-Wet Aut-Win	210	0.3	629	0.8	786	0	-	786	
D-Wet main	542	0.1	542	0.8	678	0	-	678	
Total	**4,399**		**20,639**		**26,839**		**832**	**26,007**	**26,012**
Grand total	**11,345**		**48,582**		**77,794**		**13,850**	**63,944**	**55,809**

The tables show a good agreement between the estimated and modelled diversions for all countries except Cambodia. This difference is particularly large for the high development scenario. Further investigation of the Great Lake model revealed that the differences between estimates and the model is because of limits on water availability in the tributaries around the Great Lake particularly from January to April. This affects the irrigation reliability in the model. Further work on these irrigators should be considered to determine if all of them are constrained by access to water or if they have access to water from the Great Lake. It may also be possible to distribute more of Cambodia's growth to areas that have more access to water.

A.4 Spatial and temporal distribution of water

The distribution of mass throughout the basin and each scenario gives an indication of how water extractions and inflows are affecting the flows within the basin. This gives a good indication of the relative impacts of development throughout the basin. The results of this analysis are presented in Table 8.7 – Table 8.12. Note the numbers in the tables are mean volumes in mcm.

Table 8.7. Flow and diversion distribution for Baseline Development Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**A**	**N**	**D**	**Total**
Nong Khai													
D&I diversions	13	12	13	12	12	12	12	13	12	13	13	13	**149**
Irrigation diversions	101	91	60	12	1	166	163	109	149	196	125	113	**1,287**
Simulated flows	3,493	2,617	2,919	3,836	7,572	11,467	20,892	27,309	24,896	15,532	8,219	4,990	**133,741**
Pakse													
D&I diversions	80	67	76	76	67	71	75	80	84	87	85	86	**933**
Irrigation diversions	753	661	444	131	335	747	1,375	1,177	1,166	1,545	951	773	**10,057**
Simulated flows	5,622	4,040	4,438	5,848	12,554	26,978	47,986	69,328	60,756	31,993	14,295	8,413	**292,250**
Kratie													
D&I diversions	85	72	81	81	73	77	81	86	90	93	91	92	**1,003**
Irrigation diversions	961	857	557	222	382	800	1,398	1,197	1,174	1,570	1,128	1,059	**11,306**
Simulated flows	7,167	5,089	5,405	6,791	14,637	34,831	63,481	92,349	85,886	49,449	21,737	12,055	**398,877**
Kratie to Vietnamese Border													
D&I diversions	95	80	91	91	83	87	91	97	100	104	101	102	**1,121**
Irrigation diversions	1,807	1,220	916	929	521	840	1,706	1,208	1,192	1,588	1,329	2,098	**15,355**
Simulated flows	32,342	18,501	13,344	8,585	9,072	14,868	30,553	52,489	74,339	91,481	78,330	51,231	**475,132**
Downstream of Vietnamese Border													
D&I diversions	128	111	124	123	117	119	124	130	132	137	133	134	1,511
Irrigation diversions	5,251	4,875	2,575	7,264	2,550	1,592	2,251	1,708	1,400	1,618	3,687	5,600	40,372

Table 8.8. Flow and diversion distribution for Chinese Dams Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	F	M	A	M	J	J	A	S	A	N	D	Total
Nong Khai													
D&I diversions	13	12	13	12	12	12	12	13	12	13	13	13	149
Irrigation diversions	101	91	60	12	1	166	163	109	149	196	125	113	1,287
Simulated flows	5,303	4,310	4,494	5,176	8,201	11,962	18,336	23,377	22,532	15,221	8,281	6,104	133,300
Pakse													
D&I diversions	80	67	76	76	67	71	75	80	84	87	85	86	933
Irrigation diversions	753	661	444	131	335	747	1,375	1,177	1,166	1,545	951	773	10,057
Simulated flows	7,325	5,751	6,072	7,242	13,328	27,563	45,857	65,254	58,180	31,471	14,354	9,404	291,801
Kratie													
D&I diversions	85	72	81	81	73	77	81	86	90	93	91	92	1,003
Irrigation diversions	961	857	557	222	382	800	1,398	1,197	1,174	1,570	1,128	1,059	11,306
Simulated flows	8,828	6,805	7,058	8,204	15,473	35,440	61,531	88,243	83,227	48,835	21,796	12,988	398,427
Kratie to Vietnamese Border													
D&I diversions	95	80	91	91	83	87	91	97	100	104	101	102	1,121
Irrigation diversions	1,807	1,220	916	929	521	840	1,706	1,208	1,192	1,588	1,329	2,098	15,355
Simulated flows	32,861	19,778	15,133	10,456	10,612	15,881	31,281	51,982	71,775	88,293	76,692	50,663	475,408
Downstream of Vietnamese Border													
D&I diversions	128	111	124	123	117	119	124	130	132	137	133	134	1,511
Irrigation diversions	5,251	4,875	2,575	7,264	2,550	1,592	2,251	1,708	1,400	1,618	3,687	5,600	40,372

Table 8.9. Flow and diversion distribution for Low Development Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**A**	**N**	**D**	**Total**
Nong Khai													
D&I diversions	24	22	24	23	23	23	24	24	24	25	24	25	285
Irrigation diversions	157	138	96	19	2	200	184	121	162	231	184	175	1,669
Simulated flows	4,184	3,300	3,873	4,668	7,883	11,778	19,405	24,989	23,813	14,986	8,453	5,424	132,754
Pakse													
D&I diversions	139	114	128	125	116	122	127	137	146	152	148	150	1,604
Irrigation diversions	922	798	532	149	370	912	1,492	1,333	1,394	1,803	1,172	980	11,859
Simulated flows	6,926	5,279	5,769	6,838	12,942	26,705	45,562	65,495	58,714	31,037	14,717	9,409	289,395
Kratie													
D&I diversions	151	125	140	137	129	135	140	150	158	165	161	163	1,753
Irrigation diversions	1,193	1,051	679	269	437	985	1,520	1,357	1,404	1,838	1,401	1,349	13,482
Simulated flows	8,413	6,297	6,739	7,812	15,152	34,702	61,319	88,588	83,742	48,297	22,003	12,931	395,996
Kratie to Vietnamese Border													
D&I diversions	181	152	169	168	162	167	173	183	190	198	192	194	2,128
Irrigation diversions	2,278	1,539	1,161	1,230	641	1,039	1,940	1,372	1,428	1,861	1,670	2,677	18,834
Simulated flows	32,701	19,287	14,429	9,818	10,298	15,987	31,351	51,878	72,257	89,357	75,938	50,399	473,700
Downstream of Vietnamese Border													
D&I diversions	245	210	233	230	226	229	237	247	252	262	254	256	2,881
Irrigation diversions	5,722	5,194	2,820	7,565	2,670	1,790	2,485	1,872	1,636	1,891	4,028	6,179	43,851

Table 8.10. Flow and diversion distribution for Embankment Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	F	M	A	M	J	J	A	S	A	N	D	Total
Nong Khai													
D&I diversions	24	22	24	23	23	23	24	24	24	25	24	25	285
Irrigation diversions	157	138	96	19	2	200	184	121	162	231	184	175	1,669
Simulated flows	4,184	3,300	3,873	4,668	7,883	11,778	19,405	24,989	23,813	14,986	8,453	5,424	132,754
Pakse													
D&I diversions	139	114	128	125	116	122	127	137	146	152	148	150	1,604
Irrigation diversions	922	798	532	149	370	912	1,492	1,333	1,394	1,803	1,172	980	11,859
Simulated flows	6,926	5,279	5,769	6,838	12,942	26,705	45,562	65,495	58,714	31,037	14,717	9,409	289,395
Kratie													
D&I diversions	151	125	140	137	129	135	140	150	158	165	161	163	1,753
Irrigation diversions	1,193	1,051	679	269	437	985	1,520	1,357	1,404	1,838	1,401	1,349	13,482
Simulated flows	8,413	6,297	6,739	7,812	15,152	34,702	61,319	88,588	83,742	48,297	22,003	12,931	395,990
Kratie to Vietnamese Border													
D&I diversions	181	152	169	168	162	167	173	183	190	198	192	194	2,128
Irrigation diversions	2,278	1,539	1,161	1,230	641	1,039	1,940	1,372	1,428	1,861	1,670	2,677	18,834
Simulated flows	32,872	19,312	14,418	9,842	10,261	15,969	31,353	51,964	72,695	90,139	76,334	50,668	475,827
Downstream of Vietnamese Border													
D&I diversions	245	210	233	230	226	229	237	247	252	262	254	256	2,881
Irrigation diversions	5,722	5,194	2,820	7,565	2,670	1,790	2,485	1,872	1,636	1,891	4,028	6,179	43,851

Table 8.11. Flow and diversion distribution for Agriculture Development Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	F	M	A	M	J	J	A	S	A	N	D	Total
Nong Khai													
D&I diversions	4,068	3,202	3,801	4,640	7,877	11,534	19,108	24,614	23,447	14,554	7,965	5,228	130,040
Irrigation diversions	29	26	28	27	28	27	28	29	29	30	29	29	337
Inter-basin diversion	0	0	0	0	0	187	277	359	357	365	326	0	1,871
Simulated flows	4,068	3,202	3,801	4,640	7,877	11,534	19,108	24,614	23,447	14,554	7,965	5,228	130,040
Pakse													
D&I diversions	162	142	162	158	135	141	146	157	168	176	170	172	1,888
Irrigation diversions	1,956	1,715	1,085	303	407	1,177	1,577	1,348	1,410	2,104	1,970	2,085	17,137
Simulated flows	5,909	4,352	5,134	6,625	12,846	26,314	45,201	65,085	58,325	30,400	13,639	8,258	282,087
Kratie													
D&I diversions	178	157	178	174	152	158	163	175	185	193	186	189	2,087
Irrigation diversions	2,408	2,126	1,331	535	540	1,308	1,624	1,382	1,425	2,174	2,350	2,694	19,897
Simulated flows	7,226	5,214	5,957	7,462	14,959	34,264	60,934	88,162	83,346	47,643	20,814	11,531	387,511
Kratie to Vietnamese Border													
D&I diversions	239	209	237	238	221	225	232	244	251	262	253	253	2,862
Irrigation diversions	4,510	3,110	2,332	2,567	1,065	1,445	2,521	1,416	1,476	2,222	2,893	5,222	30,779
Simulated flows	31,083	17,840	12,808	8,471	9,251	14,723	29,958	50,756	71,366	88,460	76,350	49,728	460,791
Downstream of Vietnamese Border													
D&I diversions	320	283	318	316	301	303	313	325	329	343	331	331	3,812
Irrigation diversions	7,954	6,764	3,990	8,902	3,094	2,197	3,065	1,916	1,684	2,252	5,251	8,724	55,795

Table 8.12. Flow and diversion distribution for High Development Scenario

Station and water balance component	Simulated volumes (mcm) (1986-2000 upstream of Kratie, 1996-2000 downstream of Kratie)												
	J	F	M	A	M	J	J	A	S	A	N	D	Total
Nong Khai													
D&I diversions	29	26	28	27	28	27	28	29	29	30	29	29	339
Irrigation diversions	269	234	161	36	5	285	213	133	170	306	343	319	2,473
Inter-basin diversion	0	0	0	0	0	187	277	359	357	365	326	0	1,871
Simulated flows	5,619	4,523	4,695	5,117	7,797	11,182	16,662	21,850	22,149	15,446	8,486	6,476	130,003
Pakse													
D&I diversions	163	143	162	158	135	141	146	157	168	176	170	172	1,890
Irrigation diversions	1,960	1,717	1,083	302	407	1,177	1,577	1,348	1,410	2,107	1,975	2,088	17,151
Simulated flows	7,526	5,799	6,080	7,074	12,337	25,827	43,069	62,136	56,887	31,161	14,557	9,594	282,045
Kratie													
D&I diversions	179	157	178	174	152	158	163	175	185	193	186	189	2,088
Irrigation diversions	2,412	2,128	1,329	535	540	1,308	1,624	1,382	1,425	2,176	2,355	2,697	19,911
Simulated flows	9,835	7,369	7,473	8,395	14,179	32,846	57,495	83,746	81,513	48,827	22,530	13,542	387,750
Kratie to Vietnamese Border													
D&I diversions	239	209	237	238	221	225	232	244	251	262	253	253	2,864
Irrigation diversions	4,514	3,111	2,330	2,566	1,065	1,445	2,521	1,416	1,476	2,225	2,898	5,225	30,792
Simulated flows	33,303	20,203	15,085	10,174	10,205	14,531	29,216	48,819	67,996	85,350	75,891	51,099	461,870
Downstream of Vietnamese Border													
D&I diversions	320	283	318	316	301	303	313	325	329	343	331	332	3,814
Irrigation diversions	7,957	6,766	3,988	8,901	3,095	2,197	3,065	1,916	1,684	2,255	5,257	8,727	55,809

These tables provide a large amount of information about the distribution of water throughout the LMB. These general points are noted:

(iv) The mean annual flow volume doubles from Nong Khai to Pakse, and trebles by Kratie. 20% of the mean annual flow at the Vietnamese border enters below Kratie.

(v) The domestic and industrial demand is relatively small and evenly distributed across months, with most of the demand between Nong Khai and Pakse. This can be attributed to the demand in the Mun and Chi basins. There is also a significant amount of demand in the delta.

(vi) For the baseline scenario, mean annual irrigation diversions upstream of Kratie are 3% of the mean annual flow at Kratie.

(vii) For the baseline scenario the proportion of irrigation diversions compared to the total are 3% at Nong Khai, 25% at Pakse, 28% at Kratie and 38% at the Vietnam border. The remaining 62% of the total diversions is in the Mekong Delta.

(viii) For the high development scenario the proportion of irrigation diversions compared to the total are 8% at Nong Khai, 32% at Pakse, 38% at Kratie and 57% at the Vietnam border. The remaining 43% of the total diversions is in the Mekong Delta region.

(ix) The largest component of irrigation demand in all scenarios is in the Mekong Delta Region.

(x) The major component of irrigation demand upstream of Kratie is between Nong Khai and Pakse. This is largely due to the irrigation in the Mun and Chi basins.

(xi) In the high development scenario the irrigation diversions is also significant in Cambodia.

(xii) Above Nong Khai the irrigation demand is reasonably evenly distributed between June and January.

(xiii) Between Nong Khai and Pakse the wet season demand is double the dry season demand.

(xiv) Between Pakse and Kratie the late wet season to early dry season demand is significantly increased.

(xv) The peak irrigation demand in the Mekong Delta is from December to January. The smallest demand is in September when crops are largely rain fed.

The following observations are made between scenarios:

(i) In the China dams scenario there is a decrease in flows between July to September and there is an increase in flows between January to April.

(ii) The impact of the dams in China is largest at Nong Khai. Relative impact diminishes downstream due to local inflows, which are quite significant compared to the China inflows.

(iii) There is only a small difference in flows and demands in the low and embankments development scenario.

(iv) The total demand in the agriculture and high development scenarios is approximately double the baseline scenario.

(v) In the high development scenario the flows from June to October are reduced while from November to April are increased. A large proportion of this redistribution is caused by the China dams.

(vi) The inter-basin demand is equivalent to the total domestic and industrial demand and 10% of the irrigation demand in the baseline scenario

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Appendix A: The Models

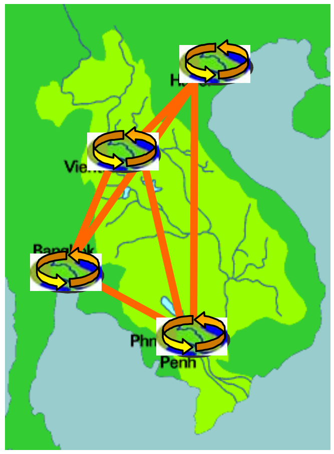
The Water Utilization Programme (WUP) Start-up Project funded by Global Environment Facilities/World Bank is intended to help the Mekong River Commission (MRC) member states to implement key elements of the 1995 Mekong Agreement. It provides the technical and institutional capacities required for a longer-term cooperation to sustainably develop and manage the basin's water and ecological resources. The goal is embedded in the "Rules for Water Utilization" and the "Basin Development Plan" (BDP) which are now in process of intensive formulation. Therefore the Component A of the project "Basin Modelling Package and Knowledge Base" was considered as fundamental to provide technical support to the "Rules formulation" (WUP Component B) and the BDP.

The objectives in developing the Basin Modelling and Knowledge Base were: (i) "Develop a Basin Modelling package for operational implementation of the Mekong Agreement, providing the analytical basis to help formulate, test and monitor the "Rules of Water Utilization", and supporting decision making for basin planning and management through assessment of the environmental and socio-economic impacts of development options; (ii) Create a sustainable modelling capability within the riparian countries (including NMCs and line agencies) and MRCS; and (iii) Build a Knowledge Base that is both physical and institutional in nature, integrating existing databases with the Basin Modelling Package".

A Decision Support Framework (DSF) has been developed, which contains the Knowledge Base, a Basin Modelling Package and Impact Assessment Tools.

The DSF was designed to assist in developing rules for water sharing amongst the four riparian countries in the Mekong River Commission and to support decision making for basin planning and management through assessment of the environmental and socio-economic impacts of development options. It was also set-up to assist planners to assess both the magnitude of changes brought about through natural and man-made interventions in the water resource system, as well as the impacts that these will have on the natural environment and upon people's livelihoods. The DSF achieves these by being able to model the behaviour of the river system under a wide range of different interventions. The DSF also provides a set of analytical tools by which to assess how these will affect key environmental and (to some extents) social indicators.

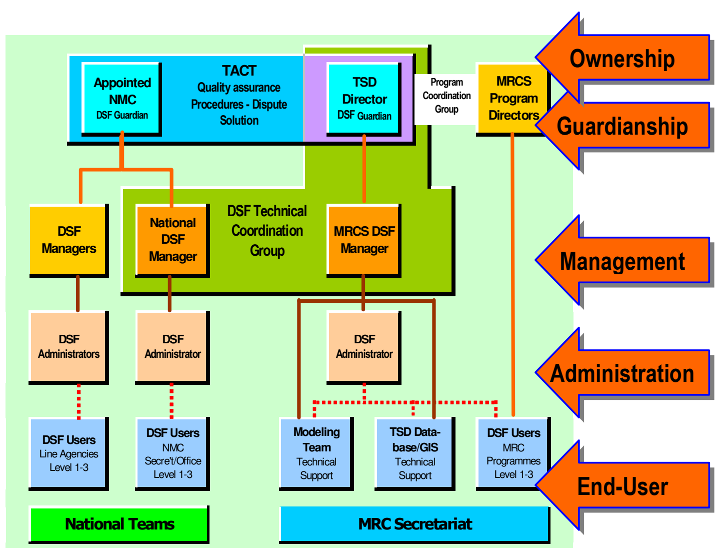
The models are set up to run simulations over a number of years (hydrological data for 1985-2000 are available throughout the LMB) or for a single year or season. The long-term simulation of data-series 1985-2000 with the system demand of year 2000 was regarded a s Baseline Conditions to numerous scenario assessment and hydrological analyses in the MRC programmes/projects, including the BDP and the technical arms of the "Rule formulation" - Integrated Basin Flow Management.



The system is being set up in each of the four countries with a master copy at the MRC Secretariat and 12 replicas installed at the NMC Office/Secretariat and designated line agencies. It is configured in a manner that allows local users to undertake their own analyses in private, to share these with others at their location when ready and finally to export these to other locations for others to review and verify.

The principle of institutional set-up is that the DSF is to be operated and maintained in a manner that encourages mutual trust between countries through the information provided and that therefore the integrity of the DSF needs to be maintained transparently.

Arrangements for administrating the DSF were stipulated in an Operational Procedures for the DSF which was unanimously agreed by all NMCs (May 2004), building around DSF Managers at each location supported by trained Administrators. Coordination amongst the DSF Operators is conducted through a DSF Technical Coordination Group (TCG) established in September 2004. While the MRCS and the four NMCs (at level of Director/Secretary General and CEO) possess ownership of the DSF copies installed in their respective agencies or (MRCS) division/programme, NMC-designated Officers and the Director of the MRCS Technical Support Division (TSD) are the guardian of the DSF and ensures coordination with other MRC programmes and national line agencies.



Programme/Project	Potential uses of the DSF within the MRC
Integrated Basin Flow Management	**Assessing acceptable impacts of alternative flow regimes (*thresholds & quantitative impacts*)**
Basin Development Plan	**Assessing impacts of alternative scenarios to find the "best", socio-economically, complying with the "Rules"**
Environment Programme	Platform for trans-boundary EIA and other studies
Flood Mitigation & Management programme	Developing flood management strategies, platform for flood planning and flood forecasting
Water Resources	Regional impacts of dams
Agriculture, Irrigation and Forest Programme	Regional impact of water use efficiency, land use strategies/planning, and catchment management plans
Fisheries Programme	Preservation of migration routes, spawning areas and impacts on habitats of fisheries species
Navigation	Identification of potential impacts on navigability
Implementation of 1995 Mekong Agreement	Impacts of proposed uses, and facilitating dispute resolution

The DSF is now intensively used in assessment works and analyses of BDP and IBFM. Potential uses of DSF in other MRC programmes/projects are quite widespread.

Each NMC is now able to use the DSF installed at their own office with constantly updated Knowledge Base (i) to test the scenarios simulated and analysed by the MRCS Modelling Team or BDP; (ii) to test for trans-boundary impacts from existing projects or proposed uses of other countries; (iii) to test their proposed use of Mekong River water prior any notification/prior consultation etc.; (iv) to create completely new scenario(s) from their national development plans and use the DSF as national analytical tool; (v) to develop their awareness and knowledge on the DSF capabilities, and DSF related skills in capacity building activities and on the endeavour of the DSF "institutionalization" to officially approve the DSF as the MRC planning and analytical tool.

- 1995 agreement
- Agreed sites for mainstream flow
- Definition of articles 6(a), (b), (c)
- Implementation Strategy
    - Phase I – Identification of flow-based rules in relation to Articles 6(a), (b), (c)
    - Phase II – Socio-economic and other implications
    - Phase III – (…)

Appendix B: Water Utilisation Programme

Rules and Procedures drafted under the Water Utilization Program and their relationship in support of the Basin Development Plan

Five rules or procedures are being drafted under the Start-up Project of the Water Utilization Program during the period 2000-2006 pursuant to the minimum requirements of the Mekong Agreement (ref. Article 26 requiring the adoption of Rules for Water Utilization and Inter-basin Diversions). These rules/procedures elaborate the Articles 5 and 6 provisions of the Mekong Agreement, and are part of the essential inputs for successful implementation of the Basin Development Plan (ref. Article 2)

1) Procedures for Data and Information Exchange and Sharing

and

2) **Procedures for Water Use Monitoring**

together elaborate the requirements of the Mekong Agreement Articles 24.C and 26 with respect to the central importance to the MRC of identifying key data areas, sharing data and information that is relevant to natural resources management, the establishing and maintaining of the MRC Information System (MRC-IS), and monitoring of water use through the improving/establishing and maintaining of a water use monitoring systems. Ongoing implementation of these procedures is carried out under the responsibility of a permanent standing committee of the MRC established by the Joint Committee known as the Technical Assistance and Coordination Team (TACT). The MRC-IS is an integrated date and information system maintained by the TSD as part of the MRC decision support system, which also includes the decision support framework (DSF) model.

3) Procedures for Notification, Prior Consultation and Agreement

elaborate the provisions of Article 5 (Reasonable and Equitable Utilization) of the Mekong Agreement, and subject to "a reasonable and equitable manner in their respective territories" and "pursuant to all relevant factors and circumstances" for any proposed use of water, especially out of the mainstream for intra-basin water uses and in-stream uses or structures that affect the flow regime (dams, weirs, channel improvement structures or actions), and inter-basin diversions of water out of the Mekong Basin.

(a) Notification" is a simple mechanism of notifying the MRC and its members of proposed intra-basin uses and inter-basin diversions on tributaries (wet and dry seasons) and the mainstream during the wet season. A notification identifies the proposed use, source, location, amount and impact, which when completed provides the continue right of use of that riparian. It enables Article 2 regarding the Basin Development Plan to assess project potential impacts, and plan the future uses of uncommitted water, thereby facilitating successful implementation of other provisions of the Mekong Agreement. Notification does not require approval or concurrence of other MRC members, e.g., it does not provide veto rights.

(b) "Prior consultation" is a more refined mechanism adopted in Article 5 because of the potential for interference with the rights of other riparians or causing harm from intra-basin water uses in the dry season on/from the mainstream and from wet season inter-basin diversions. This is to avoid or mitigate potential harm by informing the MRC and its members, and providing additional information so that each riparian could themselves assess if any potential interference or harm might occur to them. Although prior consultant

(c) "Specific agreement"' is the third mechanism of the framework for reasonable and equitable water utilization by which the proposing riparian entry into an agreement with the MRC for an inter-basin diversion project out of the mainstream (or tributary) in the dry season. This specific agreement would aim to facilitate development of water but prevent causing harm from a 100% depletion from an inter-basin diversion through the terms and conditions of project operation.

4) Rules for Maintenance of Flows on the Mainstream

Elaborate the provisions of Article 6 and 26 regarding the assessment and agreement of acceptable flows on the mainstream at 3 critical periods of its flow regime, namely:

(a) maintenance of minimum monthly flows during the dry season,

(b) maintenance of the natural reverse flow of the Ton le Sap, and

(c) prevention of peak flows during the flood season greater than what occur naturally.

In addition, theses rules define the criteria and selection of the mainstream stations required to monitor implementation of these rules. The RMFM provides the benchmark flows against which all BDP development scenarios must be assessed in order to be deemed acceptable under the terms of the Mekong Agreement and to provide awareness of the need for and the development of contingency plans during operation and management of flows on the mainstream. Flow assessments in support of determining acceptable flows under this rule are initially being developed based on the existing hydrology of the Mekong mainstream during IBFM Phase 1 in 2004 (Integrated Basin Flow Management). Following this, an integrated approach to assessing beneficial in-stream and on-stream uses and flow needs of mainstream flows (environmental, economic and social) and their trade-offs will be carried out during IBFM Phases 2 and 3 in 2005-2008, under the support initially of the WUP and latterly of the EP.

5) Rules for Water Quality (RWQ - to be agreed in 2005)

Will elaborate the water quality standards as requirements to be met by all member countries and promote integrated water quantity and quality management on the mainstream under the Mekong Agreement pursuant mainly to Articles 3, 5, 6 and 7.

The RMFM and RWQ will define institutional arrangements for implementing these rules through a venue for discussing and agreeing on the technical bases for these 2 technical rules through a permanent standing committee - the Technical Review Group (TRG) - of the MRC established by the Joint Committee. The TRG has the mandate to review and recommend flow and quality levels for implementation under the respective rule.

Appendix C: Basin Development Plan

The 1995 Mekong Agreement recognizes that development in Mekong countries is inter-dependent and that sustainable development requires consultation and cooperation between countries to maximize the opportunities for development while protecting existing uses. The Basin Development Plan provides a framework for regional cooperation among the riparian countries to develop and manage the water resources and related resources of the Lower Mekong Basin, based on the principles and practice of integrated water resource management. Phase 1 outcomes include

1. A Plan, consisting of:

- Broad, integrated analyses, at sub-area, national and basin wide level, of baseline conditions, water demand projections, opportunities, linkages and constraints, and development scenarios;
- Strategies for water-related, regional and transboundary development in the Lower Basin; and
- A portfolio of useful and practical projects and programmes that will support the strategy.

(2) A Planning Process, consisting of

- A functional, comprehensive network of participants and information flow;
- A knowledge base, comprising data, information, and decision-support tools for impact prediction and feasibility analyses;
- Routines for scoping, analysis and identification of recommended projects and programmes; and
- Initial practices for development, promotion and implementation of priority projects and programmes.

The BDP thus provides a platform for identification, promotion and implementation of important water-related development initiatives in the Lower Mekong Basin to the mutual benefit of the member countries.

The BDP has been prepared by a broad network of participants within each country, coordinated by the National Mekong Committees. The formulation process in itself has comprised a major education and capacity building programme. A close collaboration has been maintained with other MRC programmes - with WUP and the Environment Programme in connection with baseline studies and tools development; with all MRC programmes n connection with strategy formulation and project identification.

National and Sectoral Development Objectives

National development objectives and plans in each country have been reviewed under BDP as the starting point for the regional planning process, which must be congruent with national objectives. In all countries, the main emphasis is on sustainable use of water resources to promote economic growth and poverty alleviation. Protection of environment, maintenance of subsistence livelihoods and access to safe water and sanitation are very high priority. Reviews of the national plans, policies and legal frameworks are available in BDP Report 4 (2003).

National and regional sectoral plans and trends have also been reviewed (BDP Reports 9, 12, 17 (2002-2004)), and priority areas for cooperation in water resources development identified (see below).

More detailed studies have been undertaken at the level of 10 catchment-based sub-areas, to ensure that local issues and concerns are considered within the framework of a transboundary analysis. Sub-area studies have been carried out with involvement from provincial as well as national authorities. Sub-area analyses will be published in the form of reports, as well as a GIS-based BDP Planning Atlas. (Unpublished BDP reports in progress). A database is being collated on planned water resources projects within each country and each sub-area.

This information on water resource development needs, trends and plans in the LMB, combined with hydrological models provides the basis for analysis of potential water resource scenarios to inform strategy formulation (see BDP Reports 8, 14 and 15 on scenario formulation and assessment; and MRC-WUP 2004).

Trans-boundary impacts

Water resources development within one country may have impacts (both positive and negative) on its neighbours. The 1995 Agreement explicitly recognises this, and aims both to prevent and mitigate harm, and to promote mutual benefits through cooperation. Transboundary impacts of main concern include changes to:

- river flows in the mainstream (both low flows and floods)
- functioning of the Ton le Sap lake system
- water quality (including sediment and nutrient loads)
- fish migration routes and spawning areas
- navigation routes
- Channel and bank erosion.

An important concept in consideration of trans-boundary impacts is that of cumulative impacts – the state of the river is ultimately a function of all developments within the basin. While changes from a single development may not have perceptible impacts, the accumulated impacts of several developments can be large. Regional strategy formulation attempts to take into consideration the cumulative impacts of water resource developments in different sectors and different areas.

Resources availability and development opportunities

The abundance of surface water, low level of development and generally good water quality in the Mekong Basin indicate that very significant opportunities exist for exploitation and development of water and water-related resources. Except in the Vietnamese Delta and more mountainous parts of Lao PDR, land suitable for irrigation is not limiting; and abundant sites exist suitable for hydropower development. Potential for expansion of navigation and tourism is high. In many cases, access to markets may be more limiting for development than access to natural resources.

The pronounced seasonality of flows and current water shortages in some area suggest that major development of extractive uses (such as irrigation) will require construction of regulatory storages. High dependence on in-stream uses and the role of the flood pulse in maintaining the ecology of wetlands, the floodplain and Ton le Sap (and the associated fishery) mean that increased regulation must be approached with caution. Planned and on-going construction of very large storage dams in Yunnan (total planned storage of over 40,000 MCM) are likely to significantly increase dry season flows. Hydropower development in the LMB will exacerbate this effect, presenting both opportunities for increased dry season extraction, and potential threats to the fishery.

BDP has identified priority areas for development co-operation in eight major sectors:

- Navigation
- Fisheries
- Irrigation
- Hydropower
- Watershed management
- Flood management and mitigation
- Domestic water supply and sanitation
- Tourism

The emphasis is on both sectoral and cross-sectoral development, and on identifying trade-offs between sectors and between countries. Priorities for development are based on regional strategies for specific sectors formulated by MRC (for example, for navigation, hydropower and flood management), on national sector reviews, and on sub-area studies. Full descriptions can be found in the relevant BDP Reports (2003 – 2004) published as part of the BDP Archive; and in the MRC State of Basin Report (2003).

Socio-economic considerations in BDP

Socio-economic issues are of great importance in strategic basin planning, and have been reviewed at length in the MRC Social Atlas (MRC 2003a). Major issues include:

- Poverty alleviation
- Food security and food poverty
- Access to productive land and insecure land tenure
- Low agricultural productivity of subsistence agriculture
- Access to transport and marketing
- Access to education and health services
- Inequalities of income distribution

- Inequality between urban and rural areas
- Population Growth
- Unemployment and underemployment, particularly in rural areas
- Ethnicity and Gender
- Access to water, sanitation and electricity
- Human resource development

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Appendix D: Environment Programme

STATE OF KNOWLEDGE

This appendix will consider only river-related environmental issues ignoring environmental issues such as air quality, forestry, wildlife trade etc except inasmuch as they impinge on the river.

The present state of knowledge of the Mekong River environment is patchy. For some aspects of the environment there are reasonably good sets of collected data while for many others there is little or no information.

Water quality

There is reasonable information on standard chemical water quality parameters from about 50 sites in the delta and about 50 sites elsewhere in the basin and for the most part data quality is satisfactory. There is also more limited recent information on toxic chemicals (metals, pesticides and dioxins) in water and sediments from about 20 sites across the basin. Some key parameters such as chlorophyll and microbial contaminants are not presently monitored.

Hydrology

There is generally good information available on river flows although there are problems in the data from some sites. For example data between Kratie and Phnom Penh are not consistent, and show and appreciable decrease in flow which in inexplicable. Data on rainfall across the basin are generally poor – with few sites and some apparent problems with data quality.

River Health

Data on the river biota are inadequate. Data has been collected from only about 20 sites over the past 2 years, and there are still great difficulties in ensuring quality of sample analyses, and species identifications. A key to invertebrates is due to be published in 2005.

Status of Vertebrate Populations

There is good data available on dolphins, and reasonable data available on birds. There is almost no data available on reptiles and there are no data available on fish stocks.

Ecological Processes.

There is no data available on any ecological processes. There are no estimates on primary production (algal production) and chlorophyll data are too patchy to allow sensible estimates to be made. There is no data available on fish production, and there is no way meaningful estimates could be made at present. Note that fish production is not related to fish catch. Some data on fish catch have been collected under the MRC Fisheries Program.

River Geomorphology

There have been some small scale studies of river geomorphology but there are large gaps in data and understanding.

Terrestrial Ecosystems

Forest cover maps are available for the basin but are now somewhat dated. The most recent comprehensive map was produced in 1999 based on data up to 5 years previous. Since that time there has been extensive clearing for timber harvesting and to establish farming areas, particularly in eastern Cambodia.

MAJOR ENVIRONMENTAL BASIN ISSUES

Overharvesting

Overharvesting is probably the most urgent environmental issue in the Mekong Basin. It is particularly critical for fish, but there is intensive harvesting of reptiles, mainly snakes and turtles, especially around Ton le Sap Lake but also elsewhere, and also of many invertebrate species.

Harvesting pressure continues to increase both due to population increase and with improved technology. Fish traps in many areas of the floodplain are now built with insect mesh, thus trapping all fish including, larvae. The catch is often sold as feed for aquaculture operations. Replacement of the fishing lots system with community fisheries usually results in greater, albeit more equitable, fishing pressure.

In the absence of urgent action to reduce fishing pressure it is likely that there will be a large scale collapse in the fishery at least in Cambodia probably within the next decade. As some species become rarer, pressure on the more abundant species increases. As a result the decline of the fishery in Cambodia will be rapid. That will increase pressure in Vietnam – which presently obtains a significant part of the aquaculture “seed” and feed from the wild fishery in Cambodia. There is likely to be great pressure on southern Lao as fishers move from Cambodia to exploit the Lao fishery which is less heavily exploited at present, and with fish stocks sufficiently independent to be only slightly affected by the Cambodian collapse.

A number of large species are already rare or locally extinct within at least parts of the basin due to excessive harvesting. These include crocodile species, large fish species, dolphins in Ton le Sap Lake, and some turtle species.

Flow Regulation

Flow regulation occurs through construction and operation of dams. Impacts can be distinguished over a number of spatial and temporal scales. At the scale of tens to hundreds of kilometres operation of hydro dams can cause rapid fluctuations of stream discharge over periods of hours to days. This has been an issue in the basin in the river section downstream of Manwan Dam in China, at least as far as Chiang Saen in Thailand, as well as in the Se San river in Cambodia. It is likely also to be an issue in the Se Bang Fai River which will receive the discharge from Nam Theun II.

The smaller scale discharge fluctuations appear to substantially reduce fish populations and directly interfere with fishing activities. They also interfere with flood recession agriculture along river banks and sand bars. Within the river they will cause appreciable changes in the biota of the river, scouring algae and invertebrates which form the basis of the food chain.

At larger spatial scales the combined impact of dams will be a reduction of wet season flows and an increase in dry season flows. There are several potential impacts of such a change. One is a reduction in seasonally inundated are of the Cambodian/Vietnamese floodplains, including the area around Ton le Sap Great Lake. Such a reduction will reduce the overall productivity of the system, but will also trigger longer term changes in the distributions of plants and other species.

An increase in dry season flows is of concern since a number of fish species breed in the main channel during the dry season. There is an urgent need to obtain better information on the environmental triggers for breeding and migration of key Mekong River species, which is complicated by the fact that so many species are heavily utilized by local people. The river stretch from Khone Falls to downstream of Kratie is one example of a river stretch known to be a key breeding are for many Cambodian fish species.

Finally dams and smaller retarding structures trap sediment. There is very poor understanding of sediment movement, storage or loads in the Mekong. It appears likely that sediment loads increased in the 1950's when large areas of rainforest on steep topography were rapidly cleared to plant rubber to supply Chinese needs during the Korean war. Since 1985 sediment concentrations on mainstream sites and on the Khorat Plateau in Thailand have decreased, probably due to sediment trapping in dams and weirs. Certainly there was a decline in sediment concentrations in the Mekong mainstream at Chiang Saen immediately following the closure of Manwan Dam in China.

The consequences of sediment trapping by additional dams on the Mekong and its tributaries are difficult to predict. Areas of concern are areas in Lao PDR where there are already issues of bank erosion, since this could be exacerbated, and areas such as Siphandone where there are extensive areas of sand islands which could become less stable and begin to erode as a consequence of a reduced river sediment load.

Floodplain Connectivity

Floodplain connectivity refers to the connections between the floodplain and the river. It may be disrupted by the construction of levees along the river bank, or elevated roads that lack culverts across the floodplain, or flood protection structures around towns, buildings or agricultural areas.

Loss of the connections, through isolating sections of the floodplain has a number of socio-economic and ecological consequences. Flood regimes and extents maybe altered, impacting those living in the flooded areas. Biological assemblages may also change in habitats cut off from the river.

Flood prevention structures – such as levees, reduce the frequency and extent of flooding in protected areas but worsen flooding in unprotected areas. The floodwater has to go somewhere, and if the floodplain is not available, either floodwater is retained upstream or flood levels rise creating worse flooding downstream.

As well as exacerbating flooding in some areas, isolation of the floodplain from the river will lead to changes in the biota of the floodplain. Plant and fish assemblages in floodplain wetlands will change if their frequency of connection to the river alters. At present we know nothing about the extent to which these assemblages depend on particular frequencies of connection in a Mekong context. However we do know that many local communities rely heavily on the plant and animal resources present in these habitats.

In addition to levees intended to prevent flooding, roads across the floodplain are often built on solid earthen embankments to make them less vulnerable to flooding. In many cases such embankments have been built without culverts to allow the passage of water. Such structures can unintentionally alter the flooding frequency and inundation period of floodplain areas. They can also obstruct fish migration paths on the floodplain.

Finally landfilling may remove areas of floodplain. This is most common around cities such as Phnom Penh and Vientiane, floodplain cities where there is a demand for land close to the centre. While the total area of floodplain lost through landfill is small, it is often in critical areas. For example the floodplain wetland areas north and south of Phnom Penh play an essential role in purifying the city's waste water. If these are filled the impact of the city on the Bassac River in particular would be substantially more severe.

Water Quality

At present there are problems with nutrient enrichment throughout the delta, and elevated salinity at times in the Khorat Plateau streams, but throughout the rest of the basin water quality is generally good. However should there be increased industrialization as well as rapid population growth water quality problems will increase in areas around cities. The extent of the impact on the river will depend to a large extent on whether the large wetlands which are presently providing water purification services to cities such as Phnom Penh and Vientiane are retained. Should these wetlands be filled, or waste water diverted more directly to the river, pollution problems around those cities would rapidly exacerbate.

Critical Flow Related Issues

The critical flow related issues are those essentially already identified.

Changes in flow regime will potentially impact on floodplain vegetation, riparian vegetation, subsistence river bank gardens, fish, reptiles and invertebrates, and through them to the livelihoods of millions of people. We need to be aware that the impact of these changes will occur throughout the basin – not just around Ton le Sap Lake. The region in the basin most at risk from changes in the area of seasonal inundation is the Cambodian floodplain, but the stream channel will changed along its entire length, most markedly near the Chinese border. At present our ability to predict the extent of those changes for any given flow change scenario is almost nil. The present environmental flows work will attempt to improve our prediction ability, but it is working with a very limited budget and the work will take several years before predictions can be made with any confidence.

The previous work on flows in the basin has focused on model development using existing hydrological data. There has been almost no attention paid to improving understanding of the hydrology of the basin. For example the causes of anomalies in the hydrological data have not been addressed (e.g. why does the data indicate ~20% less flow at Phnom Penh than at Kratie?), and hydrology related issues such as the links between the river and groundwater have been ignored.

The significance of flow events or flow conditions as triggers or requirements for the biota of the basin has not been investigated. The MRC Fisheries program is presently refocusing to begin to address these issues for fish, but they are difficult to investigate and research capacity in the basin is low. Similarly the consequences of flow changes on human livelihoods have yet to be investigated. The interaction between people and aquatic resources have been investigated in several small scale studies but usually in ways that were technically limited.

While the DSF provides a powerful tool that can be used to assist the prediction of the consequences of flow changes we need to be aware that it is limited. When the only tool you have is a hammer everything looks like a nail. There is a tendency already apparent to ignore areas of impact which do not lend themselves readily to modelling. This can be seen in the focus on impacts on water levels around Ton le Sap Lake – a tricky and interesting modelling question, while the impact of flow changes on fish in the Kratie-Stung Treng area are ignored.

Global climate change

The impact of global climate change in the basin has been assessed through the cooperation under the ADAPT[i] Programme. For the Mekong Basin two SRES (Special Report on Emission Scenarios) of the IPCC were selected, A2 ("a differentiated world") and B2 ("local solutions"), under the HADCM3 model. The results for three time periods were produced 1961-90, 2010-39 and 2070-99, where the initial period was used for calibration. The results were downscaled to fit the SLURP model of the Mekong and the different time period results routed through the model.

The main results indicate that the mean temperature will increase from 24.3 C in the calibration period to 25.3 C in 2010-2039 and between 27.2-28.3 C towards the end of the century. Compared with the baseline 1961-90, during 2010-2039, mean precipitation in different sub-basins varies from about –6% to +6% in both scenarios A2 and B2, and increases to –12% to +32% in both scenarios A2 and B2 towards the end of the century. However, although there are differences between specific sub-basins there is little change to the overall water balance in the basin (± 0.2% for 2010-2039 and about 9-10% for 2070-2099).

The range and variability of both temperature and precipitation is expected to increase, with dryer and longer dry-seasons and shorter but more intense wet-seasons, resulting in higher maximum flows and lower minimum flows. Other studies on climate change in the Mekong region, such as the AIACC[ii] regional study AS07[iii], which used a scenario of double CO2 levels, have found similar results.

The implications of this could impact on irrigation which may need to focus on ensuring wet-season irrigation rather than expanding dry-season irrigation, it may mean that hydro power dams may need to increase their safety limits to handle greater volumes of water in shorter periods and reduce power output to ensure uninterrupted power supply. The hydrological changes are also likely result in higher frequency of extreme events such as floods and droughts. In addition to the impacts from changes in the water resources changes in temperature, evapotranspiration and relative humidity will impact on crops and vegetation in the basin.

[i] ADAPT: Water, Climate, Food and Environment under Climate Change: An Assessment of Global and Regional Impacts and the formulation of Adaptation Strategies for River Basins – The Mekong Basin in Southeast Asia (IWMI, IVL, MRC)

[ii] AIACC: Assessment on Impact and Adaptation on Climate Change

[iii] AS07: "Southeast Asia Regional Vulnerability to Changing Water Resources and Extreme Hydrological Events due to Climate Change."

Appendix E: Navigation

MRC's Navigation Strategy was approved by the MRC Joint Committee in August 2003 and the ministerial Council endorsed the Programme in December 2003. The Navigation Programme aims to promote freedom of navigation and increase the international trade opportunities for the MRC member countries' mutual benefit, by assisting in co-ordination and co-operation in developing effective and safe waterborne transport in a sustainable and protective manner for the waterway environment. The Program is based around the common drive by the four Lower Mekong Basin Countries to increase regional trade by opening up the Mekong River for cross-border navigation, as expressed in Article 9, Freedom of Navigation, in the 1995 MRC Agreement on the Co-operation for the Sustainable Development of the Mekong River Basin.

Major basin issues in Navigation

A. Legal Framework For Cross-Border Navigation

The present international regime of navigation on the Mekong is not satisfactory and operates more as an impediment than an encouragement to navigation development. The co-existence of more conventions relating to navigation on the Mekong leads to legal uncertainty as to the exact legal status of the river and causes fundamental policy and operational problems. By developing article 9 of the 1995 Agreement, the Navigation Programme will assist the MRC countries in establishing a legal and operational navigation framework, to increase trade and mitigate the risk for regional discords. The work will be founded on a comprehensive legal study of the Mekong navigational regime and will include preparation of draft framework agreements for maritime and inland navigation, facilitation of negotiations between Member States and mediation, operational cross-border procedures, and harmonisation and enforcement of common rules.

B. Safety And Efficiency Issues

The inland water transportation mode is the most efficient and safe mode for moving large quantities of bulk materials. Highway freight traffic is intermixed with cars and, in urban areas, with pedestrians. River barges however, share their right-of-way mostly with smaller craft and at a much slower speed. However, accidents to the crew and other waterway users occur, and damage to the environment will increase if no action is taken. Safety: It would be preferable if action were taken on a supranational level because of trans-boundary transportation. Issues to be addressed include:

- Safety of ship
- Safety of crew
- Safety of cargo
- safety of passengers

- safety of the port and port workers.

Efficiency: In many areas channel depths are insufficient for domestic and cross-border navigation. In order to make the inland waterway network more accessible, it would be necessary to improve the waterways concerned in such a way that they can be used by inland water vessels with a draught of 2.5~3.0 meters for not less than 300 days/year. Sea-River vessels, because of their dimensions require more depth (4 meter) and therefore can only use a limited portion of the inland waterway network to reach a certain number of river ports. The Navigation Programme will draw up an inventory of bottlenecks and look into removing the barriers, if deemed environmentally correct.

Many of the obstacles to the development of River-Sea transport are neither difficult nor expensive to solve. For example, custom procedures: maritime ships, on entering the inland waterway network on their way to an LMB inland port, have to undergo several customs clearance formalities, even if they have loaded their cargo in another LMB country. This causes increased costs, not only because of the interruption of the voyage, but also because extra fees have to be paid. It also gives River-sea transport a disadvantage when carrying out transport within the LMB (Viet Nam and Cambodia) as compared to the other modes that do not have to bear such extra expenses.

Unlike some of the world's great waterways, the flow and depth of the Mekong is essentially unregulated. This means that the passage of vessels along much of the river is constrained by the limited depth of water available in the main navigation channels during the dry season, and at the estuaries during low tide. Infrastructure for navigation along the river is otherwise limited to river training works and dredging activities on hot spots will, as is the case for most navigable waterway in the world. Other forms of infrastructure include bank protection, the provision of landing and cargo handling facilities at inland ports, and the installation of navigational aids.

C. Environmental Issues

The 1995 Agreement encourages environmental impact assessments of all investments that could have an impact on the Mekong. The existing legal frameworks for navigation do not hold any provisions for protecting the environment. There is a tendency to judge the environmental consequences of navigation projects severely. Clean navigation depends on legal and operational frameworks. The carriage of dangerous goods on the Mekong is the almost certainly the most risky scenario in an environmental sense. Spills of hazardous substances into the river might cause serious ecological damage downstream affecting large parts of the river and all those who depend on it. Spills can easily become a trans-boundary issue; it is important that all parties concerned are aware of the risks and are involved in trying to minimise these risks.

There are currently no environmental protection measures or funding to ensure 'green handling' of dangerous goods and for improving port facilities; there are no provisions for pollution prevention, nor are there contingency plans in case an accident occurs. Letting the physical development momentum continue instead of focusing on regulations, monitoring and enforcing appropriate and regional anti-pollution rules, is not sustainable at all, and therefore against the provisions in the 1995 Agreement.

D. Under-Utilisation Of The Potential

The Lower Mekong Basin has a great reserve navigation capacity which should be used. An inter-modal transport approach integrating waterborne transport with other modes is called for. It is also noted that the multiple functions of inland waterways are insufficiently borne in mind. There are great opportunities to be materialized through River-Sea navigation. It is generally recognised that investment in the waterborne transport in the LMB lags behind.

Not using the potential could not only restrict development but could result in economic losses. A socio-economic and technical feasibility study for the improvement of waterborne transport on the Mekong is required. If its potential is to be developed, inland waterborne transport and maritime access must be made a part of an integrated transport system, comprising all modes. Due to lack of data a comprehensive baseline study is a necessary step to justify and promote investments in the waterborne transport sector.

E. Social Issues

There is a limited understanding of the role of navigation in the reduction of poverty. For small communities, the Mekong River and its tributaries is a lifeline to the outside world. The knock on effects of increased trade should be recognised. MRC should develop systems to address critical social issues such as navigation in the flood season, how to promote sustainable tourism and how to assess impacts from navigation projects.

Other social issues:

- Limited access for remote areas to markets and social services (esp. women)
- Restrictions to tourist facilities on the river system
- Little employment opportunities in inland and maritime waterborne transport sector
- Low employment in related sectors
- High transport costs
- Lack of micro-finances and small scale investments for river transportation

F. Lack Of Data, Statistics And Operational Data, And Lack Of Coordination

Reliable and comparable traffic statistics and operation data are not available in the Mekong Basin. A major task for the navigation programme is to establish regional monitoring of cargo and passenger traffic. This lack of data concerns both domestic and international trade, origin-destination structures and modal split, which seriously hampers to develop a coherent view on future IWT development needs and requirements, and not sufficient for producing detailed, bankable feasibility reports concerning infrastructure related investments.

A common characteristic for the transport sector in the Mekong Region is the very strong public involvement. It will be necessary to involve the private sector in planning and coordination exercises in order to attract more investors and shipping agencies to the Mekong. The private sector itself needs assistance for better organisation of ship-owners, port authorities, and waterway administrators in order to gain influence on decisions by which they are affected. The creation of and support to regional and national industry associations is an important step in this direction.

The system itself and operational procedures should be developed in close cooperation with the future users of these systems such as port authorities, waterway administrations, pilots and operators. This will enhance the effectiveness of the system and contribute to solutions that are workable also in practice.

G. Institutional And Capacity-Related Issues

There is apparent to date a lack of regional coordination in the Lower Mekong Basin to develop, implement and coordinate regional navigation interventions. A fully functional institutional structure for the MRC Secretariat, the National Mekong Committees and at the relevant line agencies with working links to other stakeholders in the region is necessary to guarantee a successful implementation of this programme. In addition, this structure must be transparent and well communicated.

Appendix F: Fisheries Programme

1. The Importance of Mekong Fisheries

The fisheries in the LMB are immense, even by world standards. Recent studies have shown that the yield from the capture fisheries (including aquatic animals other than fish) in the rivers is around 2.5 million tonnes; from reservoirs about 250,000 tonnes; and production from aquaculture is also about 250,000 tonnes. The capture fishery yield is approximately 2% of the total world marine and freshwater capture fishery.

Extrapolation from average prices for capture and aquaculture product gives a first sale value for the fishery of about US$1.4 billion. The multiplier effect of trade in fisheries products would increase this value markedly.

There are at least 1,500 species of freshwater fish in the Mekong system. In terms of fish biodiversity, this makes the Mekong the 2nd richest in the world after the Amazon River. The Mekong has more families of fishes than any other river system. About 120 fish species are regularly traded.

The fisheries are nutritionally important for the people of the LMB. Fish are the primary source of animal protein, and a major supplier of several micro-nutrients, notably calcium and vitamin A. Consumption of fishery products (converted to fresh-fish-equivalent) is about 56 kg person-1 year-1, average consumption levels decreasing with increasing distance from the rivers. There are no readily available foods to substitute for fish in the diets of people in the LMB. Hence fisheries are extremely important for food security.

The bulk of the production comes from the riverine fishery, which is a renewable resource, available every year, unlike other natural resource industries like mining and petroleum. In addition, relatively little capital input is required in the riverine fishery to generate the product when compared to other natural resource or manufacturing industries.

Maintenance of the flood pulse and migration routes is fundamentally important for the health of the fisheries. The annual flood inundates vast areas of wetlands, creating highly productive fisheries habitats. The receding waters facilitate capture of the fish, some species of which are undergoing annual migrations to spawning grounds up-river. Many of the important commercial species (63% of the catch in the Cambodian river fishery) migrate long distances between spawning and nursery / feeding grounds. Barriers to migration have catastrophic impacts on the survival of these species, and thus fisheries productivity.

The LMB is home to approximately 60 million people. The increase in population places huge pressures on the fishery, both directly through increased fishing pressure and habitat loss, and indirectly through modification of water quality and quantity. The fishery is open access, and is one of the few sources of employment for an increasingly young, landless, unskilled rural population.

The Mekong is not just another river. It is immensely important for the livelihoods of people of the Lower Mekong basin, particularly in terms of its magnificent fisheries resources. Active management is required to protect the fisheries to ensure their availability for future generations.

2. Threats to Fisheries in the Mekong

The following 4 threats are "technical" threats to the sustainability of the fisheries resources in the Mekong.

2.1 Habitat loss

Destruction of fisheries habitat takes many forms. Any action which removes waterways and wetlands formerly available for fish is loss of habitat. It can be the removal of flooded forest from wetlands; it can be the "reclamation" of wetlands for agriculture or farming; it can be the removal of in-stream habitat for improvement of navigation; it can be as apparently benign as a road embankment, which acts as a barrier preventing the dispersion of flood waters. And habitat loss can occur indirectly, such as through watershed clearing, resulting in siltation which makes some habitats unsuitable for fish.

Very often these impacts when viewed in isolation are inconsequential, but when taken together, the cumulative impact can be severe. It is very difficult to estimate the loss of habitat available to fish in the Mekong, because the long-term data on habitats are not available. However, it is very considerable, especially in terms of flooded forests. Nevertheless, when compared to other large tropical flood-plain systems in the world, the Mekong remains in relatively good shape, as evidenced by the still comparatively high fisheries yields in the Mekong.

2.2 Barriers to Migration

Migration is a well-developed facet of the life-history of many species in the Mekong. The migration patterns of Mekong fishes have been well documented by the Fisheries Programme. Generally, the migrations occur between flood plains and spawning or refuge areas upstream of the flood plains. Any barriers, such as dams or weirs, across rivers which block these migration routes will drastically impact on fisheries production, both through loss of habitat and the potential cessation of spawning in some species. There are examples of dams in the Mekong system (but not on the mainstream) which have severely reduced previously very productive fisheries.

Fish ladders or other forms of fish passes are not a universal solution for fish passage past barriers. They do not work on high dams (higher than say 10 metres). They are incapable of taking the colossal numbers of fish sometimes migrating in the Mekong system. But, they should still be considered in any infrastructure developments involving low-level barriers.

2.3. Alterations to the natural flood pulse

The productivity of a monsoonal flood-plain system such as the Mekong depends primarily on the annual flood inundating the flood plain. Reducing the volume of the flood will result in less wetlands, hence reduced fisheries production. It is difficult to quantify the loss under different flow scenarios. One approach is to take estimated fisheries yields of 100-300 kg/ha/year from various types of wetlands, and assess the loss of wetland habitat associated with reduced flows.

Timing of the flood may also be important for fisheries production. The Mekong flood tends to peak every year within a very narrow time span (approximately 2 weeks). Fish have evolved with this flood timing. However, the relationship between flood timing and spawning or migration of fishes remains largely unknown. We simply do not know at this stage if delays in the flood of say 2-4 weeks would impact negatively on fish life cycles. Unfortunately, such data may be almost impossible to generate, except as post-hoc analyses.

2.4. Overfishing

Generally speaking, river fisheries are very resilient to fishing pressure, unlike many marine fisheries. River fish have evolved in systems subject to changing environmental conditions, and are adapted to take productive advantage of the flood. Many species also breed at a very young age. These factors allow the fisheries to be heavily exploited, yet still produce large yields every year.

Having said this, there is no doubt that many of the large, late-maturing species (such as icon species like the Mekong giant catfish and the giant barb) are already grossly overfished, to the point that they are highly endangered. And there is increasing evidence in some areas that the yields of smaller species may be reducing due primarily to intensive fishing pressure. Yields per fisher have definitely declined over the last few decades, but note this does not indicate a declining fishery – the total yield could in fact be higher now than before.

The obvious causes of overfishing are two-fold: an increasing rural population, with few employment opportunities and skills, but with right of entry to the effectively open-access fisheries; and the availability of gill nets, which are easy to use, highly effective, non-selective and cheap.

Introducing effective fisheries management in the Mekong region will be enormously difficult. We are faced with poverty, and poor people see little benefit in sacrificing short term gains for long term generalised benefits. Access to the fishery will be extremely difficult to control, especially given the ineffective governance systems currently operating. But if fishing effort is not controlled one way or another, there is no doubt that the fishery will decline within probably the next few years.

So far we have discussed "technical" threats to the fisheries of the Mekong. It is important to appreciate there are other threats, more sociological in nature. These follow.

2.5. Lack of understanding of the importance of Fisheries

It is probable that some natural resource planners and government agencies do not appreciate the importance of fisheries in the region. This represents a real danger to the sustainability of the fisheries – as can be seen above, three of the four principal threats to fisheries actually arise from interventions outside the fisheries sector. For fisheries to be adequately protected, all agencies associated with river management need to fully understand the importance of the fisheries for the livelihoods of rural people – people who generally have few other livelihood alternatives.

2.6. Difficulties promoting a "no change" approach

Maintaining the fisheries in the Mekong to a large extent requires that we minimise alterations to the natural flow and functioning of the river system. Governments, on the other hand, require changes to demonstrate their positive record on development. Hence, arguments to maintain the fisheries can easily be misconstrued as negativity, or opposition to development. This can, in turn, lead to non-acceptance of any concerns from the fisheries sectors.

2.7. Difficulties in quantifying impacts

Fisheries ecology is complex, and there are numerous variables affecting fisheries productivity. The response of fish populations to impacts cannot be predicted with certainty. Thus it is hard to give quantitative answers to questions about the impact of a particular development on the fish yields. This can result in fisheries being at a disadvantage when being compared with other uses of the land and water which can be easily quantified (e.g., megawatts of hydropower, or hectares of irrigation).

2.8. Misconceptions regarding aquaculture

Aquaculture is often put forward as the panacea for declining river fisheries. Occasionally one encounters the argument that there is no point trying to maintain the river fishery, because we can completely replace it with aquaculture. This is an absurdity, and dangerous. Aquaculture is primarily an economic activity, not a food security activity. Much aquaculture is of carnivorous species, and obviously production of those species is a net consumer of protein. The river fishery naturally produces millions of tonnes every year, which comes to us effectively free. Aquaculture requires considerable inputs. And the yields from aquaculture in the region will never equate to the yields from the Mekong fisheries.

Nevertheless, aquaculture does have a role to play in contributing to food security and livelihoods in areas remote from rivers, if the cultured species are herbivorous or omnivorous (that is, they are not net consumers of protein).

3. Opportunities

With respect to the World Bank's review of its involvement in the Mekong region, there are two higher-level opportunities that immediately come to mind. Both are within the context of maintaining the invaluable fisheries of the Mekong – which indeed is the over-arching opportunity. As discussed in Section 1, it is difficult to over-estimate the importance of the Mekong fisheries, in terms of food security, employment and income for the rural people of the region. It is one of the World's great fisheries.

3.1. Contributing to effective management of the fisheries

In Section 2.4 we discussed the importance of effective fisheries management being developed and implemented to ensure the sustainability of the fisheries. The task of reducing (or not allowing an increase) in fishing pressure is extremely difficult and complex, and extends far beyond fisheries to include governance and sociological issues. It will be necessary for governments to buy-into the endeavour. In doing so they will face difficulties because of the need to get individuals and communities to agree to long term management of a resource that has traditionally been exploited for short term gain. It seems that an agency with the prestige and influence of the World Bank could play a very positive role in fisheries management initiatives in the Mekong region. Success will result in the sustainability of a resource immensely important for the people of the region. Failure will result in greater poverty and food insecurity.

3.2 Environmentally appropriate dam development

There is an excellent opportunity for the World Bank to ensure environmentally appropriate development of dams in the Mekong region. Many dams in the Mekong have been built and continue to be operated with no regard for the ecology of the river or the use of the river by downstream communities. Consequently, there is vehement opposition to the concept of dams, which is unfortunate as this simply polarises debate. What is needed is an approach that implements the important aspects of the World Commission on Dams report. From a fisheries perspective, the most important elements are siting of dams as far up tributaries as possible, and no dams on the mainstream or downstream reaches of major tributaries; incorporating environmental management plans, especially releases of water to mimic natural seasonal cycles, into the operation of the dams; and mitigation where appropriate (for instance, fish passes, destratification of reservoirs, maintaining fisheries habitat).

For this to be successful, a change in attitude is required from agencies responsible for dam construction and operation. Again, the influence of the World Bank would be helpful in broadening the perspective and understanding of the dam agencies.

Appendix G: Hydropower

The hydro potential of the Mekong and its tributaries is considerable and largely undeveloped. In the 1960s the Committee for the Investigation of the Lower Mekong Basin (known as the Mekong Committee) carried out extensive research and planned more than a dozen hydropower projects on the Mekong Mainstream but none of these were actually built due to decades of war and civil unrest. Although war and isolation in the region ended in the 1990s, so far only 5 percent (some 1,600 MW) of the lower basin's hydropower potential of approximately 30,000 MW have been developed, and these few projects are all on the tributaries. The only dams on the Mekong's mainstream are two in the upper basin in China, although more are under construction and consideration.

1. State of knowledge

Of the total potential of 30,000 MW for feasible hydropower projects in the Lower Mekong Basin, approximately 13,000 MW are on the Mekong's mainstream, and the remaining potential is on the tributaries (13,000 MW) on tributaries in Lao PDR, 2,200 MW on tributaries in Cambodia and 2,000 MW on tributaries in Vietnam). In the Upper Mekong Basin in Yunnan Province in the People's Republic of China, total hydro potential is an estimated 23,000 MW. The hydropower projects currently built in the Mekong Basin are shown in Figure 1 and their capacity is listed in Table 1.

2. Major basin issues

Most of the power generation projects currently planned in Thailand and Vietnam will be powered either by coal or natural gas. Some hydropower projects are planned as well as tributaries of the Mekong in Lao PDR and Vietnam. A small scale of run-of-the-river project is under consideration for the mainstream at Khone Phapheng Falls in Lao PDR, but this does not involve damming the river. No plans are actively being considered for hydropower projects that would involve damming the mainstream in the Lower Mekong Basin, and tributary projects will be limited for reason that include:

(d) Difficulties finding funds

Hydropower projects generally require high initial investment and a long payback period (the payback period for a hydropower projects is typically two or three times longer than that for a thermal power project). In recently years, because investment costs are so high and hydropower projects can have adverse impacts on the environmental and on local people, international funding agencies have been much less willing to fund projects.

(e) Undeveloped power markets

Most of the hydropower potential in the Lower Mekong Basin in Lao PDR and Cambodia, but these countries do not have a large enough domestic market (demand) to warrant developing large-scale projects. In the long term, a regional power network could enable Cambodia and Lao PDR to sell power to neighbouring countries with greater need for power. In the short term, only isolated hydropower projects intended largely for one-way power exports are likely to be developed. In these cases, developers must demonstrate that their projects are competitive with other power producers.

(f) Environmental and social impacts

Development of the Lower Mekong Basin's hydropower potential is likely to take some time because extensive investigations into the social and environmental impacts of proposed developments must be undertaken to insure that projects will not have adverse impacts. Assessing possible transboundary impacts is particularly challenging. Weighing the pros and cons of projects is difficult because too often emphasis is placed either on the economic benefits or on the negative consequences, without a balanced appraisal of both.

(g) Negative impacts of hydropower projects include;

changes in the volume and timing of river flows; decline in water quality; loss of biodiversity; loss of fisheries; blocking of the flow of sediment; resettlement of population and loss of livelihoods.

(h) Positive impacts of hydropower projects include:

harnessing of a renewable natural resource; lower levels of air and water pollution than occurs when fossil fuels generate power; increasing water flow in the dry season and reducing peak flow in the flood season; generating the electricity needed for economic development and improving living standards; and increasing government revenues through the scale of power to neighbouring countries.

3. Critical flow-related issues affecting achievement of MRC basin-development goals

(a) Hydropower development in China

China currently has plans to construct six dams/power stations, in addition to the two that are already operating. These are listed in Table 2.

Now that the first two dams, Dachaoshan and Manwan, have been constructed and are operating, some downstream impacts such as changing of the river's flow pattern, blocking of sediment and impacts on the environment have occurred. The reduction in suspended concentrations resulting from sediment trapping in Manwan dam is already apparent as far downstream as Pakse in southern Lao PDR. The next two projects, Xiaowan and Nuozhadu, will have much larger reservoirs and also change the fiver's flow on a seasonal basis.

Table 1. List of completed hydropower projects > 10MW.

Country	Name	Capacity (MW)	Output (GWh/year)	Commiss -ioning
China	Manwan	1,500	7,870	1993
	Dachaoshan	1,350	5,930	2001
Lao PDR	Nam Ngum	150	900	1971-85
	Xeset	45	150	1991
	Theun Hin Boun	210	1,645	1998
	Houay Ho	150	600	1999
	Nam Leuk	60	184	2000
	Nam Mang 3	40	140	2004
Thailand	Sirindhorn	36	115	1968
	Chulabhorn	15	62	1971
	Ubol Ratana	25	75	1966
	Pak Mun	136	462	1997
Vietnam	Dray Ling	12	70	1995
	Ya Li	720	3,642	2000

Table 2 List of planned an completed hydropower projects in the Mekong in China

Name of Project	Installed Capacity (MW)	Annual Generation (GWh)	Total Storage C. (million m³)	Catchment Area (km²)	Average Flow (m³/s)	Commiss -ioning
Gongguoqiao	750	1,670	510	97,300	985	
Xiaowan	4,200	18,540	15,130	113,300	1,220	2010-12
Manwan	1,500	7,780	920	114,500	1,230	1993
Dachaosan	1,350	7,090	880	121,000	1,230	2001
Nuozhadu	5,500	22,670	24,670	144,700	1,750	2013-16
Jinhong	1,500	8,470	1,040	149,100	1,840	2012-13
Ganlanba	150	1,010		151,800	1,880	
Mengsong	600	3,740		160,000	2,020	
Total	15,550	74,060				

Appendix H: Flood Management and Mitigation Programme

1. State of Knowledge (present condition)

Floods in the Mekong River Basin are annual events. Flooding of the mainstream and tributaries of the Mekong River is an important source for the wealth of biodiversity, abundance of fish and soil fertility in the basin. At the same time, each year, flooding results in loss of life and property, causes damage to agriculture and rural infrastructure and disrupts socio-economic activities of people living throughout the basin.

The southwest monsoon produces the seasonal high flows between June and September, and is associated with the largest floods, Although the discharge of the Mekong is remarkably predictable from year to year compared with rivers elsewhere, the flat topography of the lower Mekong floodplain, the high population density, especially within the delta region of Viet Nam, and the relative poverty of the people of the basin, ensure that floods are a significant problem. Analysis of the severe flood which occurred in 2000 has shown that it occurred largely because of tropical depressions crossing the coastline of Viet Nam at more northerly locations than usual at the same time as the annual flood peak arrived in the lower basin. However the hydrology of the Mekong is influenced by "el nino" events and is also changing due to the construction and operation of dams and changes in land use within the basin. Changes in hydrology may also be occurring due to longer term climate change.

In the past flood management and mitigation issues have been mainly handled by individual riparian countries. While the nature of flooding is a trans-boundary one it was therefore difficult to effectively manage the Mekong floods at regional scale. One of the past regional flood management activities has been the flood forecasting and early warning which started in the early 1970s and is becoming even more important core task of the MRC.

The Mekong River Commission has been developing hydrological models to allow flood forecasting and to better predict the effects of dam construction and water diversion on the natural resources of the river. The Flood Management and Mitigation Programme (FMMP) has been adopted to assist in ameliorating the deleterious effects of floods on the people of the basin while still enabling them to reap the benefits of the fish and other natural resources that the floods yield.

2. Major basin issues

In the Mekong Basin, causes and effects of floods are in many cases of a regional character. It is claimed that causes and contributing factors to flooding are, among other things, prolonged, heavy rains on saturated soils leading to an increase in surface run-off that can only slowly be discharged through the river system into the South China Sea.

There is a growing awareness that the magnitude and intensity of severe flooding in the Lower Mekong Basin, particularly in low-lying areas, is increasing, in part as a result of human intervention. Other factors include climate change, deforestation and land clearance in upland areas of the basin causing an increased volume and speed of surface run-off contributing to peak discharges and water levels.

Land degradation occurs in areas of intensive shifting cultivation, shortened fallow periods where agricultural systems are not adopted to topographic and soil conditions leading to increased erosion and sediment deposit in the Mekong River and its tributaries that can reduce drainage capacity, thus contributing at a regional scale to increased flood hazards.

Flood storage capacity has been changed to construction of flood embankments and other human-made structures designed to protect areas along the Mekong, reclamation of floodplains and wetlands resulting in a loss of storage capacity and mitigating effects of natural floodplain. Cumulative effects of many embankments result in loss of significant volume of floodplain storage that causes increased discharge and higher flood levels both upstream and downstream. Other contributing factors to flooding include rapid expansion of urban settlements and infrastructure, channel migration and other human-made modifications to river channels, reservoir operation, etc.

The flood damage will increase in parallel with on-going economic and infrastructure development and intensified land use in the Lower Mekong Basin, and it is imperative that physical development proceeds in a way that in itself minimizes the flood risk.

The FMMP adopted by the MRC would give new opportunities for enhancing regional cooperation and for improved flood management and mitigation in an integrated and holistic manner. It consists of five components: 1. Regional FMM Centre, 2. Structural measures and flood proofing, 3. Transboundary mediation, 4. Emergency flood management strengthening and 5. Land use management. The FMMP will provide an able and coherent platform for incorporation of flood issues into studies, planning activities and management framework developments undertaken or supported by the various MRC programmes.

3. Critical flow-related issues affecting achievement of MRC basin-development goals

The environmental benefits of flooding are considerable. Not only do they contribute to the ecological health of the basin but they are also important in maintaining livelihoods.

Flooding of agricultural land leaves behind silt deposits that add nutrients to the soils and thereby increases the soil fertility. Regarding the ecological health of the river system, it serves to flush pollutants that are deposited in the mainstream and tributaries during low flow periods, refills flood plain wetlands and recharge groundwater. Flooding is importance for fish and other wildlife, floodplain vegetation and river channel maintenance.

While the benefits of floods are obvious the flood management and mitigation issue is in general concerning severe/extreme floods. Critical flow-related issues affecting achievement of MRC basin-development goals are increasing frequency of serious floods, particularly in low-lying areas, which cause loss of life and damage to agriculture, infrastructure and people's property, maintenance of wetlands, changes in storage capacity of river channels and flood plains due to infrastructure development and expansion of urban development.