The MRC
Basin Development Plan

Scenarios for Strategic Planning

BDP Library Volume 4

March 2005
Revised November 2005

Mekong River Commission

BDP

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Foreword

The BDP Library was compiled towards the end of Phase 1 of the BDP Programme. It provides an overview of the BDP formulation, together with information about the planning process and its knowledge base, tools and routines.

The library incorporates the essence of more than a hundred technical reports, working papers and other documents. It consists of 15 volumes:

1 The BDP planning process
2 Sub-area analysis and transboundary planning
3 Sub-area studies (including 13 sub – volumes)
4 Scenarios for strategic planning
5 Stakeholder participation
6 Data system and knowledge base
7 MRCS Decision Support Framework (DSF) and BDP applications
8 Economic valuation of water resources (RAM applications)
9 Social and environmental issues and assessments (SIA, SEA)
10 IWRM strategy for the Lower Mekong Basin
11 Monographs. March 2005
12 Project implementation and quality plan
13 National sector reviews
14 Regional sector overviews
15 Training

The work was carried out jointly by MRC and the NMCs with comprehensive support and active participation by all MRC programmes and more than 200 national line agencies. Financial and technical support was kindly granted by Australia, Denmark, Japan, Sweden and Switzerland.

The library has been produced for the purpose of the BDP and is intended for use within the BDP Programme. The work was done from 2002 to 2005, and some information may already have been superseded by new developments and new knowledge. The library does not reflect the opinions of MRC nor the NMCs.

It is hoped that the work will contribute to the sustainable development of water resources and water-related resources in support of the MRC vision of *'an economically prosperous, socially just and environmentally sound Mekong River Basin'.*

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Acronyms and abbreviations

ADB	:	Asian Development Bank
BDP	:	Basin Development Plan (of the Mekong River Commission)
DSF	:	Decision-Support Framework (of the Mekong River Commission)
EIA	:	environmental impact assessment
FMM	:	flood management and mitigation
GIS	:	geographical information system
GMS	:	Greater Mekong Sub-Regional Economic Cooperation Programme (of ADB)
HAI	:	habitat availability index
IWRM	:	integrated water resources management
LMB	:	Lower Mekong Basin (the Mekong Basin parts of Cambodia, Lao PDR, Thailand and Viet Nam)
MCA	:	multi-criteria analysis
MDBC	:	Murray-Darling Basin Commission
MRC	:	Mekong River Commission
MRCS	:	Mekong River Commission Secretariat
NGO	:	non-governmental organization
NMC	:	National Mekong Committee
NRE	:	natural resources and environment
PIP	:	potentially impacted population
RBC/RBO		River Basin Committee/Organization
SEA	:	strategic environmental assessment
TSD	:	Technical Support Division (of the Mekong River Commission Secretariat)
UN	:	United Nations
WUP	:	Water Utilisation Programme (of the Mekong River Commission)

Acknowledgement

The scenario analyses were made in a close and active collaboration with the MRC core and sector programmes, who supplied data and information, as well as expertise and guidance.

The DSF itself was developed under the Water Utilisation programme by MRC's Technical Support Division.

Within the MRC, considerable assistance in obtaining and interpreting information relating to floodplain infrastructure was provided by NMC Liaison Officers in BDP, modellers and hydrologists in TSD, the Documentation Centre, Environment Program, Fisheries Program and WUP. Other information was kindly provided by consultants currently attached to the MRC, or who had conducted previous assignments, including personnel from DHI Water & Environment, CTi Engineering International, SYKE and Halcrow Group (UK).

The National Mekong Committees, the national BDP Units, and the many participating national line agencies kindly provided guidance, as well as data and information, and supported the work in all ways.

The DSF applications involved comprehensive technical and financial support from the Murray-Darling Basin Commission (MDBC).

The MRC BDP Team

Mr. Chanthavong Saignasith, Director, Planning Division
Mr. Boriboun Sanasisane, Director, Planning Division
Mr. Cong Nguyen Chi, Team Leader
Mr. Vu Van Tuan, Team Leader
Mr. Stephen Carson, Senior River Basin Planner
Mr. Manfred Staab, Senior River Basin Planner
Mr. Iwami Yoichi, Senior Advisor on River management
Ms. Robyn Johnston, Natural Resources Planner
Mr. Minoru Kamoto, River Management Expert
Ms. Muanpong Juntopas, Socio-economist/Sociologist
Mr. Trinh Hoang Ngan, River Basin Planner
Mr. Nouanedeng Rajvong, Water Resources Development Planner
Ms. Susan Novak, Senior Social Development Specialist
Mr. Oulavanh Keovilgnavong, Development Economist
Mr. Claus Aagaard Pedersen, Associate Social Economist
Ms. Petrina Rowcroft, Development Economist
Ms. Solieng Mak, Environmental/Natural Resources Planner
Ms. Arounna Vongsakhamphouy, Junior Riparian Professional
Mr. Bountieng Sanazonh, Junior Riparian Professional
Mr. Sokhavuthea Phet, Junior Riparian Professional
Mr. Pich Sambo, Hydrogeologist, Junior Riparian Professional
Ms. Worawan Sukraroek, Junior Riparian Professional
Ms. Vongchanh Indavong, Administrative Assistant
Mr. Sytha San, Administrative Assistant
Ms. Chitlatda Keomuongchanh, Secretary
Ms. Nalinthone Vissapra, Secretary
Ms. Phally Sok, Secretary

Consultants

Mr. Richard Beecham, Numerical Modelling Specialist, MDBC
Mr. Peter Chaudhry, Sociologist
Mr. Hugh Cross, Numerical Modelling Specialist, MDBC
Ms. Colette Curran, EIA Specialist
Ms. Kit Dyer, Training Specialist, MDBC
Mr. Lieven Geerinck, Navigation and Inland Waterways Specialist
Mr. Brian Haisman, Training Specialist ,MDBC
Mr. Jacob Hook, GIS Specialist
Ms. Fiona Lynn, Training Specialist ,MDBC
Mr. Harry Nesbitt, Agricultural Specialist
Mr. Tue Kell Nielsen, Water Resources and Environmental Planner
Mr. Malcolm Wallace, Water Resources Management Specialist
Mr. Keith Avery Ward, Economist

Executive summary

Introduction

This report presents investigations of the hydrologic and environmental impacts of a range of development scenarios.

Baseline and scenarios

The analysis has been performed relative to a Baseline Condition representing the level of development current in the year 2000.

Those development sectors that most impact water resources are:

- Hydropower, which will redistribute water from the wet season to the dry season; and
- Irrigation, which will divert large volumes of water from the Mekong River and tributaries in both the wet and dry seasons.

Consequently these form the core of the scenarios evaluated in this report:

Chinese Dams scenario:	■ high development in hydropower with low development in irrigation
Low Development scenario:	■ low development in hydropower with low development in irrigation
Irrigation scenario:	■ low development in hydropower with high development in irrigation
High Development scenario:	■ high development in hydropower with high development in irrigation

For each scenario, this report provides a first level attempt at a quantitative analysis of the following sector impacts:

- Navigation potential
- Salinity intrusion
- Flood management
- Fish habitat availability
- Fisheries productivity
- Environmental maintenance

Results

Key areas of opportunity include:

- Elevation of dry season flows by Chinese and LMB hydropower dams provides benefits for
    - Navigation
    - Saline intrusion in the Delta
- The natural level of inter-annual variability in flow magnitude, duration and timing, provides some scope for changes in flows without generating substantial impacts on ecological processes or condition
- Return of irrigation tail water reduces the negative impacts of water extraction, if of adequate quality and if returned close the extraction point
- Changes of a particular magnitude, a 0.4m change in water levels for instance, have a greater proportional impact on prevailing dry season flow level than wet season flows, due to the greater flow depth in the latter season

Major constraints include:

- High levels of dry season irrigation extraction, without compensating hydropower releases, which can lead to substantial reductions in dry season flows
- At the highest levels of irrigation development, the transition months, and even wet season flows, are impacted by the high level of irrigation water use
- High levels of irrigation extraction where return flows are not made close the point of extraction have a greater impact
- Inter-basin diversions can contribute in a cumulative manner to driving significant reductions in dry season flows
- Intra-basin diversions can cause significant reductions in dry season flows in the mainstream reaches by-passed by the diversion, for instance in the mainstream reaches between the diversions near Nong Khai to where return flows re-enter the Mekong at its confluence with the Nam Num near Pakse
- Tributaries will be more severely impacted than the mainstream by both irrigation extractions, and the impacts of dams on flow regimes and fish migration
- Changes in fish yield are directly linked to changes in wet season flows through the (assumed) linkages to inundated area and duration
- Salinity intrusion is closely linked to changes in dry season flows, which in turn appear to be coupled to the duration of wet season flooding

1 Introduction

The MRC Basin Development Plan (BDP) was instituted by the April 1995 Mekong Agreement. Following a series of preparatory studies, the BDP project document was approved by the MRC Council in October 2000. The BDP formulation (Phase 1) started in October 2001 and is scheduled for completion in July 2006.

The present report presents analyses of hydrologic and environmental implications of a range of development scenarios.

1.1 Origin of document

The document is a compilation of discussion and working papers prepared between July 2002 and March 2005:

Beecham, Richard and Hugh Cross (Mar 05): Modelled Impacts of Scoping Development Scenarios in the Lower Mekong Basin. MRC-BDP Working Paper

Haisman, Brian (Sep 03): Draft guideline on sub-area scenario formulation. MRC-BDP discussion paper

MRC-BDP (Jul 02): Report on BDP workshop on scenario formulation, Phnom Penh, 24-25 July 2002, with contributions by Brian Haisman, Mingsarn Kaosa-ard, and Malcolm Wallace

MRC-BDP (Jun 03): Assessment framework for the BDP. Discussion Paper

MRC-BDP (Mar 03): Scenario formulation and assessment. Discussion Paper

1.2 Basis and context

1.2.1 Link/relationship of subject to IWRM

The potential for further water resource development in the Lower Mekong Basin is large overall, but it is not equal between the four riparian signatory countries. This is a consequence of differing levels of past development, leading to very large differences in the current utilization of land and water resources in each country. It is also due to inherent hydrologic, topographic and socio-economic differences.

What binds the countries is the common need for development to keep abreast of rapidly growing populations and resource needs. Equally, all countries depend on the natural river flows to essential maintain benefits on which both the environment and people depend.

Consequently, the principles of Integrated Water Resources Management (IWRM) need to be applied to basin development planning to consider impacts not only for the intended sector and country, but across all sectors and countries.

1.2.2 Link/relationship of subject to BDP Inception Report

The BDP Inception Report (July 2002) retains the stage-wise approach to BDP formulation that had been identified during the programme formulation:

Stage 1 - analysis of the LMB and of sub-areas

Stage 2- analysis of development scenarios

Stage 3- strategy formulation

Stage 4 - compilation of long-list of programmes and projects

Stage 5 - compilation of short-list of programmes and projects

The analyses presented in the present report represent a sustantial contribution to Stage 2.

1.2.3 Link/relationship of subject to other BDP reports / activities

The analyses presented in the present report build on preceding studies under the BDP of baseline conditions, development opportunities, constraints and preferences at basin level and sub-area level. This work has been reported in a series of working papers, and in the consolidated report

> MRC-BDP (March 2005): MRCS Decision Support Framework (DSF) and BDP Applications

The knowledge produced provide detailed indications of the basinwide hydrological and environmental implications of a range of development scenarios that, between them, are regarded as covering the most likely perspectives for the future of the Lower Mekong Basin.

The results have provided an important part of the basis for the subsequent strategy formulation.

1.2.4 Link/relationship of subject to BDP's Logical Framework Matrix

In the BDP Logical Framework, the DSF analyses contribute comprehensively to

- Output 2.3 (Development strategies for sub-areas),
- Output 2.4 (Basin-wide development & management strategies), in general and to
- Activity 2.4.1 (Scenario review) in particular.

A part of the basis for the work was produced under

- Output 2.2 (20-year scenarios)

In turn, the results of the work are carried forward to

- Activity 2.4.2 (Management strategy components). and
- Activity 2.4.3 (Formulation of basin-wide strategies).

1.3 Significance

1.3.1 Significance of subject for strategic planning

The analyses presented in the present report provide an important initial insight into the hydrological boundaries within which the future is likely to evolve.

This knowledge is of obvious importance within strategic planning, particularly when the planning spans across a variety of water-related sectors with partly different needs and preferences with regard to the time and space distribution of water: Agriculture (including irrigatated agriculture), capture fisheries, hydropower, navigation, and so forth.

1.3.2 Significance of subject for Mekong Basin

The scenario analyses have illustrated opportunities, synergies and trade-offs in connection with various realistic development patterns, and have illustrated the significance of the finite availability of water.

Hereby, they provide strategic guidance and contribute to better specific decision-making in matters that affect or depend on the water availability and/or the demand of water.

1.3.3 Significance of subject for MRCS / BDP 1

Integrated Water Resources Management aims at balancing, in a holistic perspective,

- the water availability (as determined by rainfall and storage capacity);
- the demand of water, in the widest sense, for a variety of purposes; and
- the actual water utilization, as determined by the water availability and infrastructure.

In relation to the first phase of the MRC Basin Development Plan, the scenario analyses have expanded, structured and synthesized the knowledge about water availability, demands, and actual present and future uses.

2 Summary of approach

Background

This report builds on a process of scenario building and assessment conducted by the MRC over the past three years, centred around a new capacity to quantitatively forecast the water resource related outcomes arising from future levels of basin development. Those outcomes eventually need to be described in terms of the likely environmental, social and economic impacts.

The process has proceeded along two tracks.

Within the BDP, the scenario formulation started in mid 2002, and proceeded in a dialogue among and between the MRCS BDP team, the national BDP units, and all other MRC programmes. The work interacted with the national and regional sector reviews and the sub-area studies.

In parallel, the development of the MRC's Decision Support Framework (DSF) began in late 2001. Completed in early 2004, the DSF provides the essential predictive backbone for simulating hydrological changes in the LMB rivers, including the Mekong mainstream, major tributaries, Tonle Sap Lake and salinity levels in the delta. Three major computer models within the DSF, known by their acronyms, SWAT, IQQM and iSIS, together provide the capacity to simulate changes in flows and water quality caused by changes in landuse, climate, water use and management, structures such as dams and weirs, and floodplain embankments.

Confirmation of the DSF's capacity involved the development of demonstration planning scenarios, including for comparison purposes, baseline conditions representing the level of development current in the year 2000. Those demonstration scenarios have since been refined through the acquisition of more credible data on the likely level of particular basin developments, particularly those that are likely to have the greatest level of impact on water levels; additional or enlarged dams, and irrigation developments. Whilst a report prepared for the World Bank (World Bank, 2004[i]) improved on the assumptions made in the demonstration scenarios, it was the receipt of official information on development goals obtained from each member country in early 2005 that has enabled the scenarios in this report to be defined with greater accuracy and confidence. Hence the findings of this report may differ considerably from those in the World Bank report for some indicators, due simply to the differences in the level of development for scenarios that are otherwise labelled by the same name, i.e. Baseline Conditions, Chinese Dams, Low Development, Irrigation Development and High Development.

That said, there remains a considerable amount of work to include actual physical and operational parameter parameters for many existing developments, such as hydropower dam operational rules, irrigation crop planting rules and water demands, and floodplain embankments (height, location and operation). In fact, since adequate information could not be obtained on the probable location, nature and timing of floodplain embankments

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[i] World Bank, November, 2004). Modelled Observations on Development Scenarios in the Lower Mekong Basin. A technical report for the World Bank's Mekong Regional Water Resources Assistance Strategy

(downstream of Kratie), this scenario, included in the World Bank report, has been excluded from analysis here. Instead, a review of available information is presented on existing embankments with a view to indicate likely future trends and impacts.

The modelling and impact analysis tools currently available in the DSF need to be viewed as "work in progress"; they constantly need to be refined and added to. In that regard, there are a number of other tools outside of the DSF that can assist in the simulation and analysis of impacts arising from future basin development. Key amongst these are the WUP-JICA and WUP-FIN models of water quality and hydraulics in the Tonle Sap and Cambodian floodplain area, and in isolated areas of the Mekong River upstream, augmented by those programs' historical data analysis to derive key relationships. It is understood that the current phase of WUP-FIN is providing information using those tools to the WUP's work on IBFM Phase 2 (Integrated Basin Flow Management).

Another difference to the World Bank report must also be highlighted; that of the recalibration of the hydrologic models to provide better accuracy in the late dry season, relative to historical flows. Consequently, flows in April, May and June may be up to 40% lower than those simulated in the World Bank's scenarios.

Finally, where possible, scenario impacts have been broken down to with BDP planning sub-areas level, or to country level, whichever is more appropriate. In some sectoral analyses, such as fisheries productivity, the nature of the base data and assumed impact linkages, makes this inappropriate.

Scenario formulation [i]

Scenario is one of those English words that has been taken and used by certain professionals in a rather narrow manner. *Scenario,* in normal English, is a general term meaning a narrative or story line that describes a possible future situation or possible future series of events.

However, in various types of strategic planning, including river basin planning, scenario is the word used for a set of specific but hypothetical future events and circumstances. Such events will not necessarily happen, but are included in the scenario because it is possible for them to occur. The purpose of formulating scenarios is to have a structured process for evaluating expected outcomes that could occur if any particular scenario actually becomes reality in the future.

For water resource planning in a basin context, scenarios will primarily include any or all of three kinds of specific, and directly water-related, events:

1) Possible changes in water availability from the catchments of the river system. Such changes will mainly be caused by climate change of one kind or another, and/or by changes in catchment vegetation – such as commercial forestry replacing open moving agriculture. Changes may also be caused from upstream regulation that can alter flow regimes or total water availability.

2) Possible water diversions/extractions from the river system. This is generally expressed as the amount of water extraction at various places that is needed by people, towns, industries, agriculture etc. Scenarios are used to describe and enable

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[i] Entire section quoted from Haisman (Sep 03)

structured analysis of likely changes in demand over the study period – say caused by population growth, industrial development and so forth.

3) Interventions. This word is a sort of shorthand for actions taken by governments or individuals in a basin that in some way have an effect on the water resources of the basin. Interventions can be usefully thought of as "development options". They include dams, levees, and other physical interventions, but also include such things as policies, strategies and management plans, and other management actions such as monitoring and research. Collectively, the ultimately selected interventions comprise the basin development projects and programs.

In order to formulate a scenario that contains the three elements above (catchment conditions, water demands, and development options) it is necessary to conduct a strategic analysis of the study area – that is, sub-area or regional basin. This phase is not very much different from the familiar SWOT analysis – a survey of Strengths, Weaknesses, Opportunities and Threats.

To move to the next phase, which is the identification and assembly of potential elements of development options (interventions), an examination is made of possible future events in three categories:

Trends: These are events that we can observe are already happening, such as population growth. For planning purposes it is necessary to assess the likely range in magnitude of these trends.

Risks: These are events that might or might not happen in the future, such as a change in irrigated agricultural commodity prices. For planning purposes it is necessary to assess the likelihood of occurrence. The assessment of both trends and risks are interdependent – each affects the other. It is important to note that a risk does not always have only negative outcomes.

Interventions: These are events that can be made to happen and include any or all of the development options discussed above. Both trends and risks will influence selection of interventions and the outcomes from them.

The analysis can be further detailed under the following headings:

- Drivers of development and change
- Identified trends
- Identified risks
- Local development priorities / issues and concerns
- Potential development options

Decision Support Framework (DSF) analysis

The scenario analyses have been made using the MRC Decision Support Framework (DSF).

The DSF is a state-of-the-art computer based system providing the capability to investigate the environmental and socio-economic 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. 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 system comprises three main components accessed through a single user-interface:

- A Knowledge Base containing information on the historical and existing resources and, when fully populated, socio-economic and environmental conditions, as well as predictions of how these may change under possible future scenarios.

- A suite of Simulation Models that enable the prediction of impacts of changes in conditions within the basin on the river system, and

- 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

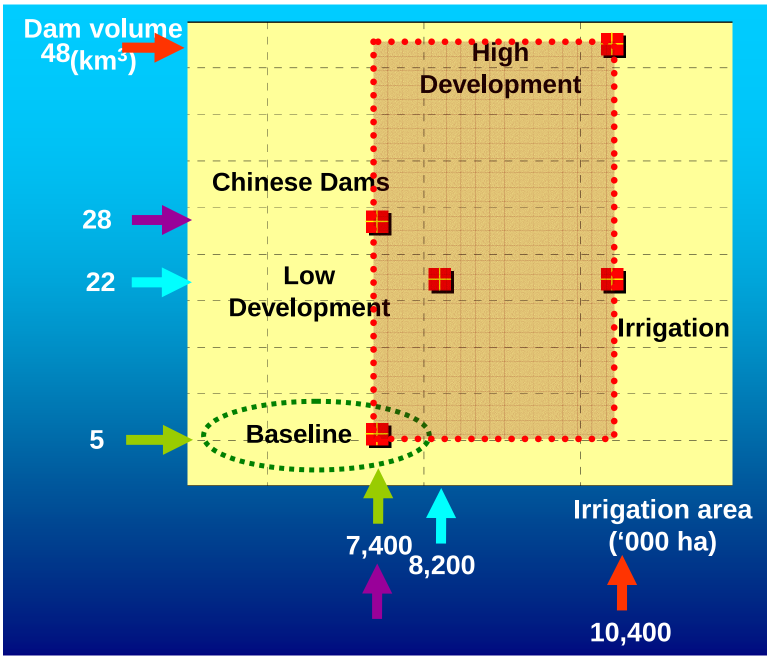
Three simulation models are included in the DSF, as follows:

SWAT: A series of hydrological models, based on the SWAT software of US Department of Agriculture, used to simulate catchment runoff based on estimates of daily rainfall, potential evapotranspiration (PET), the topography, soils and land cover of sub-basin within the 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.

IQQM: The hydrological models provide input of runoff to a basin simulation model that uses 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.

iSIS: A hydrodynamic model, based on ISIS software developed by HR Wallingford and Halcrow, 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.

The DSF was developed during the period 2001 – 2004 under the GEF-financed, World Bank-implemented Start-up Project for the MRC Water Utilization Program.



3 Analysis of development scenarios

by Richard Beecham and Hugh Cross,
March 2005

Rationale

The analysis aims to describe the hydrologic and environmental impacts of a range of development scenarios. A number of applications are intended. First and most importantly, the results will assist the BDP determine the relative scale of changes that accompany possible future states of development. By doing so, it will assist the basin planning process determine where the limits lie with respect to different concerns regarding changes in flows and subsequent impacts on environmental, social and economic parameters.

Secondly, the results will provide quantitative points of reference against which actual projects, or aggregations of projects, can be rapidly assessed. This is expected to assist BDP with the process of short-listing projects and the development of selection criteria.

The final major use will be to provide the Water Utilisation Programme (WUP) with impact descriptions that can assist the Integrated Basin Flow Management (IBFM) Phase 2 work to develop a guidelines for the management of mainstream flows and/or highlight areas of potential concern. In that regard, the number of indicators and sites reported on here has been deliberately restricted to a relatively succinct set; only those that were essential to describe the major between scenario impacts, in terms of geographic location, scale and importance, were included. There are many others that can, and will need to be included, for a comprehensive review of the impacts.

The analysis has been performed relative to a Baseline Condition representing the level of development current in the year 2000. In each scenario, the historical flow pattern for the years 1985 – 2000 is used, except downstream of Kratie, where the simulation period was confined to 1996 – 2000 because of time limitations in running the simulation models.

Analyses reported on here have evolved from those conducted during the development and testing of the DSF, as well as in a subsequent report to the World Bank (World Bank, 2004[i]). The findings of that report will differ from those there due to changes in the level of development included in each development scenario. This report's configurations are based on the best available information supplied by the member countries on likely developments at various points of time, namely by years 2010 and 2020. Such information was not available at the time of the World Bank report. In addition, the recalibration of the hydrologic models since that time has lead to changes in late dry season flows that are significantly lower than previous simulated results.

Whilst the aggregations of developments contained in each scenario, principally those that most affect the volume and flow of water (i.e. irrigation and dam developments), are based on such formal consultations, they in no way should be used as the probable levels of development. They are merely intended as realistic scoping scenarios that can be used to define the development space and thereby assist with formulation of actual basin development plans are likely to meet the terms of the 1995 Mekong Agreement.

Potential water resource development

Current levels of water use and regulation in the LMB are very low compared to most other large rivers in the world. Irrigation diversion account for less than 10% of the total water available and most tributaries in the LMB remain unregulated.

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[i] World Bank, November, 2004). Modelled Observations on Development Scenarios in the Lower Mekong Basin. A technical report for the World Bank's Mekong Regional Water Resources Assistance Strategy

Dam projects recently completed or under construction in China's Yunnan province, however, are rapidly changing that, at least for the upper reaches within the LMB. Within five years Xiaowan will come on line providing another 9.9 km^3 of active storage to further regulate the Lancang (as the Mekong is known in Yunnan), followed by Nuozhadu most probably well prior to 2020 with another 12.4 km^3. These two dams in Yunnan provide a substantially different pattern of flows in the lower Mekong and thus development opportunities and constraints.

Potential for further water resource development, whilst large overall as noted above, is not equal between the four riparian signatory countries. This is a consequence of differing levels of past development, leading to very large differences in the current utilization of land and water resources in each country. It is also due to inherent hydrologic, topographic and socio-economic differences.

What binds the countries is the common need for development to keep abreast of rapidly growing populations and resource needs. Equally, all countries depend on the natural river flows to essential maintain benefits on which both the environment and people depend. Consequently, the principles of Integrated Water Resources Management (IWRM), need to be applied to basin development planning to consider impacts not only for the intended sector and country, but across all sectors and countries.

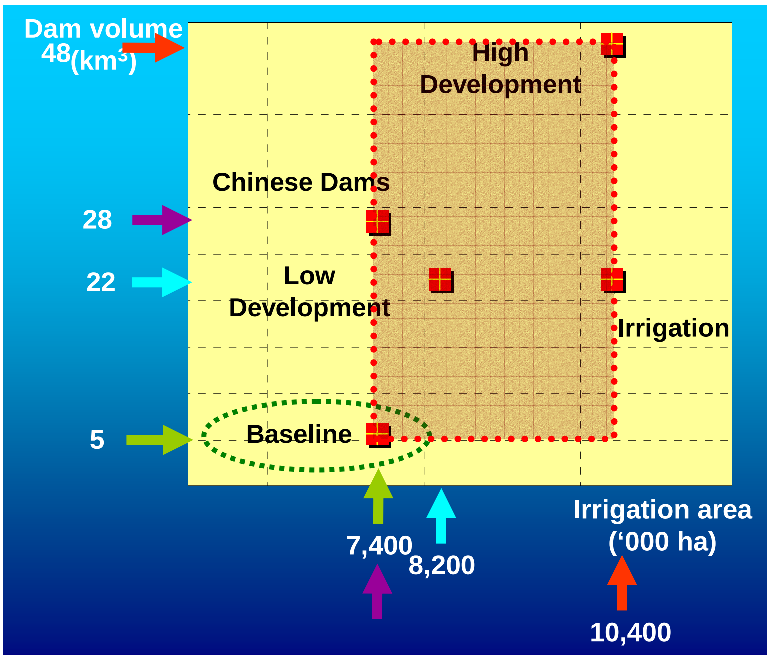
Those development sectors that most impact water resources are:

- Hydropower, which will redistribute water from the wet season to the dry season; and
- Irrigation, which will divert large volumes of water from the Mekong River and tributaries in both the wet and dry seasons.

Consequently these form the core of the scenarios evaluated in this report:

Chinese Dams scenario:	■ high development in hydropower with low development in irrigation
Low Development scenario:	■ low development in hydropower with low development in irrigation
Irrigation scenario:	■ low development in hydropower with high development in irrigation
High Development scenario:	■ high development in hydropower with high development in irrigation

The relative "position" of each of these scenarios is shown in the diagram below.



Reporting impacts

An analysis of impacts begins with the changes to flow and water level parameters, including:

- Mean monthly dry season flows (Article 6A).
- Wet season flow volume at Kratie (Article 6B).
- Reverse flow volume at Prek Kdam (Article 6B).
- Water levels in Great Lake (Article 6B).
- Inundated areas in Great Lake. (Article 6B).
- Changes in mean monthly water levels along mainstream (Article 6C).
- Changes in peak water levels along mainstream (Article 6C).

These hydrological changes are reported at selected key monitoring stations along the Mekong River, namely:

Luang Prabang:	to monitor changes from China and Northern Thailand.
Nakhon Phanom:	to monitor changes from hydropower dams in the northern part of Laos, irrigation, and intra-basin diversions.
Pakse:	to monitor irrigation changes and hydropower changes in the central part of Laos, and irrigation in the Mun-Chi river basins.
Kratie:	to monitor changes from irrigation and hydropower development from southern Laos, eastern Cambodia, and the Central Highlands.

Tan Chau: to monitor changes into the Vietnamese part of the Mekong Delta.

Various aspects of the above changes cause environmental, social and economic impacts, either directly, or through subsequent changes in biological and physical variables. This report provides a first level attempt at a quantitative analysis of the following sector impacts:

- Navigation potential
- Salinity Intrusion
- Flood Management
- Fish Habitat Availability
- Fisheries Productivity
- Environmental Maintenance

Scenario outcomes

Water Utilisation:

The extent to which the scenarios differ in these parameters is a direct function of the assumed interventions. Consequently irrigation diversions are greatest for the Irrigation and High Development scenarios. Total irrigation diversions increase from 40.8 mcm (million cubic metres) under the Baseline and Chinese Dams scenarios, to 46.1 mcm under Low Development and to 58.4 mcm for the Irrigation and High Development scenarios.

The reliability of water availability for these diversions is reported on by BDP planning sub-area. Whilst those figures do not separate the Mekong mainstream from the tributaries, essentially reliability of supply for irrigation schemes on the Mekong is 100% for all scenarios in both the wet and dry seasons. Therefore, where the sub-area reliabilities fall below 100%, as they do most significantly for sub-area 2T in Thailand and 9C in the Great Lake area in Cambodia, it is in tributary areas. The reductions in reliability in the two areas cited need to be viewed with caution as the model simulations do not take into account the many dams in Thailand (due to lack of data) and the areas around the Great Lake are affected by a number of local water management regimes that also may not be well simulated.

Most of the sub-regions do not show significant constraints, and in some cases improve for larger irrigation areas (e.g., the central Laos region) improve, presumably as a result of the regulated water from hydropower dams.

To the above irrigation diversions must be added the Nam Mae Kok and Nam Mae Ing inter-basin diversion schemes from Mekong tributaries in Thailand, as part of the Low, Irrigation and High Development scenarios. An average annual volume of 2,048 mcm is diverted during wet season months and December. Overall, about 90% of the diversion target is met.

The total modelled diversions for urban and industrial needs in the High development scenario increases by more than 120%, or about 0.7% of the total Mekong water resource. Relative to the above irrigation demands, these needs are comparatively small, however, at times there are shortfalls in supply, as is most apparent in BDP sub-areas 3L, 7V and all the Thai sub-areas. Some degree of storage of water should be considered in these areas, or water needs to be supplied from alternate sources, such as groundwater. As discussed in Section 0, existing storages in Thailand that would currently serve this purpose have not yet been included in the simulation models.

Hydropower generation in the LMB remains the same under the Chinese scenario, but trebles under Low and Irrigation Development. Some 31,097 Gwh (gigawatt hours) per year for the High Development scenario is nearly five times that of the Baseline situation. Most of this increase is in Laos, up by nearly 20,000 Gwh, but Cambodia and Viet Nam do record 1,236 and 2,970 Gwh increases, respectively.

The net effect of all diversions and the regulation imposed by the hydro-power dams, can be summed up in the following points:

- The impact of dam regulation of dam regulation increases by a factor of 4-5 for the Chinese Dam scenario, and a factor of 6-7 for the High Development scenario.
- The combined diversions upstream of Kratie increase significantly, especially in relative terms. These changes are balanced by dam regulation in the Baseline, Low Development, and High Development scenarios.
- The degree of regulation for the Irrigation scenario only offsets half the diversions during the dry season.

Changes to Flow:

The principal changes in mainstream flows can be summarised as being:

- Reductions in wet season flows matched by increases in dry season flow – a result of seasonal flow regulation by hydropower dams; and
- Net flow reductions, principally in the dry season, but also in the wet season for scenarios with high water demands – caused by diversions for irrigated agriculture and inter-basin transfers.

The extent to which these two predominate in each scenario and at each reporting location, is a function of the level of irrigation and hydropower development. Some key observations are as follows:

- Reductions in the wet season flows by the storage of water in hydropower dams is most noticeable in the early wet season, impacts being much less for second and subsequent flood peaks.
- Smaller flood years are more heavily impacted by hydropower flow regulation and high irrigation demands, than are large flood years.
- The large Chinese dams cause the bulk of the seasonal flow regulation and these impacts are largest for the upstream sites, most notably Luang Prabang and Nong Khai.
- Impacts of large dams in the Nam Ca Dinh river system in Lao are felt by Nakhon Phanom, whilst those caused by additional large dams in the Se San-Song-Pok system in Cambodian and Viet Nam, impact on most noticeably on Stung Treng and Kratie.

- Upstream of Pakse increases in dry season flow levels are about half the size of peak wet season flow reductions, e.g. +0.50m verses -1.16m at Luang Prabang for the Irrigation scenario. However, this reverses downstream of Pakse.

- At Nakhon Phanom, Pakse, Kratie and Tan Chau, the Irrigation scenario causes dry season flows to be reduced to the same level or lower than the Baseline condition, despite the elevation of flows by the hydropower dams. Other scenarios maintain higher dry season flows in all months at all sites.

- Mean annual flow reversal volumes at Prek Kdam are reduced by 5-6% for all but the High Development scenario, which causes an 11% reduction. Corresponding reductions in peak lake levels are of the order of 20 – 24cm for the first three scenarios mentioned, and -36cm for the High Development scenario. The change in peak flooded area is less than 3.5% for all scenarios.

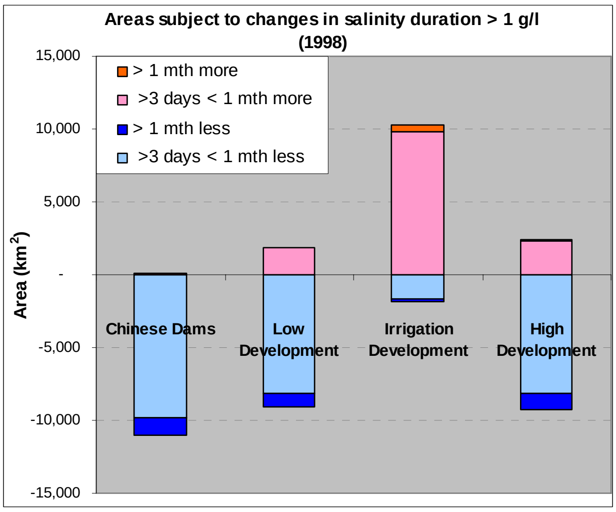
- Changes in flow reversal volumes can be much greater in drier years; up to 22% less in 1998 under High Development.

Impacts of Flow Changes:

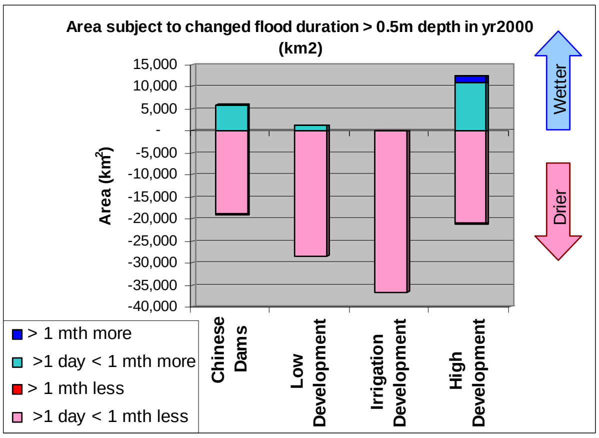
Changes in navigability are assessed against achieving a target of 300 days/year on average for vessels of 3m draft, upstream of Kampong Cham, and 4m draft downstream of there to the sea.

Downstream of Kratie the number of navigable days exceeds 300 for all scenarios. Conversely, none of the scenarios provide sufficient flows in the river reaches from Mukdahan to Stung Treng. From Chiang Saen to Nong Khai, only Chinese Dams and High Development meet the 300 day target, whilst from Nong Khai to Mukdahan, only the Baseline fails. All development scenarios increase navigability by 10% or more in the reaches upstream from Mukdahan and the Chinese Dams scenario does so for Mukdahan to Pakse also. The Irrigation scenario is the odd one out, being the only scenario to reduced navigability, but only from Pakse to Stung Treng, a reach that has poor conditions for navigation in any case.

The greatest reduction in salinity durations in the delta is achieved under the Chinese Dams scenario, where 35% of the maximum saline intrusion area of 28,466 km² (under Baseline conditions) experiences shorter durations (see adjacent figure). Both the Low and High Development scenarios achieve similar, but less reductions (29% of the area), whilst the unbalanced hydro-irrigation development in the Irrigation scenario causes a much larger area to experience longer durations (35%) with few areas experiencing shorter ones.



Peak annual flooded areas downstream Kratie, averaged over the six years 1996 – 2000, reduce by only 3% under the development scenarios, with the exception of the High Development scenarios which reduces them by 5%. However, inter-annual differences in peak annual flood levels, such as between 1998 and 2000, can exceed 3 m in Tonle Sap Great Lake, with associated differences in flood durations and inundated areas.



Bearing in mind this natural variability, the graph to the right shows the amount of area experiencing changes in flood duration in the year 2000 caused by each scenario. The greatest reduction in flood durations is that for the Irrigation scenario, whilst the Chinese Dams and High Development scenarios have similar areas. However, both the Chinese Dams and High Development scenarios increase flood durations in some areas, more particularly for the latter. This impact only occurs in low lying areas subject to flooding at the beginning and end of the wet season. At those times, the elevated dry season and transition month flows increase the duration of flooding.

Crop damage was assessed for the two seasonal crop types that dominate Cambodia and Viet Nam; the "wet Season – mid planted" rice crop and the wet season "summer-autumn crop", respectively. The most critical times for each crop, relative the period of highest flood risk, were determined and the depth and duration criteria established. Scenario impacts were assessed against the 1996 flood in Cambodia, as this was a late flood which is more likely to impact on the crop's flowering period, and the year 2000 flood in Viet Nam, as this is a relatively early large flood that caused damage to the harvest period of the summer-autumn crop.

Reduction in the area in Cambodian potentially exposed to crop damage reduced by 1% to just 3%

Only a 1% to 3% reduction in 1998 potential crop damage area is achieved, with the best result being for the High Development scenario and the worst for the Chinese Dams scenario. In Viet Nam the year 2000 flood analysis presented slightly greater impacts and of a different pattern. The least benefit of about 4% less area damaged is achieved by the Low and High Development scenarios. Reductions around 5% to 5.5% in area are caused by the Chinese Dams and Irrigation scenarios.

Fish habitat availability is assessed by two different indicators upstream and downstream of Kratie. Changes in annual flood volumes above an assumed threshold of inundation are used to indicate the former at four reporting sites, whilst a fish Habitat Availability Index (HAI) is used downstream. The latter is based on the duration days of flooding above 0.5m and which occurs for between one and six months.

Reductions in the partial flood volumes (1985 – 2000) range from around 50% at Luang Prabang under the Chinese Dams and High Development scenarios, to just 10% at Kratie under all but the High Development scenario, which retains an impact of -23%. Changes at intermediate sites, such as Nakhon Phanom, whilst differing between scenarios due differences in the impacts of LMB dams and irrigation, still lie between these extreme values. If the partial flood volumes indicator is truly representative of hydrologic conditions that are of importance to fish, then these changes are of considerable concern to maintenance of biodiversity and fisheries productivity.

Average changes in the HAI (1996 – 200) for the flooded area downstream of Kratie, being around -6% to -7% for all scenarios but the High Development scenario, which has -12% impact. Although these average values are less than those for the partial flood volumes upstream of Kratie, the different period of analysis may be partially responsible. The 1998 flood, whilst the lowest in the period 1996 – 2000, is only slightly less than the median year over the longer period, 1985 – 2000. Consequently, if 1998 changes are compared, we see reductions averaging 16% for the Chinese Dams, Low and Irrigation development scenarios and 22% for the High Development scenario. Again, these are of considerable concern for the maintenance of healthy and productive aquatic ecosystems.

To augment the analysis of fish habitat availability, some simple flood – fish production assumptions were made such that indicators of potential annual capture fish production, upstream and downstream of Kratie, could be produced. Upstream of Kratie most scenarios show only a small reduction from Baseline conditions in the average potential annual fish yield (1985 – 2000). Chinese Dams, Low and Irrigation development scenarios reduced by about 3%, but the High Development scenario reduces by 19%. That difference is caused by the much greater length of tributary river reaches impacted by dams in the High Development scenario relative to the other development scenarios, particularly the rivers in the Se San-Kong-Pok system.

It is noted that the potential increases in yields from reservoir fisheries in the new dams are generally less than 10% of the decreases in the capture fisheries. They therefore do not adequately "compensate" for the lost productivity. Also of note, is that assumptions on which the index is based suggest a 28% reduction in fish productivity has already occurred between the "natural" situation and the Baseline condition (year 2000 development).

Potential annual fish yields downstream of Kratie, as for the HAI, are based only on the period 1996 – 2000. Average annual potential yields for Chinese Dams, Low and Irrigation development scenarios reduce by about 5%, whilst the High Development reduces by nearly double this (9.7%). Again, because 1998 is closer to the median flood year over the period 1985 – 2000, a comparison of those changes was made. These 1998 reductions are about 14 - 18% for the first three scenarios mentioned above and 23% for the High Development scenario. These impacts are generally much larger than those anticipated upstream of Kratie, but in fact the two may not be comparable. Of the two indices, the fish productivity upstream of Kratie is subject to a greater degree of assumption. Critically, it does not take flow volume into account when distributing "natural" fish populations through the mainstream and tributary system. Rather the critical aspect is stream length, a surrogate for the unknown area of floodplain habitat in each reach.

Use of results

The character of this work is a scoping study, i.e., to more or less define the boundaries of possible changes in the hydrologic regime, and positive and negative impacts of these changes on key sectors. Areas of possible change that have not been evaluated, via additional scenarios, include landuse changes, climate change and floodplain embankments.

With regard to the scenarios evaluated, various aspects relating to existing structures and their management have not been incorporated, including water resource developments in north east Thailand, operation of salinity barriers and other regulators in the delta, use of groundwater, small dams in Laos and Cambodia, provisions for maintenance of instream flows.

Whilst the DSF has adequate technical capability to be used for scoping study the robustness of the analyses can be improved over time though additional technical and data upgrades. Complementing these improvements, should be a program of formalising procedures relating to the formulation of scenarios, generation of outputs, quality assurance and forms of analysis.

Scenairo Appraisal:

The evaluation of each development scenario against the Baseline condition reveals a diversity of impacts, some positive and other negative. Whether a particular scenario is "acceptable" or not will depend on the importance assigned to individual indicators, as much as to the overall balance or imbalance of positive and negative outcomes. Critically, a decision must be made relative to agreed criteria, and those must relate to the riparian countrys' development objectives. Whilst the indicators could be assumed for the analyses conducted for this report, the criteria generally could not. That is properly the task of MRC, as assisted by the BDP and other programs.

Water utilisation indicators merely show the level of beneficial uses arising from the combination of existing and new developments contained in the scenario to achieve the scenario's "purpose". Those scenarios that have the greatest interventions will therefore "score" the highest, with the High Development scenario clearly providing the greatest level of benefits. Both hydropower and irrigation outcomes are much greater than for other scenarios. The Chinese Dams scenario score the lowest in this regard, as it contains no new LMB developments.

Perhaps the next most straight forward indicators are hydrologic changes; they contain no assumptions other than those inherent in the simulation models, including the important consideration of the period of analysis. Differences between the development scenarios are large, but not so large as to be clearly "acceptable" and "unacceptable", although the Irrigation scenario comes closest to directly failing one of the core Article 6 conditions. It alone causes mean water levels in the dry season months to reduce below the equivalent Baseline values at most reporting sites, which may contravene guidelines being developed for Article 6a.

Whilst the observed reductions in wet season water levels for all development scenarios do not threaten the Article 6c requirement not to increase wet season flows, they do have consequences for Article 6b. Tonle Sap annual reverse flow volumes are reduced by as much as 11% on average under the High Development scenario, although they are only 5 – 6% for the others. Much greater changes do occur in dry years, when High development can cause a 22% reduction and the least impact of any scenario is 14% (Low and Irrigation development).

Whether these changes are "acceptable" with respect to Article 6b is largely determined by the consequent changes in flooded area. It must be assumed that the primary consideration in drafting Article 6b was the intent to maintain the productive fisheries of the Great Lake, therefore the focus is on any reduction, rather than increases. Average annual maximum flooded areas in Tonle Sap are observed to change by much less than the above volume changes; < -3.5% in all cases. But it may be that the duration of flooding is more important than just the peak annual flooded area.

For the whole of the area downstream of Kratie, the magnitude of change in the average annual maximum flood extent was similar to the Tonle Sap area, -3% for most and -5% for High development. However, some 82% of the total flooded area was subject to shorter flood durations under the worst case (Irrigation development), but it must be said that virtually no area experienced flood durations that were shortened by more than one month for any scenario. On this basis, it might be concluded that the change in peak annual flooded area and durations is not clearly significantly adverse, but neither is it clear that they are not.

Reductions in peak water flood levels, areas and durations, observed for all the scenarios to varying degrees, have consequences for salinity intrusion in the delta. There, the pattern of changes inversely mirrors the flood duration changes, at least approximately. Where flood durations are shortened over large areas, as occurs to the greatest degree for the irrigation scenario (36,643 km^2), a correspondingly large area of the delta is subject to longer salinity durations (9,836 km^2). Essentially, it is the elevation of flows in the dry season and transition months, that are reflected in increased in flood durations (in lower elevation areas), and that drives a reduction in salinity durations.

Potential crop damage in Cambodia and Viet Nam reduces under all scenarios, but not dramatically so being less than 5% in each case. The relatively small changes are most probably a function of the relatively small differences in flood levels between scenarios and indeed between them and the Baseline condition. In any case, this analysis would benefit from additional sensitivity analysis and confirmation of crop sensitivities to flood depths and durations.

Changes in average fish habitat availability and potential annual fish yields of capture fisheries are of considerable concern. Even without considering the likely impacts of floodplain embankments and other pressures, the impacts shown by these indicators are quite high, particularly when the 1998 drier flood year are considered. That reductions in the fish HAI for 1998 are never less than 14% for any scenario is most probably a testament to the impact of the Chinese dams in reducing flood durations. Finally, in none of the scenarios, do reservoir fisheries in the new storages compensate more than 10% of the loss estimated for capture fisheries.

The High Development scenario, in particular, is shown to have clear and substantial impacts on habitat and fish production, which presents a serious challenge to assigning the term "sustainable development" to this scenario. Due to the "work in progress" nature of the indicators, it is more problematic to assign the other scenarios one way or the other.

Purpose

Stating the obvious, information is crucial to making good decisions, and this applies especially for an approach based on Integrated Water Reources Management (IWRM), where developments designed to benefit one sector will result in changes to the value, positive or negative, to another sector. Increasing populations and economic growth in the six countries that make up the Mekong Basin will need to increasingly use the land and water resources within the Mekong Basin to meet their food and energy needs. Development will take place regardless of whether information is available on the full range of possible cross-sectoral or trans-boundary impacts.

The most likely consequence of this is that development will take place in an uncoordinated way, and with unintended negative impacts for other sectors and for people elsewhere in the basin. An informed decision will understand what these impacts would be, and be able to put in place coordinated plans that will "*maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*"[i].

Institutional framework

The institutional framework in which a IWRM strategy can be developed is the Mekong River Agreement (MRC, 1995). The parts of the four MRC member countries within the Mekong catchment boundary; Laos, Thailand, Cambodia and Viet Nam; define the Lower Mekong Basin (LMB) from the Chinese border to the South China Sea. The other two non-member countries within the upper part of the Mekong Basin are Myanmar and China, who are dialogue partners.

The 1995 Agreement is a framework for cooperation in ".. *all fields of sustainable development, utilisation, management and conservation of water and related resources..*" (Article 1), and established the Mekong River Commission (MRC) for this purpose (Article 11). The Agreement defined a number of roles for the MRC, including:

- *".. formulation of a basin development plann that would be used to identify, categorise and prioritise the projects and programs to seek assistance for and to implement at the basin level."* (Article 2).

- developing *"Rules for Water Utilisation and Inter-Basin diversions"* (Article 26) that maintain flows in the mainstream to meet certain objectives (Article 6) allowing for *"Reasonable and Equitable Utilisation"* of the waters of the Mekong River system (Article 5).

- To *"…avoid, minimize and mitigate harmful effects that might occur to the environment …….from the development and use of the Mekong River Basin water resources…."* (Article 7).

- To keep the Mekong River free of *"…measures, conducts and actions that might directly or indirectly impair navigability…."* (Article 9).

A Basin Development Planning (BDP) group has been set up to implement Article 2, with consideration of other requirements of the Agreement. The BDP has a number of activities, with an emphasis on participation with the member countries at a national, provincial, and local administration levels. The BDP has been working towards identifying national development proposals that are consistent with IWRM objectives of the member countries.

The BDP group interacts with two other MRC core programmes, the Water Utilisation Program (WUP) and the Enviroment Program (EP), as well as sectoral programs for Fisheries, and Navigation. The WUP, has developed the DSF that was used in this work, and is developing Integrated Basin Flow Management (IBFM) rules (Articles 5 ,6, 26) in collaboration with the EP.

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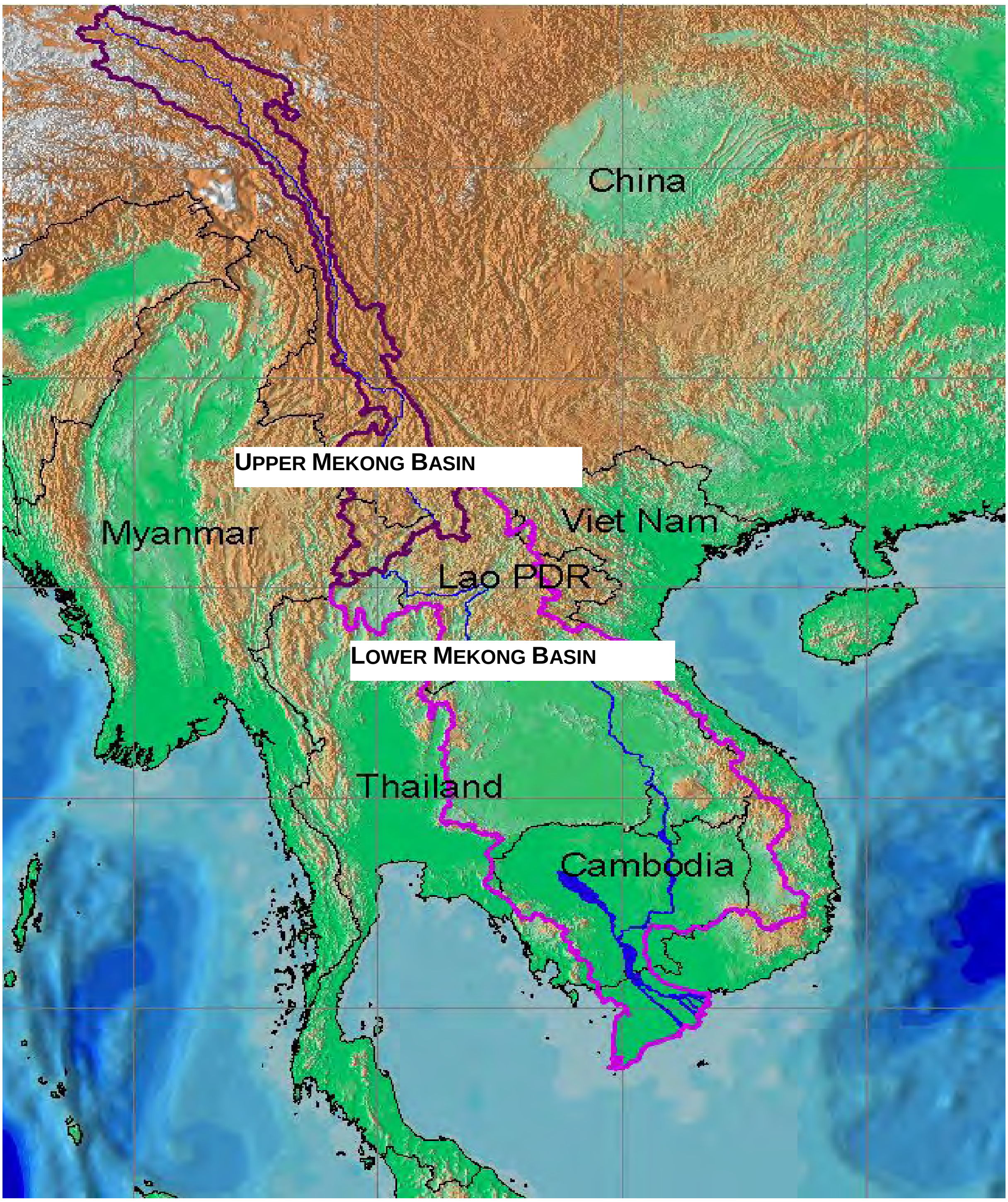
[i] The objective of IWRM based on definition in Global Water Partnership (2000).

Map 3.1: The Mekong River and its catchment



4 Physical setting

by Richard Beecham and Hugh Cross,
March 2005

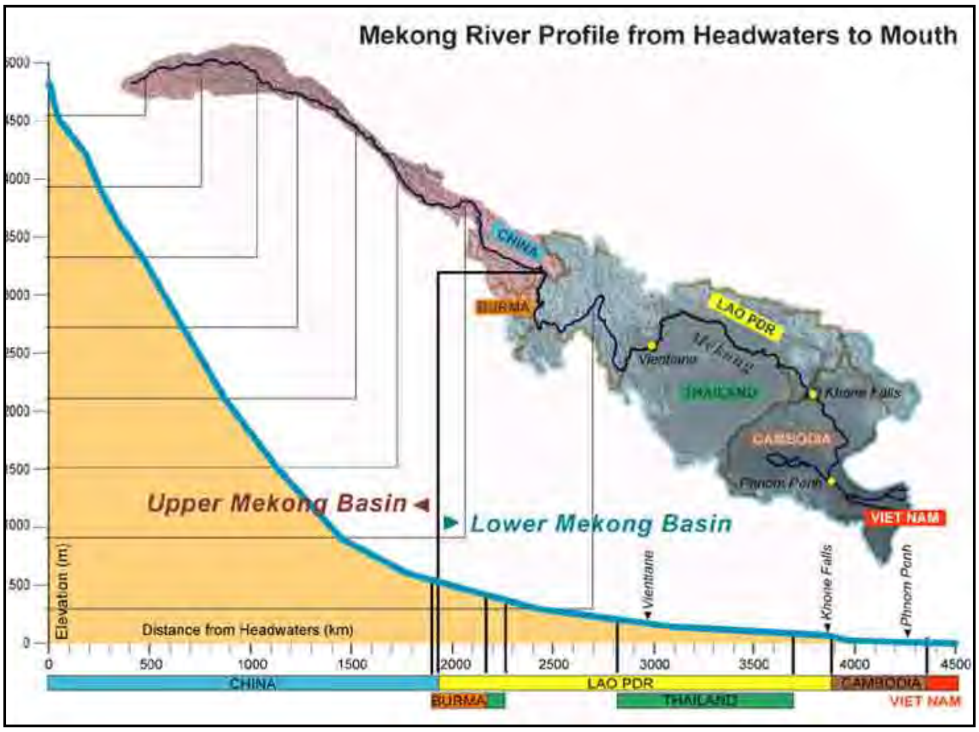
The Mekong River and its physical and social geography has been described in detail in many places, including *The State of the Basin Report* (MRC, 2003) and the *Overview of the Hydrology of the Mekong Basin* (MRC, 2004b). Salient features have been drawn from these two comprehensive reports for this section.

The Mekong River is one of the world's largest rivers, flowing south and east for a length of about 4,500 km from its origins in the Tibetan plateau in Yunnan province in China to the South China Sea. The river drains a catchment area of about 795,000 km^2 from six countries, and has an average total flow of 14,500 m^3/s, or nearly 460,000 million cubic metres (mcm) per year. The contributions of each country of catchment area and flow are reported in Table 4.1.

Table 4.1: Mekong Basin catchment areas and flow contribution by country (MRC, 2004).

Country	Area		Flow % of Basin
	('000 km^2)	% of Basin	
China	**165**	**21**	**16**
Myanmar	**24**	**3**	**2**
Laos	**202**	**25**	**35**
Thailand	**184**	**23**	**18**
Cambodia	**155**	**20**	**18**
Viet Nam	**65**	**8**	**11**
TOTAL	795	100	100

Figure 4.1: Longitudinal profile of the Mekong River



A schematic of the elevation along the Mekong River is shown in Figure 4.1. The river (known as the Lancang in Yunnan Province) flows for a distance of over 1,900 km in the Upper Mekong Basin with an elevation change of about 4,300 m. By comparison, for the remaining length of about 2,600 km, the elevation change is only 500 m. This profile highlights the hydropower potential of the Upper Mekong Basin.

Average annual evaporation in the basin does not vary greatly from year to year, and is in the range 1200-1800 mm. The south-west monsoon dominates the climate of the Mekong Basin, with most of the rainfall occurring from about mid-May to early October, with influnces from the north-east monsoon contributing to rainfall in the southern part of the basin until early November. Rainfall varies considerable over the Mekong Basin, with an annual average from 1200 mm in north-east Thailand, to 1300 mm in the Mekong Delta and Great Lake regions in the south of the Basin, 2200 mm in the Central Highlands, and up to 3,000 mm further north the uplands and plateaus in Central Laos. Consequently, runoff from this part of the LMB is significantly higher than the average.

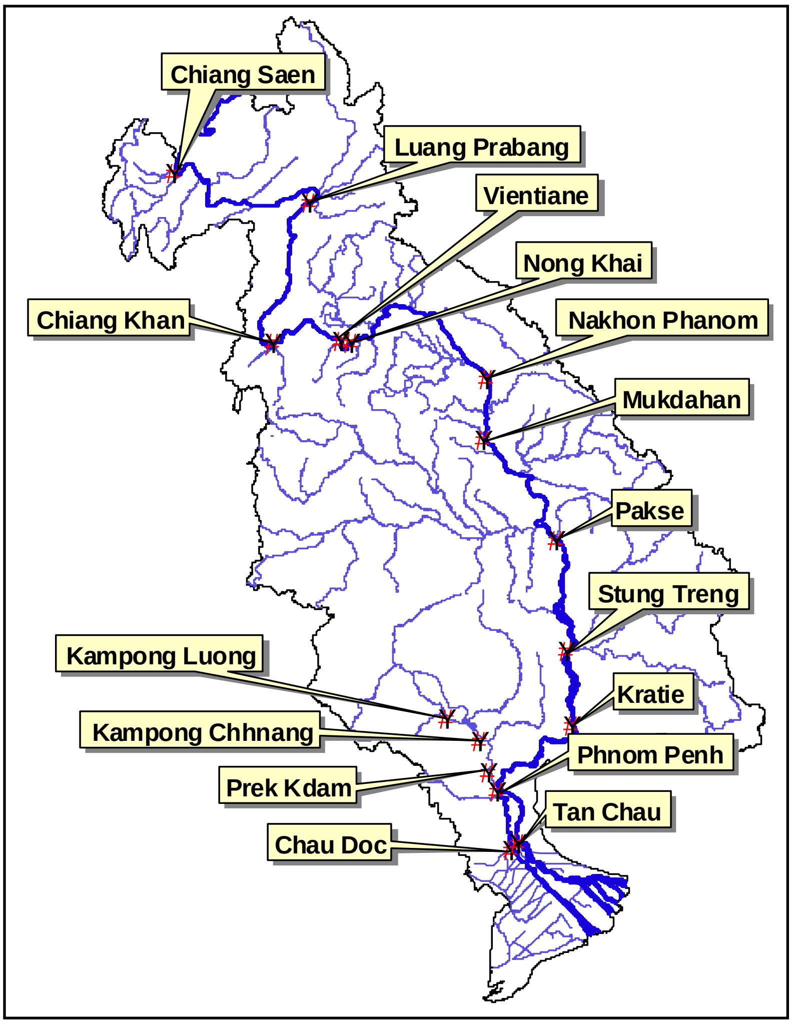
The spatial distribution of runoff varies significantly across the basin. Key hydrographic stations along the Mekong River (and the Great Lake) are shown in Map 4.1, and the mean annual flow, including as depth of runoff is reported in Table 4.2.

Table 4.2: Lower Mekong Mainstream: mean annual flow (1960 –2000) at selected sites

Mainstream Site	Catchment area ('000 km^2)	Mean annual flow as discharge m^3/s	volume km^3	runoff mm
Chiang Saen	189	2,700	85	450
Luang Prabang	268	3,900	123	460
Chiang Khan	292	4,200	133	460
Vientiane	299	4,400	139	460
Nong Khai	302	4,500	142	470
Nakhon Phanom	373	7,100	224	600
Mukdahan	391	7,600	240	610
Pakse	545	9,700	306	560
Stung Treng	635	13,100	413	650
Kratie	646	13,200	416	640

(adapated from MRC, 2004b).

Map 4.1: Monitoring stations along Mekong River



Note the average depth of runoff increases slightly from Chiang Saen to Nong Khai, but increases nearly 30% by Nakhon Phanom, after some of the significant Laos tributaries from the north and east join the Mekong River. This 30% is the increase for the total catchment area upstream, which means that the incremental area from Nong Khai to Nakhon Phanom has an average annual runoff of more than 1,100 mm. The decrease of 50 mm in average depth of runoff from Mukdahan to Pakse is a result of below average runoff (~400 mm) from the Mun-Chi Basin in Thailand. The important contribution of the Se Kong-Se San-Sre Pok river system is seen in the increase in depth of runoff between Pakse and Stung Treng.

The variation of runoff at four of the monitoring stations is shown in Figure 4.2 and modelled estimates of the relative runoff from each country is shown in Figure 4.3.

Figure 4.2: Variation in mean flow along Mekong River

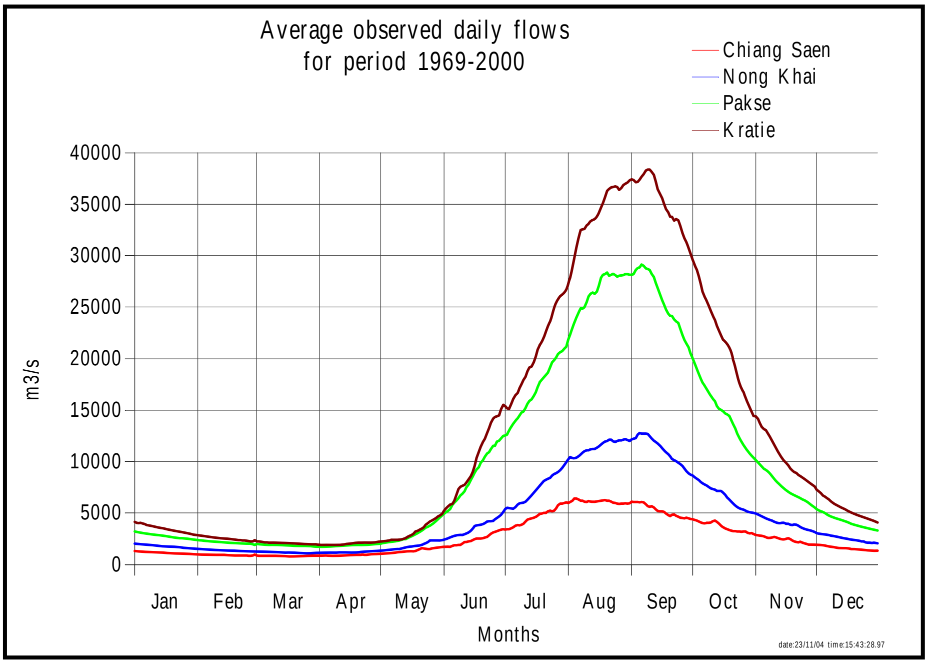
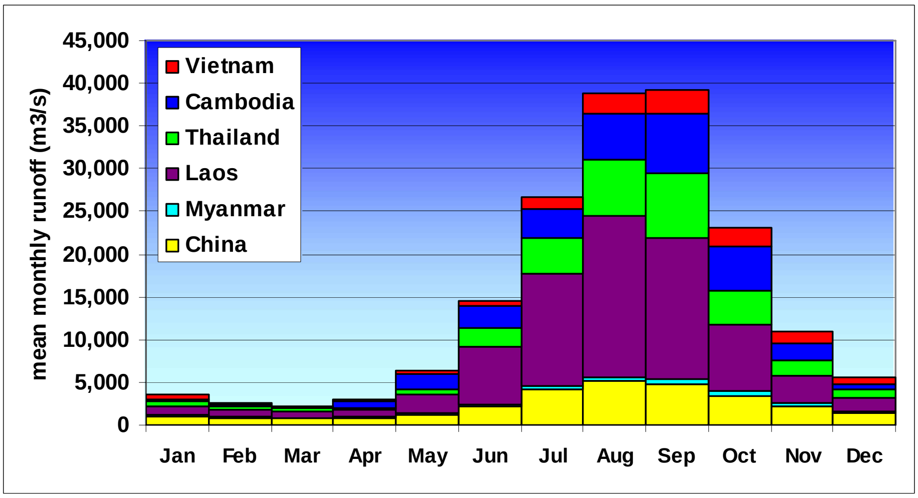


Figure 4.3: Modelled mean monthly inflows (1985 2000) to Mekong River



The LMB had a population of about 55 million people in 2000, with the number of people from each country compared with the total population of that country reported in Table 4.3. Most of the population of Laos and Cambodia is in the LMB, and a significant part of the populations of Thailand and Viet Nam.

Table 4.3: Population in the Lower Mekong Basin

Country	**Population (million people)**	
	Country	**In LMB**
Cambodia	13.1	9.8
Lao PDR	5.3	4.9
Thailand	62.8	23.1
Viet Nam	74.1	16.9
TOTAL	**159.3**	**54.7**

(from MRC, 2003)

Water usage for domestic and industrial purposes is correspondingly highest in Thailand, reflecting not only their higher population, but also greater access to water supply and higher level of industrialisation. Domestic and industrial water usage is relatively small compared with that used by irrigation, which uses an estimated thirty times as much water.

Irrigated agriculture is important to the countries of the LMB, contributing significantly to food production, and also to export income. Over seven million hectares were irrigated in 2000, with over half of that in the Mekong Delta region. Land suitable for irrigation is not limiting, with the exception of the highly developed Vietnamese part of the Mekong Delta, and some of the more mountainous parts of Lao PDR. However, the seasonality of flow limits water availability, especially in the tributaries in Laos and Thailand. This currently limits the expansion of irrigation without significant infrastructure development. Access to markets is also currently a constraint on diversification of irrigation. Data on irrigation distribution in the LMB is presented in Section 0.

Navigation plays a major role in transport, trade and tourism in the LMB. For navigation to meet its potential contribution to economic development in the Mekong Basin, there needs at the least to be more coordination of regional and transboundary activities. Issues

Much of the hydropower currently in the LMB was developed prior to 1990. This includes several storages in the North-East Thailand region, and Nam Ngum in Laos. Several significant hydropower projects have been completed in the LMB in the last decade, including Nam Theun-Hin Boun Dam, Ya Li Dam, Houay Ho Dam, and others. The Manwan Dam and Dachaoshan Dam have also been built in the Upper Mekong Basin.

A hydropower potential of some 13,000 MW has been estimated for the tributaries of the LMB. This estimate does not include mainstream dams in the LMB. Several hydropower projects have been started, or are at an advanced stage of planning in the LMB, as well as very large developments in the Upper Mekong Basin.

Many of the concerns about development in the Mekong Basin are about the impact that these dams may have on fisheries. This concern is very understandable considering the vital importance of fisheries to food security and income for large parts of the population, particularly in Cambodia and Laos.

The annual flood pulse in the Mekong Basin inundates vast areas of wetlands and creates highly productive fisheries habitats. The average annual yield of capture fisheries is estimated as around 2.5 million tonnes. This yield is the case for the current low level of development in the Mekong Basin, however there is concern that dams could significantly reduce the yield by reducing the size of the flood pulse, and by blocking fish breeding migration routes.

The recent large flood in 2000 has brought flood management to the forefront in the MRC, where it is now one of the core programs. The benefits floods bring to fisheries production and agricultural productivity by sediment deposition are offset by loss of life and economic damage, particularly for large floods of long duration.

5 Water resources development and impacts

by Richard Beecham and Hugh Cross,
March 2005

5.1 Introduction

Taken in whole, the water resources of the Mekong Basin are relatively undeveloped compared to other large river basins in the world. The degree of regulation by dams is relatively minor, and the amount of water diverted for irrigation is less than 10% of the total water resource of the Mekong Basin, with the majority of that usage in the Mekong Delta region.

Water resources development in the irrigation and hydropower sectors across the basin is uneven because of physical, historical, and economic reasons. Northern and North-East Thailand have a highly developed irrigation infrastructure, as does the Mekong Delta region in Viet Nam. By contrast, large areas of Laos, Cambodia, and the Central Highlands in Viet Nam have low intensities of irrigation, and Laos and Central Highlands of Viet Nam also have significant unexploited hydropower potential.

Development pressures in the Mekong Basin are building, with increased population and economic growth increasing food and power demands within the basin, as well as in the context of the Greater Mekong Region. Further development of the water resources is planned to meet these demands. There has been a surge recently in hydropower development, and plans for further irrigation development. This development needs to be done according to principles of Integrated Water Resources Management, so as to consider impacts not only for that sector and country, but across all sectors, as well as impacts on other parts of the LMB.

All countries in the LMB benefit from the Mekong River's ecosystem function, with its hugely productive fisheries. This benefit is widespread, and provides food and income to much of the population of the LMB. The economic and sociologic worth of this sector is difficult to underestimate, and yet it is under threat from a number of causes arising from planned and unplanned development. These are discussed in some detail in Appendix D and Appendix F of World Bank (2004).

The study undertaken here is an attempt to look at a range of feasible large-scale developments that may take place in the Mekong Basin over the next twenty or so years, and the trans-boundary and cross-sectoral impacts of these developments.

The approach taken in this study was to:

1. Formulate a range of feasible development scenarios,
2. simulate the water utilisation aspects of these development pathways;
3. analyse the flow changes caused by this water utilisation; and
4. assess the cross-sectoral and transboundary impacts.

5.2 Formulating development scenarios

A detailed and comprehensive understanding of how the different countries will develop for a planning horizon of twenty or so years is a complex undertaking, and is the domain of national, and regional planning agencies. The main objective for this study was to understand the range of water resources impacts of these.

The main development sectors that will impact water resources are:

- Hydropower, which will redistribute water from the wet season to the dry season; and
- Irrigation, which will divert large volumes of water from the Mekong River and tributaries in both the wet and dry seasons.

There are a large number of possible combinations of these scenarios. The approach here was to select combinations of these that would encompass these possible combinations. The impacts of development scenarios other than those chosen can be inferred from the results of these, or alternate development scenarios can be formulated and analysed as part of the MRC's ongoing use of the DSF.

Where possible, the location and magnitude of developments in these two sectors was based on information supplied by the countries either in BDP sub-area reports, or directly by consultation, or by a informed judgement from members of the BDP team at the Secretariat.

The combinations selected had these characteristics:

1 High development in hydropower with low development in irrigation (Chinese Dams scenario)

2 Low development in hydropower with low development in irrigation (Low Development scenario)

3 Low Development in hydropower with high development in irrigation (Irrigation scenario)

4 High Development in hydropower with high development in irrigation (High Development scenario).

Other components of the scenarios included inter-basin and intra-basin diversions, which support irrigation within the LMB as well as elsewhere in the Greater Mekong Sub-region, and increases in Domestic and Industrial water demands.

These were all compared against a Baseline scenario, which is an approximation of the current level of water resources development in the basin.

5.3 Reporting water utilisation

The first aspect of the simulations reported is the utilisation of water by the development sectors configured in the DSF by reporting on:

- how much water is diverted for irrigation;
- how reliable the water availability is for irrigation;
- how much water is diverted for domestic and industrial water supply;
- how reliably domestic and industrial water is supplied;
- how much water is diverted inter-basin;

- how water is redistributed in regulation by hydropower demands; and
- how much hydropower is generated.

5.4 Reporting flow changes

The seasonal patterns of water usage will change the hydrologic regime to some degree. Understanding these changes is important, as Rules regarding maintenance of flows in the mainstream are an essential component of the Mekong River Agreement. Indicators describing the changes in flow were developed to directly address the information requirements of Article 6 of the Agreement.

These indicators were reported at selected key monitoring stations along the Mekong River, namely:

- Luang Prabang; to monitor changes from China and Northern Thailand.
- Nakhon Phanom; to monitor changes from hydropower dams in the northern part of Laos, irrigation, and intra-basin diversions.
- Pakse; to monitor irrigation changes and hydropower changes in the central part of Laos, and irrigation in the Mun-Chi river basins.
- Kratie to monitor changes from irrigation and hydropower development from southern Laos, eastern Cambodia, and the Central Highlands.
- Tan Chao, to monitor changes into the Vietnamese part of the Mekong Delta.

The changes monitored included:

- Mean monthly dry season flows (Article 6A).
- Wet season flow volume at Kratie (Article 6B).
- Reverse flow volume at Prek Kdam (Article 6B).
- Water levels in Great Lake (Article 6B).
- Inundated areas in Great Lake. (Article 6B).
- Changes in mean monthly water levels along mainstream (Article 6C).
- Changes in peak water levels along mainstream (Article 6C).

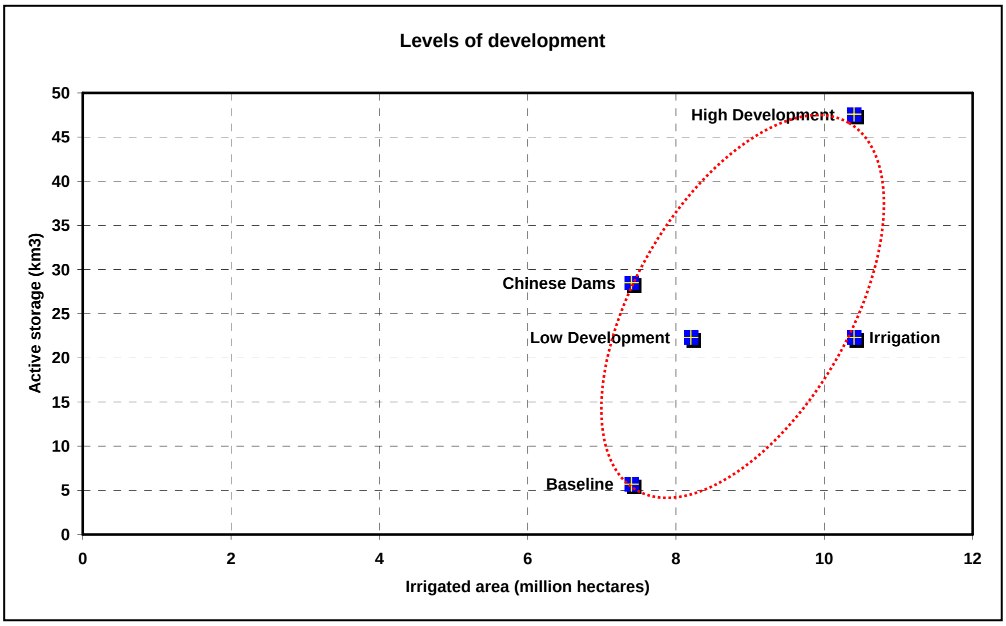
5.5 Analysing impacts of flow changes

It is possible to describe some of the scenarios' environmental impacts by applying certain assumptions about the linkages between changes in river flows, flood level and extent, and salinity intrusion. This report provides a first level attempt at a quantitative analysis of the following sector impacts:

- Navigation potential
- Salinity Intrusion
- Flood Management
- Fish Habitat Availability
- Fisheries Productivity
- Environmental Maintenance

In each case, indicators have been selected that are considered to best represent the issues of concern and draw out the differences between scenarios. Each analysis in 0 sets out its rationale and assumptions. This transparency is vital for ensuring that the findings are used in the context of the analysis's assumptions/simplifications, and to provide for critical review and subsequent improvement.

Not too much attention need be paid to the exact thresholds used for comparison, i.e. the evaluation criteria, such as the 20th percentile exceedance flow for the partial flood volume analysis. They provide a useful benchmark for assessing the relative changes between scenarios, rather than being important for establishing the absolute level of a particular parameter, such as annual potential fish yields. In general, selection of another level will not have a dramatic impact on the magnitude of these relative changes.



6 Scenario formulation

by Richard Beecham and Hugh Cross,
March 2005

6.1 Purpose of scenarios

Five scenarios were formulated to provide information on impacts of levels of water resources development will have on different sectors. The five scenarios have a range of levels of development in the two key water resource sectors of hydropower and irrigation. The impacts of these developments was assessed using indicators for a range of sectors as discussed in Chapter 0.

The five scenarios selected are:

(i) Baseline

(ii) Chinese Dams

(iii) Low Development

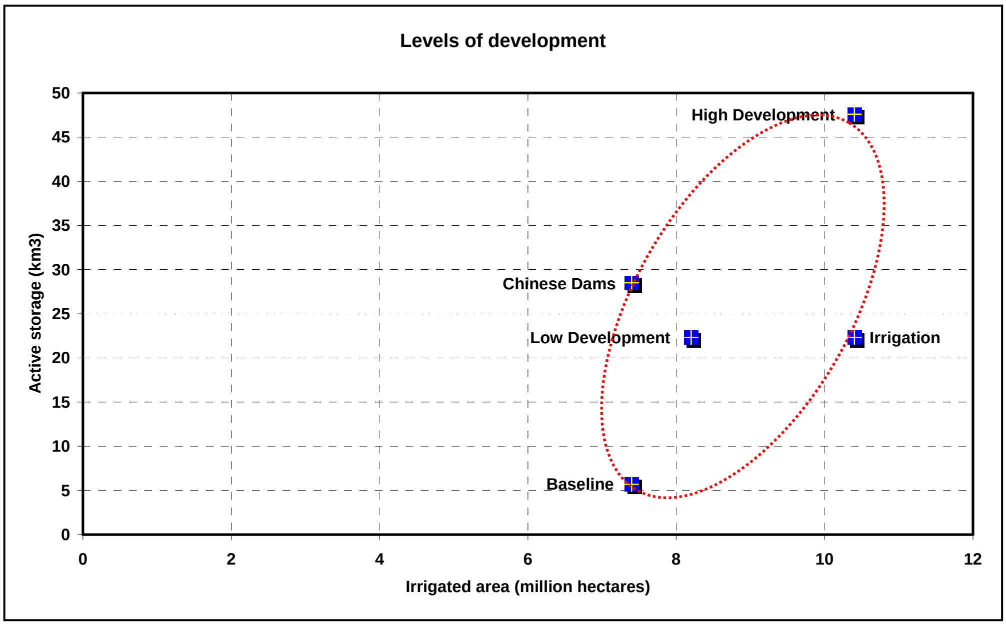
(iv) Irrigation

(v) High Development

The strategy of selecting the scenarios was to consider combinations of low and high development in hydropower and irrigation. This is illustrated by the comparison of Total Irrigated Area v Total Active Storage (Figure 6.1).

By choosing these combinations, the flow regime will be changed by different amounts during the wet and dry season respectively.

Figure 6.1: Levels of hydropower and irrigation development scenarios modelled



6.2 Baseline scenario

The purpose of the Baseline scenario is to provide a reference point, defining the level of development, climatic evaluation period, and resulting flow regime against which the other four scenarios are compared.

The Baseline scenario level of development was selected as that which existed in the year 2000. This includes physical characteristics such as land use , irrigated areas, dams and embankments, as well as known operational characteristics of the dams at that time. This choice gives the best available approximation of the current hydrologic characteristics of the LMB. The year 2000 is the latest for which complete data is available for the whole LMB.

The climatic evaluation period used is 1985-2000. This was selected early in the DSF development phase, as it is longest period for which there is sufficient basin-wide data. This climatic data set has been statistically tested compared with longer term time series in the basin, and found to satisfactorily represent the full range of climatic inputs to the LMB. All scenarios are simulated using the same climatic data set.

6.3 Chinese dams

The purpose of the Chinese Dams scenario is to estimate the change in flow regime and the resulting impacts that would result if the large Chinese Dams in the Lancang (the upper reaches of the Mekong River) are developed. These developments are likely to take place independent of decision-making in the four riparian countries. However, the hydrologic changes from these developments need to be considered in integrated water resources management in the LMB.

Table 6.1: 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	-

6.4 Low development

The purpose of the Low Development[ii] scenario is to estimate the change in flow and resulting impacts that would result with the level of development that is nearly assured in the Upper and Lower Mekong Basin.

Water resources development has taken place since that defined in the baseline, however, there is not at this time a complete data set compiled to describe it. Further developments have either already started, or are at an advanced stage of technical and financial planning.

This level of development may be all that takes place for some time, depending on decisions made on water sharing and flow management between the four riparian countries based on, and future economic conditions and the investment climate. For example, work has already started on Xiaowan Dam in China, but not yet on Nuozhadu Dam.

6.5 Irrigation

The purpose of the Irrigation scenario is to estimate the change in flow and resulting impacts that would result if the countries decided to expand further development only in the irrigation and water supply sectors.

This type of scenario is possible if, for example, economic or community pressures prevented significant further development of hydropower dams beyond those included in the Low Development scenario. The outcomes of the analysis of this scenario are meant to bring to light stresses in dry season flows that may occur, without balance from releases from regulating storages.

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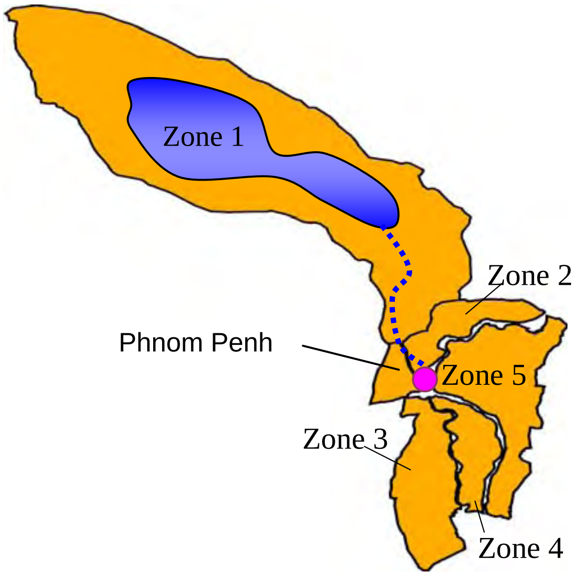
[i] Adapted from Plinston and Daming (2000)

[ii] In the scenario formulation phase of this work, it was initially framed as the 2010 level of development. This was changed after further discussion within the MRCS BDP team.

6.6 High development

The purpose of the High Development scenario is to estimate the change in flow and resulting impacts that would result if there is significant further development in the hydropower sector in addition to the development of the irrigation and water supply sectors described in the Irrigation scenario.

The impacts from this level of development on environment related sectors such as fisheries will be the greatest, and need to be understood if the countries want to go down this development pathway.



7 Key elements

by Richard Beecham and Hugh Cross,
March 2005

A range of developments will happen across all economic sectors in the LMB over the next twenty years. Only those that significantly impact the water resources are considered directly in the scenario formulation here, and they are:

(i) Irrigated agriculture;

(ii) Inter and intra-basin diversions;

(iii) Domestic and industrial water supply; and

(iv) Hydropower development.

7.1 Irrigated agriculture

Irrigated agriculture consumes the most water in the LMB, diverting about 10% of the mean annual flow from the whole basin, with over half of this diverted in the Mekong Delta region (World Bank, 2004).

This data show a wide range of concentrations of irrigation in different regions, dominated by large areas of wet season irrigation in the Mun-Chi basin and the Mekong Delta region. There are significant areas in northern Thailand, the Thai sub-area adjacent to the Mekong (3T), central Laos, and the Great Lake region in Cambodia. Relatively small areas of land is irrigated in the wet season Northern and southern Laos has much smaller areas, as does eastern Cambodia.

The pattern of dry season irrigation is similar, with the exception that it is dominated by the 1.5 million hectares of dry season irrigation in the Vietnamese part of the Mekong Delta, which is more than 2 ½ times the total dry season irrigation for the rest of the LMB. Regions with significant areas of dry season irrigation are the Mun-Chi, the Cambodian part of the Mekong Delta, and central Laos.

While still only a small percentage of the overall water resources, there are constraints on water availability in the dry season. There are opportunities to develop irrigation further in the LMB if water availability can be improved during the dry season.

The scope to improve water availability in the dry season may be achieved by:

- developing further irrigation infrastructure;
- improving management of irrigation systems;
- releasing stored water from the wet season; and
- diverting water from rivers with relatively high availability.

The relative levels of irrigation development by country for all scenarios shown graphically in Figure 7.1 and 7.2. This shows the relative dominance of wet season irrigation over dry season irrigation for all countries except Viet Nam. This also shows the dry season irrigated areas in Viet Nam, principally in the Mekong Delta region, far exceed the dry season irrigation areas in the upstream regions. Further detail of the distribution by BDP sub-area of irrigation areas for all scenarios is reported in Table 7.1. The following subsections describe how these were derived.

Figure 7.1: Areas of wet season irrigated areas for all scenarios by country.

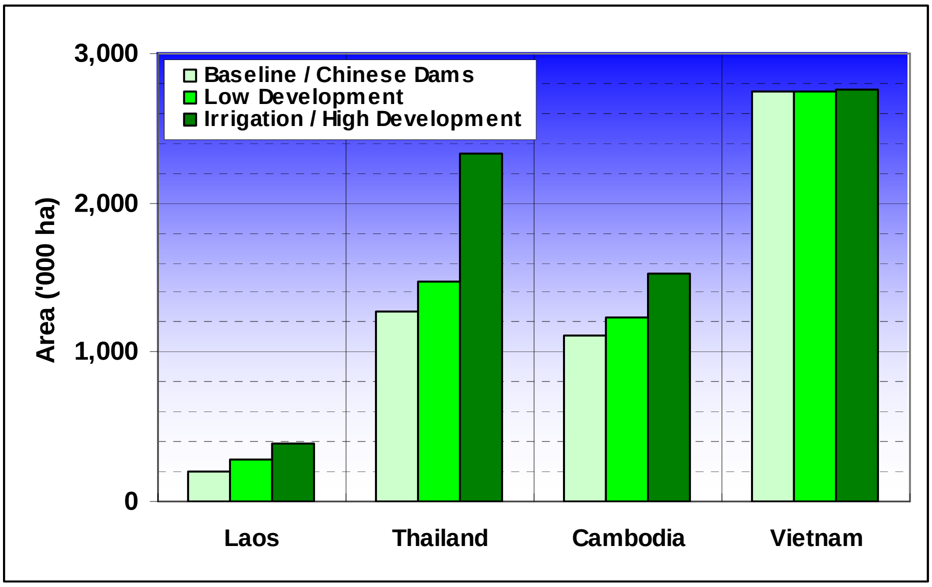
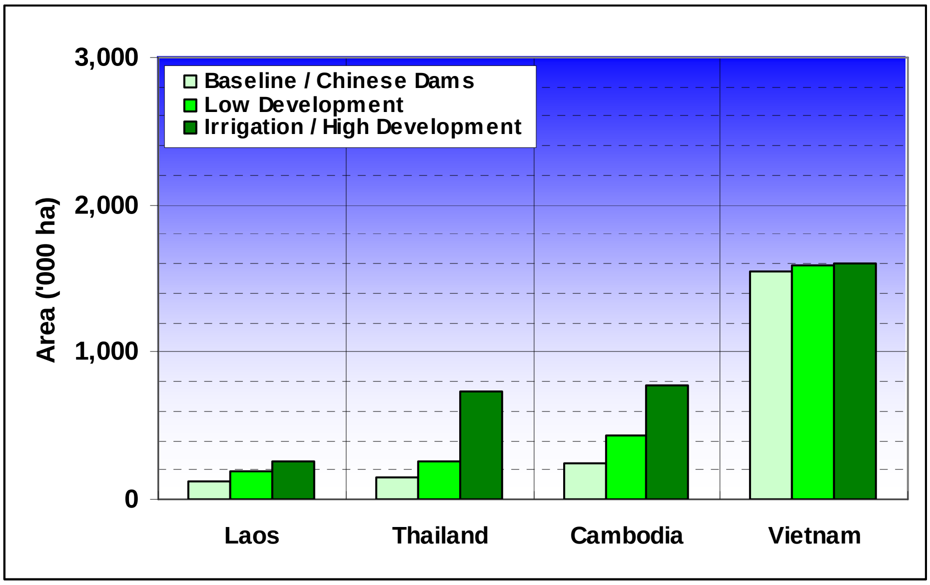


Figure 7.2: Areas of dry season irrigated areas for all scenarios by country.



Baseline

The areas for the Baseline scenario are based on national statistics for the year 2000 (MRC, 2004). The majority of the irrigation is for rice crops, however, significant areas of non-rice crops in the dry season are modelled for Thailand and Laos.

Chinese dams

This scenario did not consider LMB development, and the levels of irrigation development are exactly the same as for the Baseline scenario.

Low Development

For Laos, increases in proposed crop yield supplied by LNMC were used to estimate a percentage increase in agricultural area compared with the Baseline scenario. An increase of 60% crop yield was discounted by 25% allowing for improvements in yield per hectare to give a net increase of 45%. This figure was uniformly applied to all crop areas in Laos.

Changes for Thailand were based on areas of planned irrigation projects proposed by 2020 in the sub-area report supplied by Thailand (TNMC, 2004). this total increase was staged with 50% included for this scenario. Assumptions were made about the future distribution of these areas for wet season and dry season.

Wet season areas were increased for all Thai regions by 17-21%, whereas the increases in dry season irrigation were estimated based on water availability. Areas in northern Thailand (2T) was increased by 190% from a low base. A similar increase was applied to only those irrigation areas diverting water directly from the Mekong River (3T), taking advantage of additional flow released in the dry season by Xiaowan Dam. Dry season irrigation areas in the Mun-Chi basin (5T) were increased by 60%, using supplemental water from an intra-basin diversion from the Nam Ngum tributary.

Increases in irrigation areas for all sub-areas in Cambodia used figures supplied directly by CNMC, with the greatest increases planned for the Mekong Delta region (10C), followed by the Great Lake region (9C). More modest increases were proposed for the parts of Cambodia upstream of Kratie.

Changes in irrigation areas in the Central Highlands region of Viet Nam (7V) were based on percent increases from the sub-area report (VNMC, 2004). Wet season irrigation was increased by 2%, whereas dry season irrigation was increased by 76%.

Irrigation areas in the Mekong Delta region of Viet Nam (10V) were not changed. The reason for this are:

- there are no net significant increases in irrigation areas proposed as the region is already highly developed.

- The changes proposed are complex, and require a deeper understanding of what environmental factors are driving the changes, e.g., flooding, salinity intrusion, land and soil types, and economic factors. These will all change based on the upstream interventions and internal interventions not modelled.

- The changes will not have a transboundary impact on water resources.

These factors are worthy of a detailed scenario formulation in their own right, however they are beyond the scope that can be considered in these scenarios.

Irrigation

A similar method was applied for Laos as for the Low Development scenario, with further increases of 50% from the Low Development areas. Discounting for increased yields results in an net increase of 38% compared to the Low Development scenario, effectively doubling Baseline scenario areas.

The changes for Thailand used the same information as reported in the Low Development scenario. However, the increases are substantially greater, with a net increase of 84% in the wet season, and 370% in the dry season. The dry season increase is facilitated by intra-basin diversions from Nam Ngum and from the Mekong mainstream increasing water availability.

As for the Low Development scenario, increases in irrigation areas for all sub-areas in Cambodia used figures supplied directly by CNMC. These increases are three times those proposed for the Low Development scenario. A substantial additional increase was included for the upstream of Kratie (8C) to take advantage of the potential in this area.

The increases for the Central Highlands region of Viet Nam were also based on figures from the sub-area report, with increase of 105% in the dry season and 15% in the wet season compared with Baseline scenario levels.

As with before, no increases were considered for the Mekong Delta region of Viet Nam.

Table 7.1: Irrigated areas ('000 ha) modelled in scenarios

Sub-area	Baseline and Chinese Dams		Low development		Irrigation and High Development	
	Wet season	*Dry season*	*Wet season*	*Dry season*	*Wet season*	*Dry season*
Laos						
1L+3L	22	14	32	20	44	28
4L	133	85	193	124	266	171
6L+7L	42	28	61	41	85	56
Thailand						
2T	148	13	180	38	211	69
3T	268	18	309	34	550	173
5T	850	125	985	192	1,571	494
Cambodia						
6+8C	16	4	20	10	103	40
7C	13	0	14	2	18	9
9C	451	44	491	103	541	162
10C	629	203	711	323	868	564
Viet Nam						
7V	123	44	126	78	141	90
10V	2,618	1,510	2,618	1,510	2,618	1,510
TOTAL	5,312	2,088	5,739	2,475	7,015	3,365

High Development

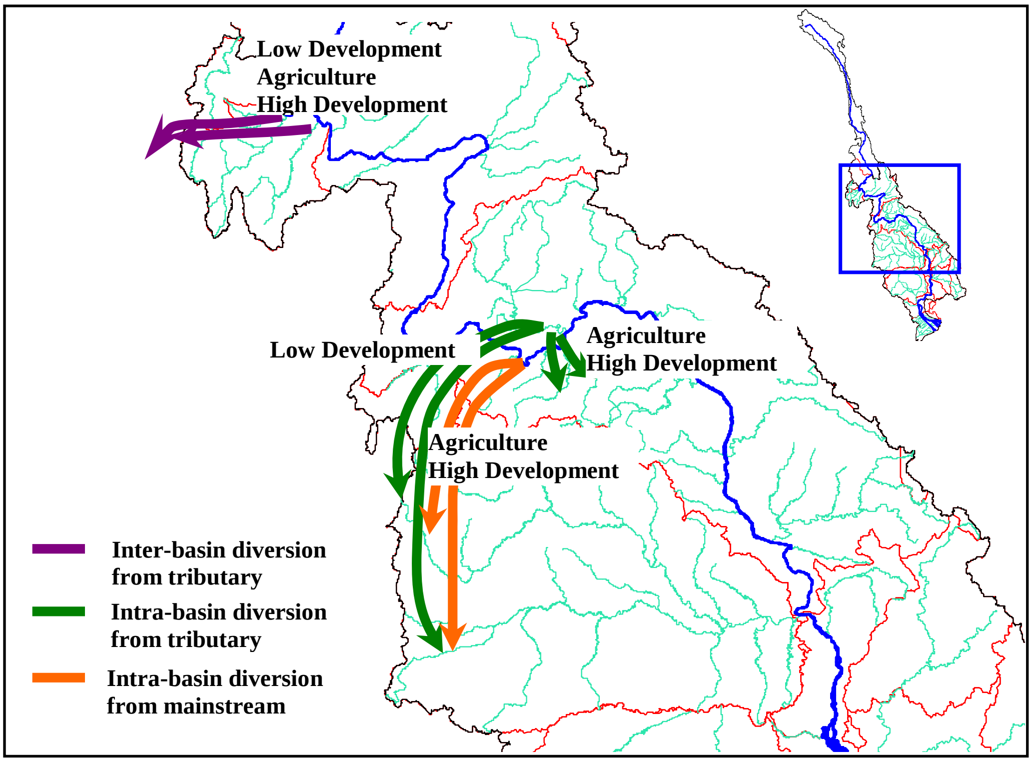
Uses same irrigation areas as for Irrigation scenarios.

7.2 Inter- and intra-basin diversions

Inter-basin diversions are those large scale diversions of water from the Mekong River and tributaries out of the basin. Intra-basin diversion are large scale diversions of water from the Mekong River and its tributaries into another part of the Mekong Basin.

Several combinations of inter- and intra basin diversions were included in the scenarios as shown in Figure 7.3 based on information supplied by TNMC.

Figure 7.3: Schematic of types and locations of inter-basin and intra-basin diversions in development scenarios.



Low Development

The Kok-Ing-Nam inter-basin diversion, represented by the purple arrows in northern Thailand (Figure 7.3), are proposed to alleviate water shortages in the adjacent Chao Praya river basin. These divert water from the Nam Mae Kok and Nam Mae Ing tributaries with the target diversion rates reported in Table 7.2.

Table 7.2: Target inter-basin diversions (m³/s) from Nam Mae Kok and Nam Mae Ing

Tributary	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kok	0	0	0	0	0	40	97	136	139	132	101	70
Ing	0	0	0	0	0	8	21	36	33	33	20	8
TOTAL	0	0	0	0	0	48	126	172	172	165	121	78

Intra-basin diversions were also proposed by TNMC to increase water available for irrigation in north-east Thailand, including directly from the Laos tributary Nam Ngum, and also the Khong-Chi Mun diversion project. The diversion from the Nam Ngum is proposed by building a tunnel under the Mekong (Sanyu, 2002). However, this has exactly the same hydrologic effect as taking it directly from the Mekong River downstream of the Nam Ngum confluence.

For this scenario, a constant rate of 100 m³/s for the whole year was diverted from Nam Ngum, apportioned equally to the headwaters of the Mun River and Chi River as shown by the orange arrows in Figure 7.3. In reality, this water would be diverted into large irrigation storages, such as Lam Pao, in Thailand. However, these storages have not yet been included in the simulation model.

Irrigation / High Development

The Kok-Ing-Nam interbasin diversion was also included for the Irrigation and the High Development scenarios. Significant changes were made to the intra-basin diversions to increase water availability in north-east Thailand.

Instead of diverting Nam Ngum water into the Mun-Chi, this time it was diverted into the Huai Luong and Nam Songkram tributaries, based on the proposal described in Sanyu (2002). The total diversion target of 900 mcm was apportioned to these tributaries according to their relative needs.

To do this, the simulation model was run without the only the sub-catchment inflows, and then a second time with a large addition of water. The difference in the amount of water diverted is an estimate of the water availability deficit for the proposed irrigation areas in these tributaries. The 900 mcm was then shared in ratio to these deficits. The resultant diversion from Nam Ngum, and the amount diverted to Huai Luong and Nam Songkram are shown in the table below.

Table 7.3: Target intra-basin diversion (m³/s) from Nam Ngum to Huai Luong and Nam Songkram

Tributary	Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Huai Luong	39	49	23	0	0	12	9	0	0	20	0	22
Nam Songkram	38	50	24	0	0	21	16	0	0	13	0	22
TOTAL	77	99	47	0	0	33	25	0	0	33	0	44

The Khong-Chi-Mun proposal was included using average monthly diversion estimates supplied by TNMC. This diverts water from the Mekong below Nong Khai into Lam Pao reservoir. As discussed in the previous section, it was not possible to configure this as storages in north-east Thailand have not been included. Instead, these were diverted directly into the headwaters of the Mun River and Chi River. The volume was apportioned into the two rivers based on the ratio of their total areas in the wet season and dry season. The net diversion is reported in Table 7.4.

Table 7.4: Target intra-basin diversion (m³/s) from Mekong below Nong Khai to Mun River and Chi River

Tributary	Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chi River	210	155	149	95	112	43	95	62	35	95	167	240
Mun River	70	52	48	32	38	43	95	62	35	95	167	80
Total	280	207	196	127	150	88	190	122	70	190	334	322

7.3 Domestic and industrial water supply

The domestic and industrial (D&I) demand in the LMB is economically very important, but small compared with irrigation, and 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.

D&I demands were estimated for the baseline in MRC (2004) based on year 2000 populations and estimated per capita demands. Similar estimates were made using projected populations for 2020, and increases in per capita demands in World Bank (2004). These estimates are also used for the development scenarios simulated in this report, and are summarised in Table 7.5.

Table 7.5: Average annual domestic and industrial demands for scenarios

Country	Average annual demand (mcm)		
	Baseline / Chinese Dams	Low Development	Irrigation/High Development
Thailand	935	1,545	1,750
Laos	116	305	388
Viet Nam	443	855	1,079
Cambodia	126	404	977

7.4 Hydropower dams

Physical characteristics

Hydropower development in the LMB has been relatively low to date, with the aggregate active storage of existing dams about 2% of mean annual Mekong flow. The next twenty years could see considerable development of hydropower dams. Plans are well advanced or construction has started on several medium to large storages in China and the LMB, and additional medium to large storages are being actively considered for future development.

Large scale hydropower development will significantly change flows in sections of the Mekong River and its tributaries. In terms of water resource impacts, there are two different types of dams: (i) regulating which store part of wet season flow, and releases it during the following dry season to generate electricity; and (ii) run-of-river which store small amounts of water.

The direct effect of the dams with large regulating storage is to reduce wet season flows and increase dry season flows. The relative size of the change is determined by how much of the flow that dam can store. Large dams on tributaries may cause large changes directly downstream, but after they join the mainstream Mekong, the changes as a percent of the flow are far lower. However, the combined changes of several large tributary storages may become significant.

Run-of-river dams do not significantly change flows. Typically, they are used for rivers with a reliable and significant dry season flow, or are placed below large regulating storages to take advantage of their releases. They have been included in the model for some of these types where they do change flows, either by trans-basin diversion in the case of Nam Theun-Hin Boun, or where there is a large volume evaporated from a surface area of stored water, such as that of the proposed Lower Se San 2 and Lower Sre Pok 2. Run-of-river dams also present potential barriers to fish migration, and are should be considered in scenario analysis, even though they may not have water resource impacts.

Traditional reporting of hydropower has focused on the installed capacity (MW) of the dams. While this is clearly important for valuing its direct economic contribution, it is only part of what needs to be considered for estimating water resource impacts. Active storage, that is the amount of water stored, and the release rates of water are far more important.

The locations of all the hydropower dams included in the scenarios are shown in Map 7.1, along with an indication of their relative size. The dams included in each scenario are listed in Table 7.6.

Map 7.1: Location and relative active storage of hydropower dams modelled for scenarios.

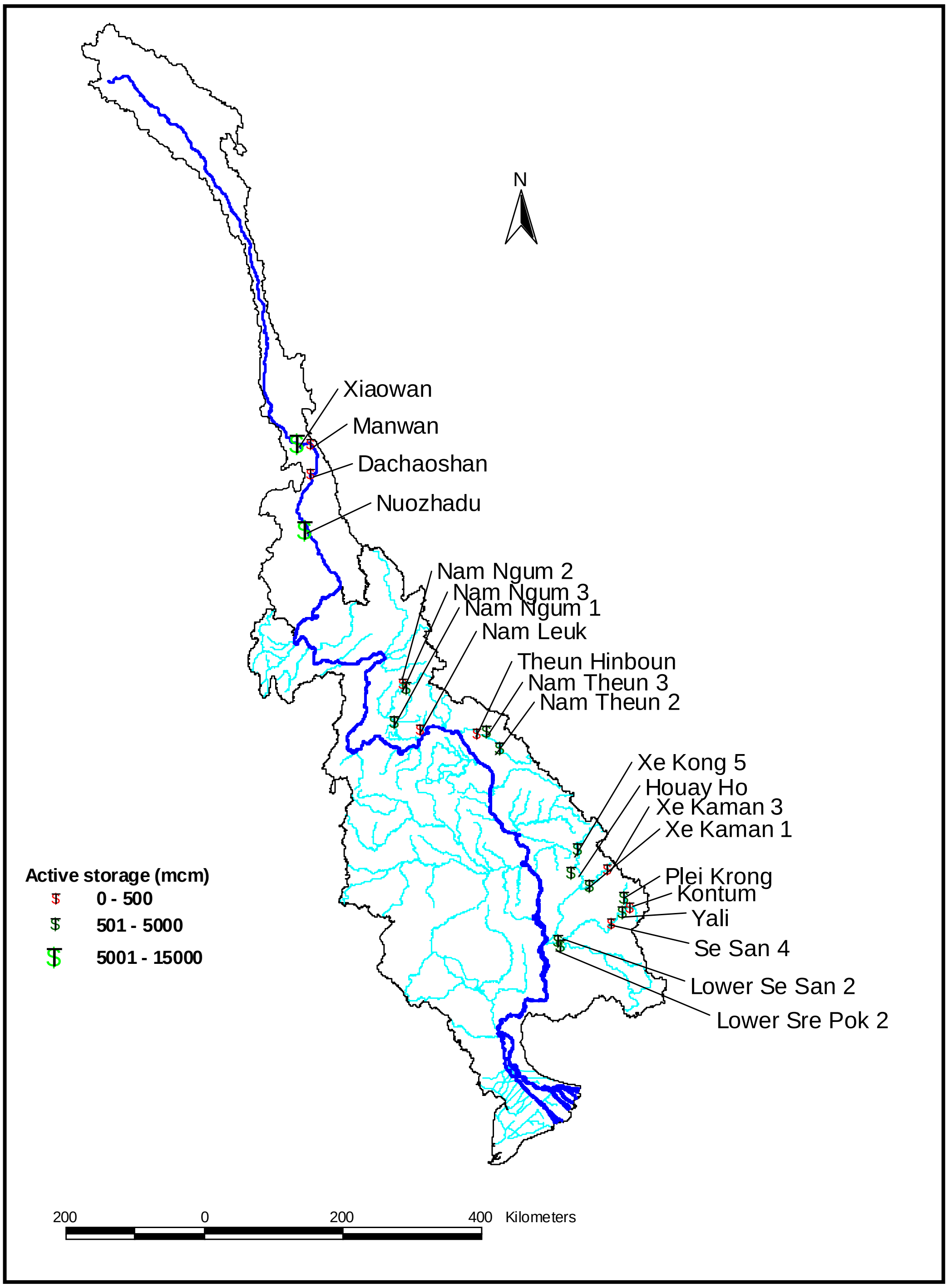


Table 7.6: Hydropower dams modelled in scenarios

Dam Name	Active storage volume (mcm)	Baseline	Chinese Dams	Low Development	Irrigation	High Development
Xiaowan	9,850		+	+	+	+
Manwan	258		+	+	+	+
Dachaoshan	267		+	+	+	+
Nuozhadu	12,400		+			+
Nam Ngum 3	981			+	+	+
Nam Ngum 2	150			+	+	+
Nam Ngum	4,270	+	+	+	+	+
Nam Lik	154	+	+	+	+	+
Nam Theun 2	3,370			+	+	+
Nam Theun 3	3,000					+
Nam Theun-Hinboun	15	+	+	+	+	+
Houay Ho	527	+	+	+	+	+
Se Kong 5	4,703					+
Xe Kaman 1	3,300					+
Xe Kaman 3	467					+
Plei Krong	895			+	+	+
Upper Kontum	300			+	+	+
Ya Li	779	+	+	+	+	+
Se San 4	484			+	+	+
Lower Se San 2	720					+
Lower Sre Pok 2	720					+

Operation rules

What is also important is the operational rules of these dams, that is how much water they release at different times of the year. Power is proportional to the product of flow rate through the turbines and the vertical distance the water falls prior to flowing through the turbines. In some cases large amounts of power can be generated by dropping a large vertical distance, as is done with Houay Ho, which discharges a relatively small volume (10 m^3/s) with a large water drop (660 m).

Operational rules are determined based on economic returns from power generation, and will vary for each dam depending on the which market is supplying power to. At any given time, the water released will be decided on the marginal cost of power which will vary according to demand. For example, demand is higher in the hotter months to supply electricity for air conditioning. This peak demand coincides with the dry season, when dam inflows are lowest. Therefore, judgements are made during the wet season to restrict release rates so that there is sufficient volume remaining in the storage to maximise power generated during the drier months.

Sophisticated methods are used by the dam operators to determine optimal operational rules, based on these economic considerations, but also on patterns of inflows and the current volume stored in a dam. These methods, and the data to use them is often commercial-in-confidence, and not available at this stage at the MRCS.

Simplified methods have been adopted for this study. They focus on maximising hydropower production by minimising spills from the dam, but also maintaining a minimum power production, i.e., not allowing the dam to completely empty. The maximum release rate is determined directly from dam data sheets. Minimum release rates are derived by iterative simulations, refining monthly average release rates based on drawdown patterns. The monthly average release rates are also decreased if the volume falls below certain thresholds.

Where dams are part of a cascade, e.g. Chinese Dams, Nam Ngum 1/2/3, and the Se San cascade, operational rules are derived for the most upstream dam first, and the resulting releases used to determine operational rules for the next downstream dam.

Baseline

Five hydropower dams in operation at year 2000 were included in the Baseline scenario as reported in MRC (2004). These are Nam Ngum, Nam Leuk, Nam Theun Hinboun, Houay Ho, and Yali (Ya Li). Operational rules were derived for these based on historical release data, and for Yali, rule curves supplied by the VNMC.

Manwan Dam, although operating from 1993, was not explicitly included. This omission is not important as Manwan has a low active storage compared with inflows, and only has a negligible effect on long term average monthly flows.

Chinese dams

The proposal to develop a cascade of dams to take advantage of the large hydropower potential of the Lancang have been known for over ten years. The proposal has been described in some detail by Plinston and Daming (2000). The storage volume and installed capacity are listed in Table 6.1 in geographic order. An additional six dams have also been proposed in the reaches of the Lancang above Gonguoqiao (Sanyu 2002). What is apparent from this data is that the size of Xiaowan Dam and Nuozhadu Dam far exceeds the combined size of all the remaining dams

In this scenario only the existing dams (Manwan and Dachaoshan) and the two largest (Xiaowan and Nuozhadu) have been included. The remaining dams are not expected to change flows significantly more than these four.

Low Development / Irrigation

Several dams in the LMB have been started, or are at an advanced stage of planning. The most significant of these is Nam Theun 2, on the upper reaches of the Nam Theun River. This will actively store over 3,300 mcm, and will discharge water through its turbines into the adjacent Se Bang Fai river basin. This will result in less flow year round along the Nam Theun, effecting the operation of the Nam Theun Hinboun hydropower dam downstream. Flows will also be reduced year round in the reach of the Mekong River between the confluence of Nam Cadinh (the Mekong tributary the Nam Theun joins) and the Se Bang Fai.

Proposals are also advanced to develop Nam Ngum 2 and Nam Ngum 3 above the existing Nam Ngum storage. Nam Ngum 3 is a regulating storage and Nam Ngum 2 will rely on releases from Nam Ngum 3 to reliably generate electricity year round. These will increase dry season flows into Nam Ngum 1, allowing for refinement of the operational rules.

Several dams are proposed along the Se San river by Viet Nam (VNMC, 2004), including Plei Krong, Upper Kontum above the existing Ya Li Dam, and Se San 3A and Se San 4 below Ya Li Dam. Both Plei Krong and Se San 4 have significant regulating storage capacity, whereas Se San 3A is effectively a run of river dam and is not modelled. Upper Kontum generates power by diverting water through a 900 m drop towards the coast of Viet Nam, and could be considered an inter-basin diversion. It is understood that the derivation of operational rules the subject of a current study. These have not been supplied, so have been derived independently for this study.

Viet Nam has also proposed dams on the Sre Pok river, however, insufficient data is currently available to simulate these.

The proposed Nuozhadu Dam in China was not included in this study, as plans to construct are not sufficiently advanced.

Irrigation

The same dams as used for the Low Development scenario.

High Development

Several additional large dams were included for the High Development scenario. A significant feature of this is the concentration in the Se Kong tributary in southern Laos, which is currently relatively unregulated. Xe Kaman 1 and Xe Kaman 3 are located on one of the branches, and Se Kong 5 on the northern branch. Se Kong 5 will have the largest active storage of all the LMB dams modelled.

Two large run-of-river dams were included near the junction of Se San and Sre Pok, just upstream of their joining the Mekong River. These do not have a regulating storages, so operational rules are based on either the maximum release rate, or if the inflow is lower than this, the inflow – evaporation from the large water surface area.

Nam Theun 3 is also included, on a tributary of the Nam Theun. This storage will have the effect of improving flows into Nam Theun Hinboun, effectively compensating for the flows diverted by Nam Theun 2 into Se Bang Fai.

7.5 Floodplain embankments

Current analytical status

The iSIS hydro-dynamic model within the DSF includes major existing floodplain embankments within its schematisation. Some are explicitly modelled, their physical height and extent being directly mirrored in the model's parameters and configuration, however, others are not. Instead their effects on water levels and flow distributions are taken into account by adjustments to general parameters used to achieve a good calibration against flood levels recorded at particular locations during past floods.

Consequently, the DSF provides a good representation of existing floodplain conditions, from which to assess the impacts of changes in flows or other upstream interventions. However, should a development scenario involve alteration to the topography of the floodplain (through land fill for instance), or construction of new structures, such as roads, irrigation canals, flood mitigation works, etc, then the configuration of the hydro-dynamic model needs to be adjusted appropriately.

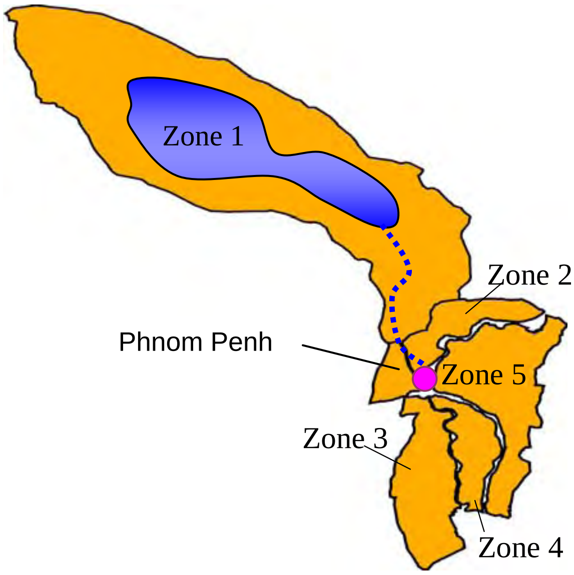
Credible information on the likely location, physical parameters and operation of new floodplain embankments was considered inadequate to develop a fifth scoping scenario to add to the four already considered in this report. Were it possible, such a scenario would be used to assess the likely impacts of a "probable" future development condition, say in 2010 or 2020.

Future embankment analysis

A review of likely future embankments and the probable nature of their impacts is provided in Chapter 7.

Apart from aforementioned the DSF iSIS hydro-dynamic model, a hydro-hydraulic model and tools have been developed for the Cambodian portion of the floodplain, including Tonle Sap. This work, conducted as part of the WUP-JICA study on *Hydro-Meteorological Monitoring for Water Quantity Rules in Mekong River Basin*, has been used in the development of a dry season flow management system and work on downstream flow prediction. In addition, it has supported the other JICA funded work, the *Tonle Sap Lake & Vicinities Study* (TSLV). Figure 7.4 shows the location of floodplain zones used in the WUP-JICA study.

Figure 7.4: Extent of floodplain zones delineated by WUP-JICA



Importantly, it has already evaluated the impact of some the most significant existing floodplain embankments, as well as some potential changes to those embankments. Whilst it has not been used to evaluate the likely impacts of future works, the following conclusions from work to date can provide some indication of the significance of likely future works on flood behaviour:

- Between Kampong Cham and Chrui Changvar approximately 30 % of the discharge is conveyed on the flood plains;. approximately 60 % by the left (southern) bank and 40 % by the right bank.

- The total volume of flow entering and leaving the Cambodian floodplains (zones 2 to 5 in the WUP-JICA study), outside of the Tonle Sap Great Lake area (zone 1), are an order of magnitude larger than the actual storage within them.

- The storage capacity of the floodplains is only 15-20 % of the capacity of the Great Lake and its surrounding plains. From this and the preceding point, the WUP-JICA consultants suggest that flood management in zones 2 to 5 focus on:

- flood extent and depth;

- the flux of water through the flood plains;

- the velocity field on the plains and in flow controls; and

- obstacles for flow.

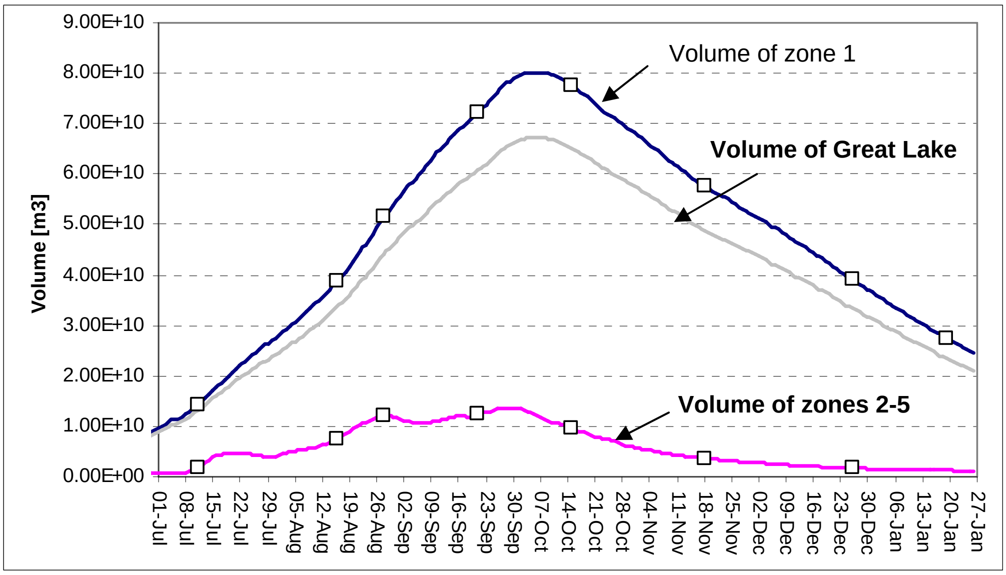
- The floodplain area lying between the Mekong and Tonle Sap rivers (zone 2) exhibits a slow release of stored flood water at the end of the wet season.

- The release of stored wet season flows from floodplains outside of the Great Lake area is largely completed by the end of November, whereas the Great Lake and surrounds still retains half its stored volume at this time.

- Isolated bridges and embankments are the main controls on the flood plains. Changes of these facilities has large impacts on the flow distribution and inundation pattern on the flood plains

Figure 7.5 shows the difference in flood storage volumes for the Great Lake, all of zone 1 (which includes the Great Lake) and the rest of the Cambodian floodplain (zones 2 to 5).

Figure 7.5 Cambodian floodplain and Tonle Sap Great Lake flood storage volumes



(Source: TLSV Project Regional Workshop II presentation, March 2003 (MRC, 2004b))

Other conclusions have been reached through an analysis of the impacts of road development at various points in time since the 1920s, when the first significant embankments were constructed, as well as the effects of widening current bridge openings (Figure 7.6). The key findings (using the year 2000 hydrograph) include:

- Construction of Cambodian National Roads 6 and 61 across the entrance to the Great Lake at Prek Kdam in the late 1920's caused most of the current impact on flood flows

- Volumes entering zone 2 (on the right bank) are now half that which occurred in the 1920s

- Floodplain reverse flow volumes entering the Great Lake from zone 2 are now (at 2003 development levels) 1/3rd of natural volumes in the 1920s

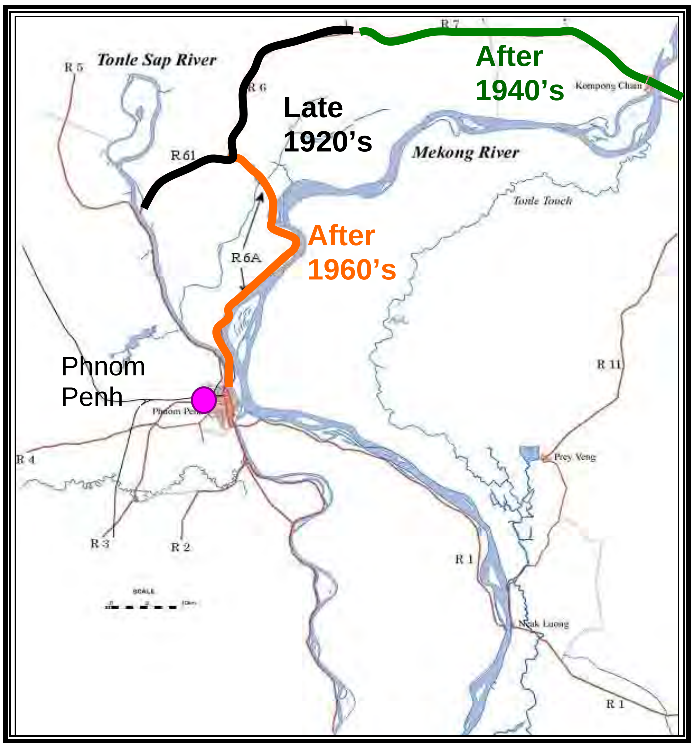
- The total volume entering the Great Lake is now 62 mcm verses 70 mcm previously and of this, 48 mcm now enters via the Tonle Sap River, whereas previously it only conveyed 27 mcm

- The volume draining from the Great Lake at Prek Kdam is now only 22 mcm, almost 30% lower than the previous 31 mcm

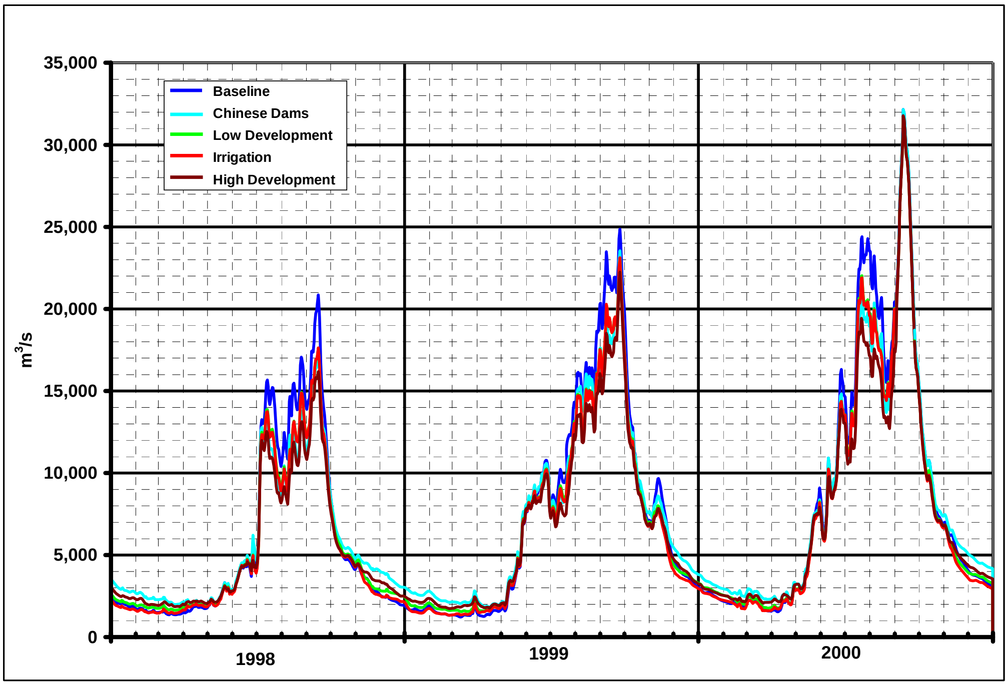
- Flow volumes in the Bassac River are now 1/3rd higher than previously with a corresponding decrease in Mekong mainstream flows downstream of Phnom Penh

- Blockages caused by major roads, such as National Road No.1 near Neak Luong, can increase water levels by 40 to 50 cm up to 20 km upstream

Figure 7.6: Location of major road developments (1920s to 2003) considered by WUP-JICA in a historical impact analysis



(Source: TLSV Project Regional Workshop II presentation, March 2003 (MRC, 2004b))



8 Flows and water levels

by Richard Beecham and Hugh Cross,
March 2005

8.1 Water utilisation

The development scenarios simulated in the DSF considered changes in the scale and location of sectors that were significant users of water; irrigation, domestic and industrial consumption, hydropower, and large scale diversions. These sectors would all be expected to benefit from their use of water; by increased crop production from irrigation, economic and quality of life benefits from domestic and industrial water usage, and increased energy production from hydropower.

Results are calculated within the DSF of some of the production outputs from this use of water, as well as how much water is used to produce this output. These are reported in the following Sections. This analysis provides the context to understand the changes in flows reported subsequently.

Irrigation diversions

Diversions from the Mekong River and tributaries to irrigate crops is the largest consumptive use of water in the Basin, about 10% of the total water resources (World Bank, 2004). The distribution of irrigation areas is reflected in the geographic distribution of water usage, with over 60% of irrigation water consumed in the Mekong Delta region.

The characteristics of this irrigated crop distribution for the Baseline scenario are based on interpretations of official provincial statistics of agriculture. The disaggregation of provincial level crop areas by country for the year 2000 to the 289 irrigation nodes in the DSF simulation models (142 in the LMB upstream of Kratie, 25 in the Great Lake region, and 120 in the Vietnamese part of the Mekong Delta region) is described in detail in MRC (2004). Also described are cropping calendars, crop factors, irrigation efficiencies, and return fractions.

Crop water demand is calculated in IQQM using standard techniques based on crop areas, crop factors, soil properties, and climatic inputs of rainfall and potential evapo-transpiration (PET). Estimated demands were in the range of 0.7-1.1 m for dry season rice, 0.2-0.4 m for other dry season crops, and 0.1-0.4 m for wet season rice. Taking account of irrigation efficiencies and returned water, the net water use is typically between 20-60% higher.

Expressed as a volume, net water usage for dry season rice varies between 8-16 m^3/ha, other dry season crops use between 4-8 m^3/ha, and wet season rice uses 2-4 m^3/ha. Detailed calculations of these are reported in Appendix A of World Bank (2004). Using a mid-range water usage rate for each, 2.1 million hectares of dry season rice and 5.3 million hectares of wet season rice will use an average 25,000 mcm/year and 16,000 mcm/year respectively, approximately 9% of the average annual flow of 470,000 mcm year.

Results for simulated diversions for the five scenarios by the BDP sub-areas are reported and summarised in the following tables.

Table 8.1: Mean annual modelled net irrigation diversions (mcm) by BDP sub-area upstream of Kratie

Sub-Area		Baseline & Chinese Dams	Low development	Irrigation & High Development
Laos	1L	213	315	428
	3L	22	35	47
	4L	1,726	2,494	3,437
	6L	389	562	766
	7L	161	233	327
	Total:	2,510	3,640	5,006
Thailand	2T	532	774	1016
	3T	883	1091	2760
	5T	6,660	8,621	14,198
	Total:	8,075	10,485	17,974
Cambodia	6C	9	14	14
	7C	63	75	95
	8C	118	203	955
	Total:	191	292	1063
Viet Nam	7V	586	930	1,052
	Total:	585	929	1,052

Table 8.2: Mean annual modelled net irrigation diversions (mcm) by BDP sub-area downstream of Kratie

Sub-area		Baseline & Chinese Dams	Low Development	Irrigation & High Development
Cambodia	9C	1,280	1,585	1,797
	10C	2,802	3,654	5,289
	Total:	4,082	5239	7,086
Viet Nam	10V	21,838	21,838	21,838
	11V	3,380	3,380	3,380
	Total:	25,219	25,219	25,219

*Table 8.3: Mean annual modelled net irrigation diversions (mcm * 1,000) by country for Lower Mekong Basin*

Sub-area	Baseline and Chinese Dams	Low development	Irrigation and High Development
Laos	2.5	3.6	5.0
Thailand	8.1	10.5	18.0
Cambodia	4.3	5.5	8.1
Viet Nam	25.1	26.1	26.3
Total:	40.8	46.1	58.4

The increases in diversions reflect the changes in irrigation areas as expected. Changes for Laos were uniformly 45% and 100% for the Low Development, and Irrigation / High Development scenarios respectively. Similar increases of 30% and 120% were estimated for Thailand; 60% and 80% in the Central Highlands region of Viet Nam, and 30% and 90% for Cambodia.

These changes in national figures are distributed according to where the greatest changes in irrigation were, especially North-East Thailand, enabled by large scale intra-basin diversions, and Cambodian regions along the Mekong River.

Irrigation reliability

The success or otherwise of any irrigation development depends on several factors, including institutional and management arrangements, market prices, and water availability. Institutional, management, and economic factors are beyond the scope of this assessment of scenarios, although they clearly need to be part of the broader planning process. This assessment focuses on water usage and availability issues.

The simulation models as configured allow irrigation areas to increase regardless of any constraints in water availability. The simulation models could be configured in the future to consider water availability for calculating how much irrigated crop to plant. As configured, the simulation models can calculate how reliably water is supplied to the irrigation areas specified in the scenario formulation.

A result labelled 'Sustainable Area' was developed in the simulation model during the DSF development stage, and is calculated on a daily basis. The way it works is to calculate every day the crop area that could be irrigated with the water available. If the water available matches the demand, then the sustainable area would match the area of crop planted. If, however, the water available is less than the demand, the sustainable area is less than the area planted by the same ratio. This calculation is subjected to a ten-day moving average, to allow for short-term unavailability that would not necessarily result in crop failure.

The calculation is restarted whenever a new crop is started. This calculation is scenario specific, as any activity that takes place upstream that affects water availability would result in a different estimate. Changes in either the crop mix, or irrigation efficiency would also produce different estimates.

The value of sustainable area at the end of the growing season for a particular crop type is a measure of the area that could have been reliably irrigated during that year. Defining the end of the growing season is a simple matter where there is only the one crop grown. Where there are overlapping crop growing seasons, some judgement is needed to select a suitable time to report this. These dates are reported in the following table.

Table 8.4: Reporting dates for sustainable area by BDP sub-area and season.

Country	Wet season	Dry Season
Laos	31 October	31 March
Thailand	31 October	30 April
Cambodia	31 December	30 March
Viet Nam	31 October	30 March

A different value is calculated for each year for each season for each BDP sub-area. The ratio of (Sustainable Area: Planted Area) is a measure of the reliability of water availability for irrigation. These are reported as the mean reliability of the sixteen years of the simulation, as well as the reliability for 80% of the time. This latter is an indicator of how much area can be reliably irrigated for four years out of five. The results of these are reported in the following tables for Laos, Thailand, Cambodia and Viet Nam respectively.

Table 8.5: Changes in irrigation areas and irrigation reliability in Laos

Sub-area		Baseline and Chinese Dams		Low development		Irrigation and High Development	
		Wet season	*Dry season*	*Wet season*	*Dry season*	*Wet season*	*Dry season*
1L+3L	Area	22	14	32	20	44	28
	Mean reliability	100	95	100	94	100	93
	80% reliability	100	97	100	96	100	95
4L	Area	133	85	193	124	266	171
	Mean reliability	100	88	100	91	100	90
	80% reliability	100	92	100	95	100	95
6L+7L	Area	42	28	61	41	85	56
	Mean reliability	98	90	98	96	98	95
	80% reliability	100	99	100	100	100	99

Table 8.6: Changes in irrigation areas and irrigation reliability in Thailand

Sub-area		Baseline and Chinese Dams		Low development		Irrigation and High Development	
		Wet season	*Dry season*	*Wet season*	*Dry season*	*Wet season*	*Dry season*
2T	Area	148	13	180	38	210	69
	Mean reliability	98	93	99	82	99	73
	80% reliability	100	100	100	93	100	81
3T	Area	268	18	309	34	550	173
	Mean reliability	98	74	98	78	99	68
	80% reliability	100	91	100	86	100	81
5T	Area	850	125	985	192	1,571	494
	Mean reliability	95	94	95	93	93	85
	80% reliability	100	100	100	100	100	95

Table 8.7: Changes in irrigation areas and irrigation reliability in Cambodia

Sub-area		Baseline and Chinese Dams		Low development		Irrigation and High Development	
		Wet season	*Dry season*	*Wet season*	*Dry season*	*Wet season*	*Dry season*
6C+8C	Area	16	4	20	10	103	40
	Mean reliability	100	100	100	100	100	100
	80% reliability	100	100	100	100	100	100
7C	Area	13	0	14	2	18	9
	Mean reliability	100	-	100	100	100	100
	80% reliability	100	-	100	100	100	100
9C	Area	451	43	491	103	541	162
	Mean reliability	98	38	98	32	98	25
	80% reliability	100	46	100	42	100	37
10C	Area	629	203	711	323	868	564
	Mean reliability	Diversions from Mekong River- reliability assumed 100% under all scenarios					
	80% reliability						

Table 8.8: Changes in irrigation areas and irrigation reliability in Viet Nam

Sub-area		Baseline and Chinese Dams		Low development		Irrigation and High Development	
		Wet season	*Dry season*	*Wet season*	*Dry season*	*Wet season*	*Dry season*
7V	Area	123	44	126	78	142	90
	Mean reliability	100	90	99	90	99	90
	80% reliability	100	94	100	96	100	95
10V + 11V	Area	2,618	1,510	2,618	1,510	2,618	1,510
	Mean reliability	Diversions from Mekong River- reliability assumed 100% under all scenarios					
	80% reliability						

Constraints on water availability would result in lower reliability as larger crop areas are planted. This outcome is apparent in particular for the Thailand regions, for example the mean reliability for BDP Sub-area 2T decreased from 93% to 82% and 73% for the larger dry season crop areas. The reliability for the other Thai sub-areas was moderated by the increased water availability from intra-basin diversions. The conclusions from these results should be highly qualified however. The impacts of the significant storage and regulation were not included in the simulation models as no data was made available. These important processes would significantly affect irrigation reliability estimates. this issue is discussed further in Section 0.

The only other region to show significant changes in the reliability measures was the Great Lake (9C) where mean reliability decreased from 38% to 32% and 25% for the larger irrigation areas. The low value of these reliabilities, however, is thought to indicate simulation model limitations, rather than robust estimates of reliability. This is discussed further in Section 0.

The reliabilities for some regions did not change significantly as areas increased, indicating that there are no significant constraints on water availability within the range of irrigation areas considered.

Most of the sub-regions do not show significant constraints, and in some cases improve for larger irrigation areas (e.g., the central Laos region) improve, presumably as a result of the regulated water from hydropower dams.

Inter-basin diversions

The mean annual diversions out of the Mekong Basin from the Nam Mae Kok and Nam Mae Ing takes place during wet season months, and December. The diversions targets, expressed as mcm/month in the table below, were not fully met each month or year, especially in the earlier part of the wet season. Overall, about 90% of the diversion target is met, for an average annual total of 2,048 mcm.

Table 8.9: Target inter basin diversion targets and simulated diversions.

Month	Nam Mae Kok		Nam Mae Ing	
	Diversion target (mcm)	% Demand met	Diversion target (mcm)	% Demand met
Jun	62	59	15	75
Jul	175	69	40	75
Aug	324	92	85	91
Sep	350	97	81	94
Oct	340	99	79	92
Nov	263	100	48	92
Dec	173	96	15	71
TOTAL	1,685	91	363	0.88

Domestic and industrial water supply

Domestic and Industrial water supply is a relatively minor, but economically important user of water, using less than 0.5% of the total water resource of the Mekong Basin. The D&I demand is directly related to population, and was estimated in MRC (2004) based on provincial populations, and a per capita demand, which reflected the level of water supply infrastructure. Increases for the scenarios were based on projected population increases and an increased level of water supply.

Supplying domestic and industrial demand 100% of the time is considered a high priority. Coupled with the requirement for high reliability, domestic water use also requires high water quality, even where supplies are treated.

Reliability of supply was estimated by taking the ratio of (demands / diversions) for the whole simulation period, and also by comparing the frequency distribution of diversions at a BDP sub-area level of aggregation. In a similar manner to the reporting of irrigation reliability, the mean percentage of demand supplied, and the percentage of time 80% of demand is met is calculated. These results are reported in the following tables for Laos, Thailand, Cambodia and Viet Nam respectively, as well as the total diversions by country.

Table 8.10: Domestic & Industrial demands, diversions and reliability for Laos

Sub-area		Baseline and Chinese Dams	Low development	Irrigation and High Development
1L	Diversions	32	84	107
	% demand met	96	96	96
	% time 0.8*demand met	94	94	94
3L	Diversions	2	5	6
	% demand met	83	93	89
	% time 0.8*demand met	74	74	73
4L	Diversions	55	143	183
	% demand met	96	95	96
	% time 0.8*demand met	95	95	95
6L	Diversions	12	31	40
	% demand met	97	96	96
	% time 0.8*demand met	95	92	90
7L	Diversions	8	22	28
	% demand met	96	94	96
	% time 0.8*demand met	85	85	100

Table 8.11: Domestic & Industrial demands, diversions and reliability for Thailand

Sub-area		Baseline and Chinese Dams	Low development	Irrigation and High Development
2T	Diversions	60	97	110
	% demand met	91	90	90
	% time 0.8*demand met	84	83	83
3T	Diversions	180	290	347
	% demand met	87	85	89
	% time 0.8*demand met	74	70	84
5T	Diversions	545	933	977
	% demand met	82	85	79
	% time 0.8*demand met	59	71	49

Table 8.12: Domestic & Industrial demands, diversions and reliability for Cambodia

Sub-area		Baseline and Chinese Dams	Low development	Irrigation and High Development
6C	Diversions	0.3	1	2
	% demand met	100	100	100
	% time 0.8*demand met	100	100	100
7C	Diversions	2	6	14
	% demand met	100	100	95
	% time 0.8*demand met	93	91	90
8C	Diversions	2	7	15
	% demand met	100	100	100
	% time 0.8*demand met	100	100	100
9C	Diversions	49	154	365
	% demand met	98	96	95
	% time 0.8*demand met	97	94	89
10C	Diversions	70	223	530
	% demand met	Diversions from Mekong River- reliability assumed 100% under all scenarios		
	% time 0.8*demand met			

Table 8.13: Domestic & Industrial demands, diversions and reliability for Viet Nam

Sub-area		Baseline and Chinese Dams	Low development	Irrigation and High Development
4V	Diversions	1	4	5
	% demand met	67	80	83
	% time 0.8*demand met	81	81	81
7V	Diversions	43	83	104
	% demand met	82	77	82
	% time 0.8*demand met	80	79	79
10V	Diversions	390	390	390
	% demand met	Diversions from Mekong River- reliability assumed 100% under all scenarios		
	% time 0.8*demand met			

Table 8.14: Mean annual modelled domestic and industrial diversions (mcm) by country for Lower Mekong Basin

Country	Baseline and Chinese Dams	Low development	Irrigation and High Development
Laos	109	285	365
Thailand	784	1,320	1,434
Cambodia	123	390	927
Viet Nam	435	477	500
TOTAL	1,450	2,473	3,225

The results show, that even though demand is comparatively small, at times there are shortfalls in supply. The BDP sub-areas that this result is most apparent include 3L, 7V, and all the Thai sub-areas. The conclusions from these results are that some degree of storage of water should be considered in these areas, or that water is supplied from alternate sources, such as groundwater. As discussed in Section 0, existing storages in Thailand that would currently serve this purpose have not yet been included in the simulation models.

The total modelled diversions for D&I in the modelled scenarios increase by more than 120%, or about 0.7% of the total Mekong water resource. The largest user of water for this purpose is Thailand, but the largest percentage increases are simulated in Cambodia and Laos, as access to water is improved.

8.2 Hydropower

The Mekong Basin until recently had a very low level of hydropower development. The notable exceptions to this were the Mun-Chi river system generally, and Nam Ngum Dam, completed in the early 1970's. Several have been developed in the LMB during the 1990's, including Nam Theun-Hin Boun, Houay Ho, Nam Leuk and Ya Li, as well as Manwan in China. Plans to develop several more, especially in Laos, were deferred after the economic downturn in Asia in 1997.

The degree hydropower dams can regulate flows is determined by the relationship between the active storage and inflows. The dams developed over the last decade did not greatly add to the total active storage capacity in the Mekong Basin compared with Nam Ngum and the Thai dams. Total active storage in the Mekong Basin is still less than 10,000 mcm, or about 2% of the annual average flow.

However, this figure is likely to increase significantly as a result of the dams modelled in the scenarios. Xiaowan alone will double the total active storage in the basin. Nam Theun 2, and the Se San cascade will also add significantly to this total. Additional dams considered in these scenarios increase the total active storage to the region of 50,000 mcm, or in excess of 10% of the annual average flow.

Operation rules

For run-of-river type storages, i.e. those with low active storage relative to inflows such as Manwan, Dachaoshan, and Lower Sre Pok 2 and Lower Se San 2, operational rules were developed as described in the corresponding subsections. For storages with significant regulation capacity, a generic method was developed.

The degree to which these dams seasonally redistribute the flow depends on the operational rules, i.e., how much water is released at any time of the year. These operational rules should be designed to produce the maximum benefit for the community generally, and would consider all sectors, including hydropower generation, water supply, maintaining in-stream flows, flood protection, etc.

The information to define these objectives is not available, and is also beyond the scope of this study. Only hydropower generation was considered in deriving these rules. These operational rules need to maximise some objective, e.g.., hydro-energy generated, or some economic measure. Once an objective function is defined, some form of optimisation program could then derive guidelines for how much water to release, against the constraints of installed capacity, available water, and the necessity reserve water so as to be able to generate a minimum amount of power throughout the year The release rules would functionally depend on the time of year, and the amount of water in storage.

Consultations with experts in this field (P. Richet, pers. comm) elaborated on the principles of this. It can be assumed as a general case that the amount of water released depends on maximising revenue based on the marginal cost of power, which is higher during periods of higher than average energy consumption. This varies during on a sub-daily basis (eg. 05:00-21:00), weekly (e.g., lower on weekend) a nd seasonal basis.

The seasonal basis is the temporal scale of key interest, as the others can be averaged within a daily time-step model. The seasonal period of peak demand in this region is during the hottest months (March-May), to supply energy for air-conditioning. Therefore, the periods when energy is needed most coincides with the period of lowest flows in the Mekong River and tributaries.

Reserving water to maximise power for this periods alone is not the optimal solution however, as opportunities are lost to generate energy during the months before, and could also result in lost opportunities through water spilling because the storage is too full.

Deriving these rules requires substantial information, not only of hydrology and energy generating characteristics of the dam, but also of energy markets and the marginal cost of energy across the year. This level of information, and the methods to generate operational rules for multiple dams based on this is in the domain of specialists in the private and public sectors of the hydropower industry. Simpler methods had to be employed based on the information and time available to do the analysis.

A generalised simple method was developed to maximise hydro-energy production, while maintaining a minimum level of hydro-energy ('Firm Energy') at any time of the year. The steps in the method were as follows:

Determine maximum release rate from firm capacity and head (Q_{max}=*f(Installed capacity/Head)*).

Determine minimum release rate (where available) based on firm power targets, where reported. (Q_{min}=*f(Firm power/minimum head)*). Reduce based on utilisation factor (daily hours of operation 1/24)

Configure dam in simulation model with inflows, rainfall, evaporation, and storage characteristics.

Use a type 3.2 or 9.5 node[i] to derive operational rules. Develop rules heuristically by multiple simulations and graphically analysing the results.

Start with minimum releases throughout the year. Increase to maximum for months preceding spills.

Increase releases for months after spilling ceases until dam reaches empty for one time during period of record.

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[i] These devices order water from the dam based on time of year, and the amount of water stored. Separate releases can be specified for each month (or day if required), and these can be reduced by a fixed percentage when the storage level falls below a threshold. The 3.2 node can redirect the demand to elsewhere in the river system, whereas the 9.5 keeps the water in the same stream.

Increases releases for fuller state of storage while maintaining minimum during emptier state by adjustment of releases and restriction thresholds.

These simplistic operating rules capture the essential characteristics of regulation for hydro-energy generation. However, because of the simplistic nature of them, they are probably underestimating the dry season releases (by about 20% in the case of Nam Theun 2, P. Richet, pers. comm), and overestimating spills. The resulting comparisons of average monthly inflow and average monthly outflows are shown in graphs below each table.

Most of these show significant redistribution of flow from the wet season to the dry season. The largest regulations are Xiaowan and Nuozhadum, as well as Nam Theun 2, Nam Theun 3, and Xe Kaman 1. All dams are discussed in aggregate in Section 8.6.4. They also show the benefits of regulation of inflows for dams in cascade, such as before and after for Nam Ngum 1 and Ya Li dams.

Hydro-energy generated

Hydro-energy generated is calculated directly in IQQM as:

$$E = P * \Delta t$$

$$E = Q_{out} * \gamma * \varepsilon * \Delta t$$

Where: E = Energy generated (MWh)

Q_{out} = Turbine release (m^3/s)

γ = weight of water (kg/m^3)

ε = turbine efficiency

Δt = time step (hours)

The mean annual energy generated for each dam for each scenario is reported in Table 8.15. The total energy generated for each country is reported in Table 8.16.

Table 8.15: Simulated mean annual energy generated

Dam Name	Average Annual Power (GWh)	Scenarios
Xiaowan	22,050	2,3,4,5
Manwan	8,070	2,3,4,5
Dachaoshan	7,200	2,3,4,5
Nuozhadu	26,320	2,5
Nam Ngum 3	2,816	3,4,5
Nam Ngum 2	377	3,4,5
Nam Ngum	1,116	1,2
	1,171	3,4,5
Nam Lik	242	1,2,3,4,5
Nam Theun 2	5,540	3,4,5

Dam Name	Average Annual Power (GWh)	Scenarios
Nam Theun 3	2,138	5
Nam Theun-Hinboun	1,946	1,2
	1,410	3,4
	2,444	5
Houay Ho	638	1,2,3,4,5
Se Kong 5	2,564	5
Xe Kaman 1	2,572	5
Xe Kaman 3	3,385	5
Plei Krong	661	3,4,5
Upper Kontum	1,169	3,4,5
Ya Li	3,003	1,2
	3,067	3,4,5
Se San 4	1,077	3,4,5
Lower Se San 2	1,236	5
Lower Sre Pok 2		5

1 = Baseline

2 = Chinese Dams

3 = Low Development

4 = Irrigation

5 = High Development

Table 8.16: Mean annual simulated energy generated by country and scenario

COUNTRY	Mean annual energy (GWh)			
	Baseline	Chinese Dams	Low Development & Irrigation	High Development
China	-	63,640	37,320	63,640
Laos	3,942	3,942	12,194	23,887
Thailand	-	-	-	-
Cambodia	-	-	-	1,236
Viet Nam	3,003	3,003	5,974	5,974
Total:	6,945	70,585	55,488	94,737
Total LMB:	6,945	6,945	18,168	31,097

For individual dams, slight improvements in mean annual energy generated are caused by upstream regulation, such as Nam Ngum 1 Dam and Ya Li Dam. The impacts of Nam Theun 2 and Nam Theun 3 are evident in the energy generated by Nam Theun Hin Boun. Nam Theun 2 diverts water out of the basin upstream of Nam Theun Hin-Boun, reducing the water available to generate power. Whereas, Nam Theun 3 regulates inflows to Nam Theun Hin Boun, making it possible for it to generate energy during the dry season.

The net effect is a two-fold and five-fold increase in energy generated by Laos for the Low Development and High Development scenarios respectively, and a doubling of energy generated by Viet Nam. Significant energy is also generated by Cambodia in the High

Development scenario. Combined, the total energy generated by the LMB countries is approximately half of that generated by China in the High Development scenario.

8.3 Net diversions

The impacts of water utilisation by the irrigation, domestic and industrial water supply, and hydropower on the sectors themselves was discussed in the previous sections. In all cases there were increases in production in these sectors. The next stage is to assess how this water utilisation has changed flow. It is important to consider how these have changed in absolute and relative terms during all months.

This has been done by calculating the changes in flow by sector for the Mekong Basin above and below Kratie for each scenario, and showing them graphically in Figures 8.1 to 8.18. Where a sector has reduced the flow by either diversion or storage of water, the change is negative and plots below the zero line on the vertical axis. This is the case for all irrigation, domestic and industrial, and inter-basin diversions. Where the hydropower increases flow, as happens in the dry season months, the change is positive, and plots above the zero line. To assist comparison these have all been plotted to the same scale. These change plots can also be compared against the simulated inflow plot to understand the significance of these changes compared to the underlying hydrology.

Key features of these plots are:

1 The changes under current conditions are a low proportion of flow upstream of Kratie. There is currently little net impact in the dry season, and the relative impact during the wet season is low compared to the inflows of 30-35,000 m^3/s.

2 Dry season and total diversions under current conditions downstream of Kratie far exceed those upstream

3 Wet season diversions under current conditions upstream of Kratie exceed those downstream .

4 Domestic and industrial diversions are barely noticeable at the current level of consumption (

5 The impact of dam regulation of dam regulation increases by a factor of 4-5 for the Chinese Dam scenario, and a factor of 6-7 for the Hugh Development scenario.

6 The combined diversions upstream of Kratie increase significantly, especially in relative terms. These changes are balanced by dam regulation in the Baseline, Low Development, and High Development scenarios.

7 The degree of regulation for the Irrigation scenario only offsets half the diversions during the dry season.

Figure 8.1: Baseline scenario mean monthly modelled changes by sector to flow in Mekong River upstream of Kratie (1985-2000)

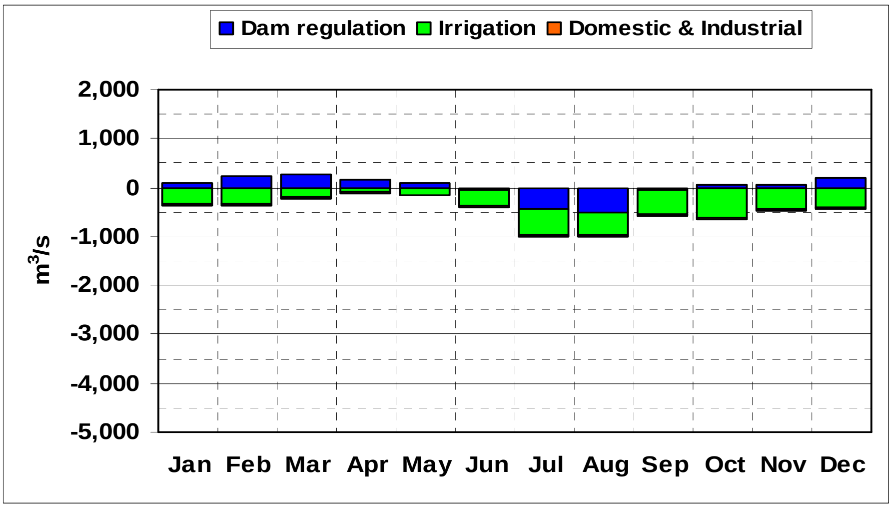


Figure 8.2: Baseline scenario mean monthly modelled changes by sector to flow in Mekong River downstream of Kratie (1985-2000)

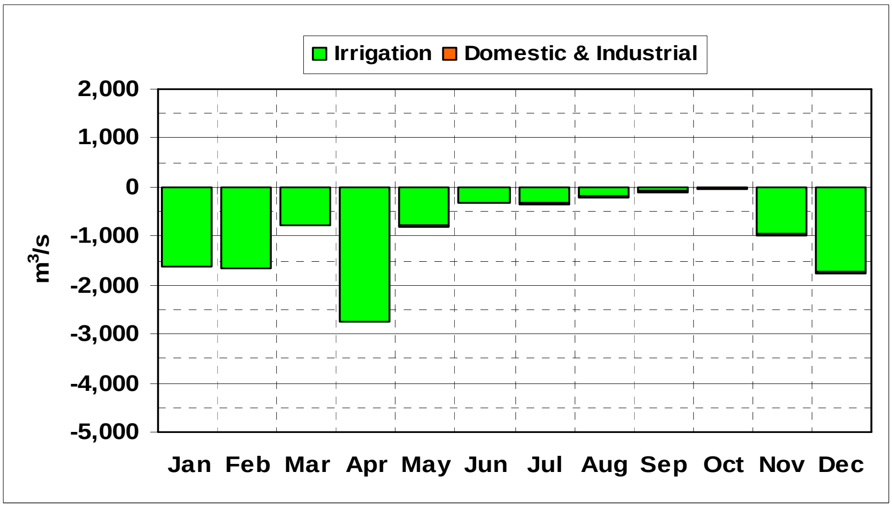


Figure 8.3: Chinese Dams scenario mean monthly modelled changes by sector to flow in Mekong River upstream of Kratie (1985-2000)

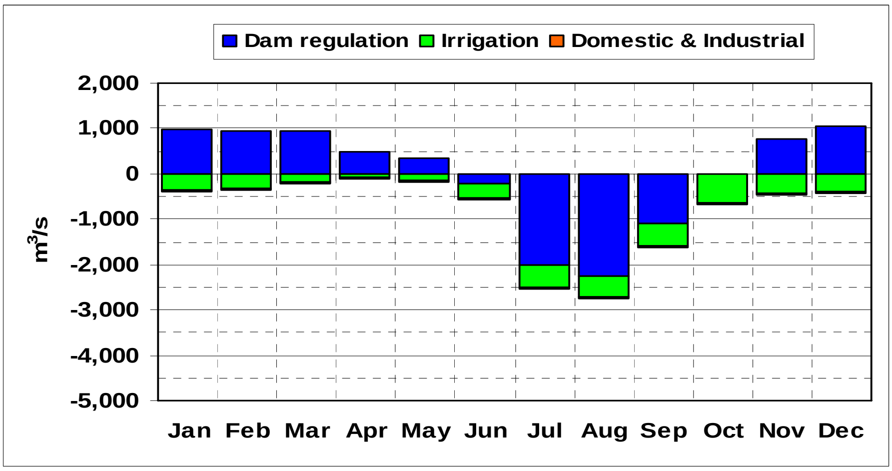


Figure 8.4: Low Development scenario mean monthly modelled changes by sector to flow in Mekong River upstream of Kratie (1985-2000)

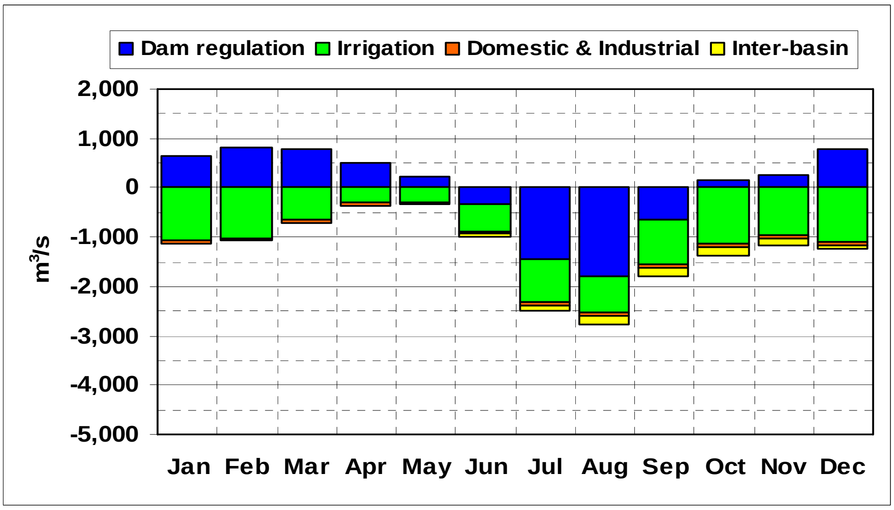


Figure 8.5: Low Development scenario mean monthly modelled changes by sector to flow in Mekong River downstream of Kratie (1985-2000)

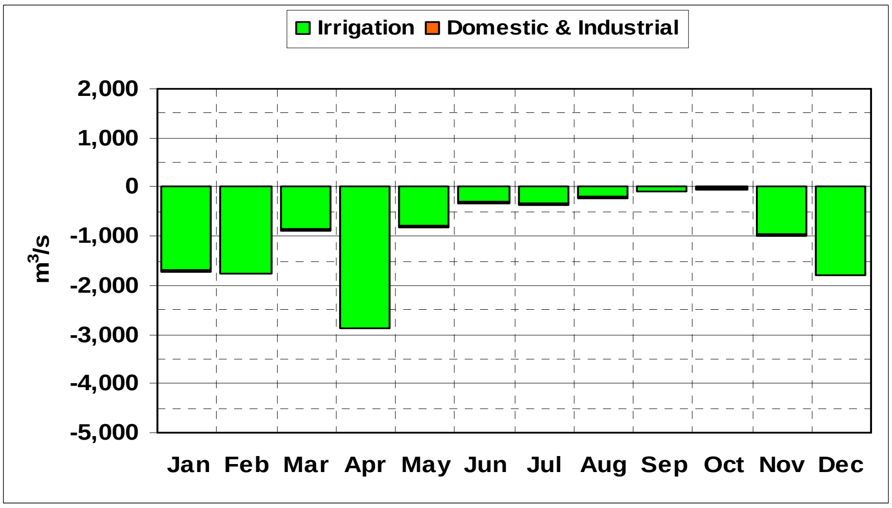


Figure 8.6: Irrigation scenario mean monthly modelled changes by sector to flow in Mekong River upstream of Kratie (1985-2000)

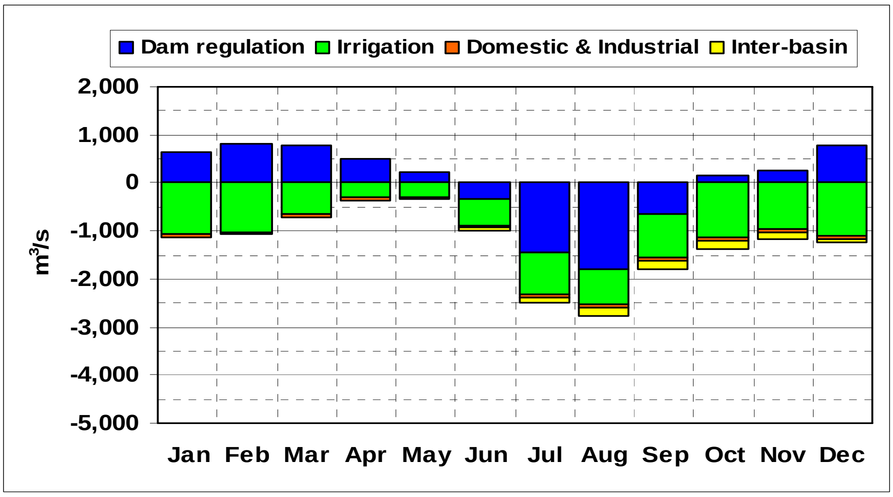


Figure 8.7: Irrigation scenario mean monthly modelled changes by sector to flow in Mekong River downstream of Kratie (1985-2000)

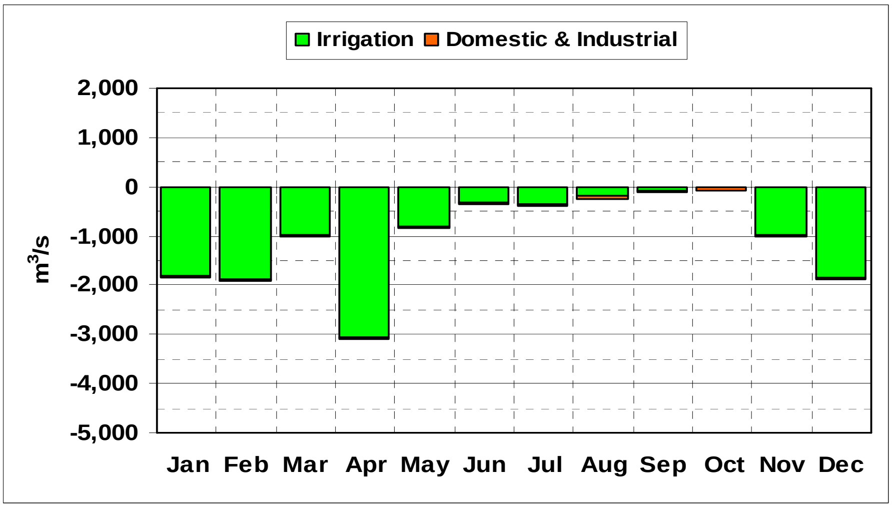
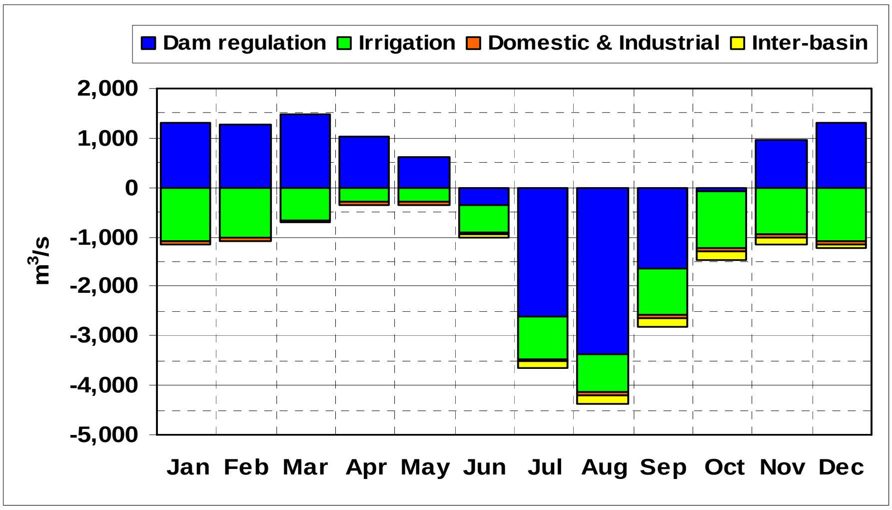


Figure 8.8: High Development scenario mean monthly modelled changes by sector to flow in Mekong River downstream of Kratie (1985-2000)



8.4 Changes to flow

Mainstream flows - annual changes

Assessing changes to mainstream flows are an essential part of the 1995 Mekong Agreement. Article 6 of the Agreement sets out three requirements that need to be considered in the formulation of flow rules under Article 5:

6A. Maintenance of minimum mean monthly flows in each month of the dry season that would occur naturally.

6B Ensure acceptable natural reverse flows in the Tonle Sap that provides an optimum level in Tonle Sap lake

6C. Peak flood flows that are not higher than those which occur naturally during the wet season

The flow changes are caused by the water resource developments described in Sections 0 to 0, and the contributions of each of these sectors is summarised in Section 0. The changes to simulated flows along the Mekong is a direct result reportable from the simulation models at a daily time step for the simulation period of 1985-2000.

Examples of a three year sub-period of these are shown at the following five stations Luang Prabang, Nakhon Phanom, Pakse, Kratie, and across the Vietnamese border in the figures below. Most of the analysis in following sections are done at these stations for the sixteen year simulation period. Analysis for the region downstream of Kratie is done for a five year simulation period 1996-2000.

Key characteristics of these hydrographs are that their fundamental shape has been maintained, however, the wet season flow has been noticeably reduced, and the dry season flows noticeably increased. These changes are quite dramatic in the upstream stations, and the relative size of these changes relative to the Baseline scenario hydrograph decreases for stations downstream. Reductions in the dry season flow can be detected in some cases for the Irrigation scenario.

The first part of the quantitative analysis of flow changes is within the context of Article 6 requirements. A number of indicators have been selected to address these.

Figure 8.9: Simulated flow (1998-2000) for five scenarios at Luang Prabang

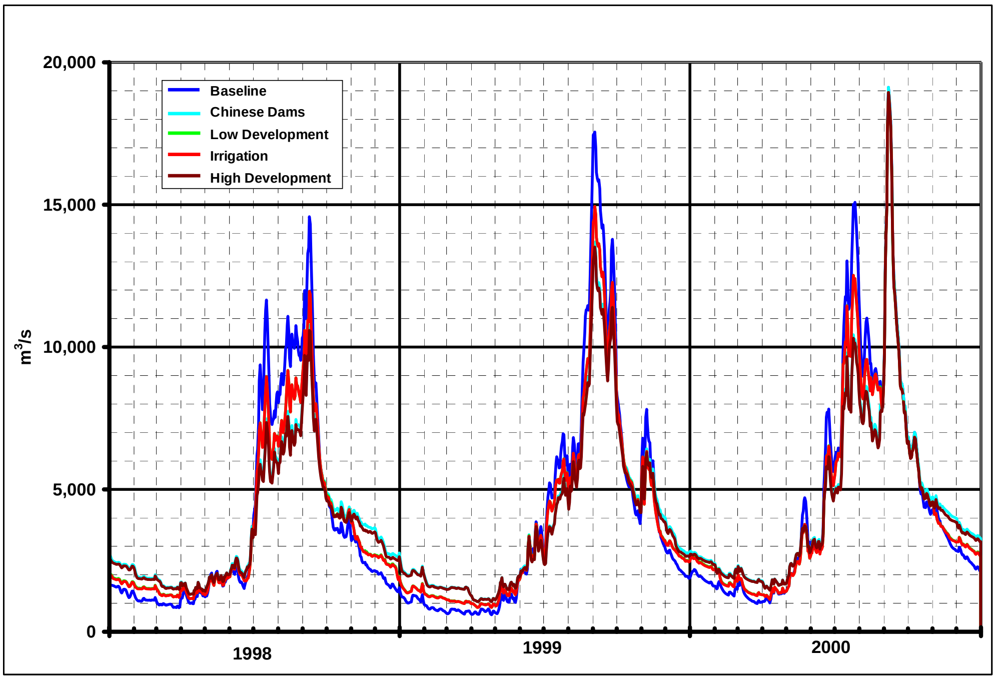


Figure 8.10: Simulated flow (1998-2000) for five scenarios at Nakhon Phanom.

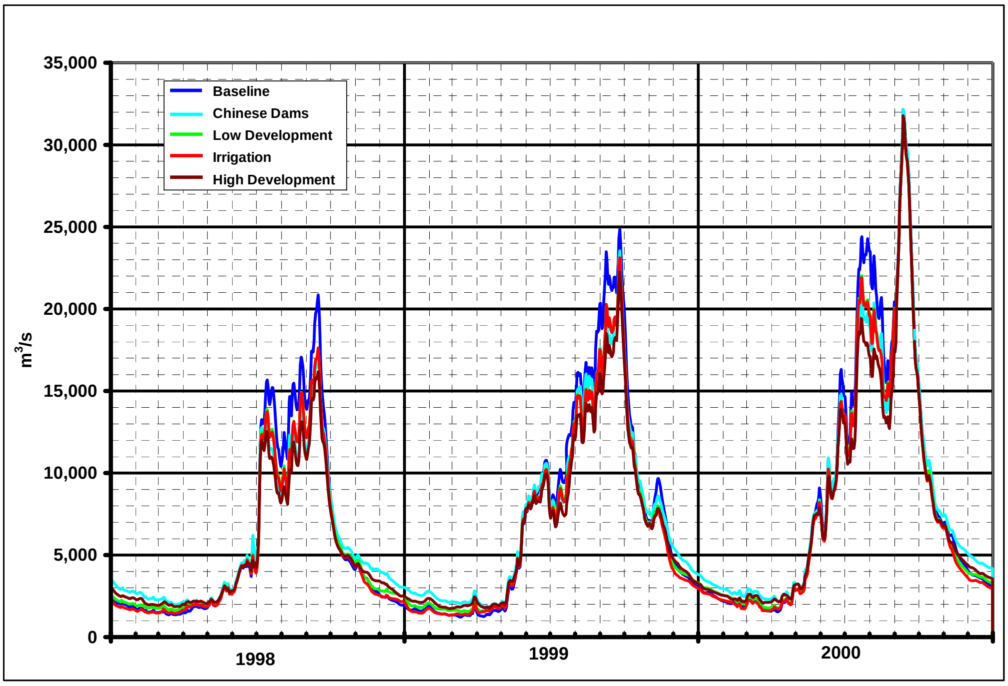


Figure 8.11: Simulated flow (1998-2000) for five scenarios at Pakse.

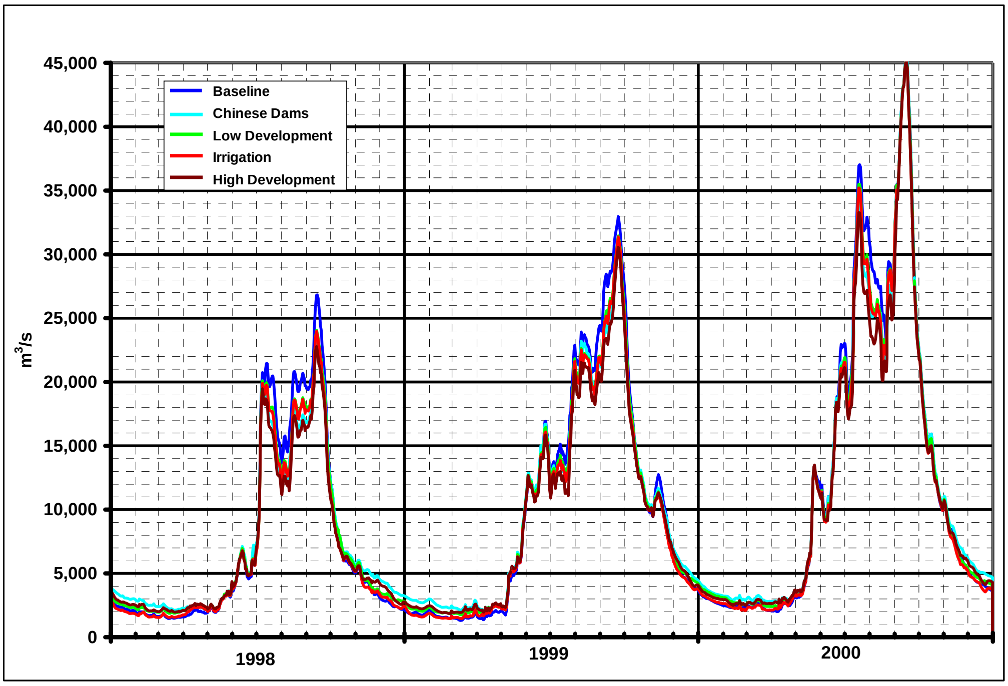


Figure 8.12: Simulated flow (1998-2000) for five scenarios at Kratie.

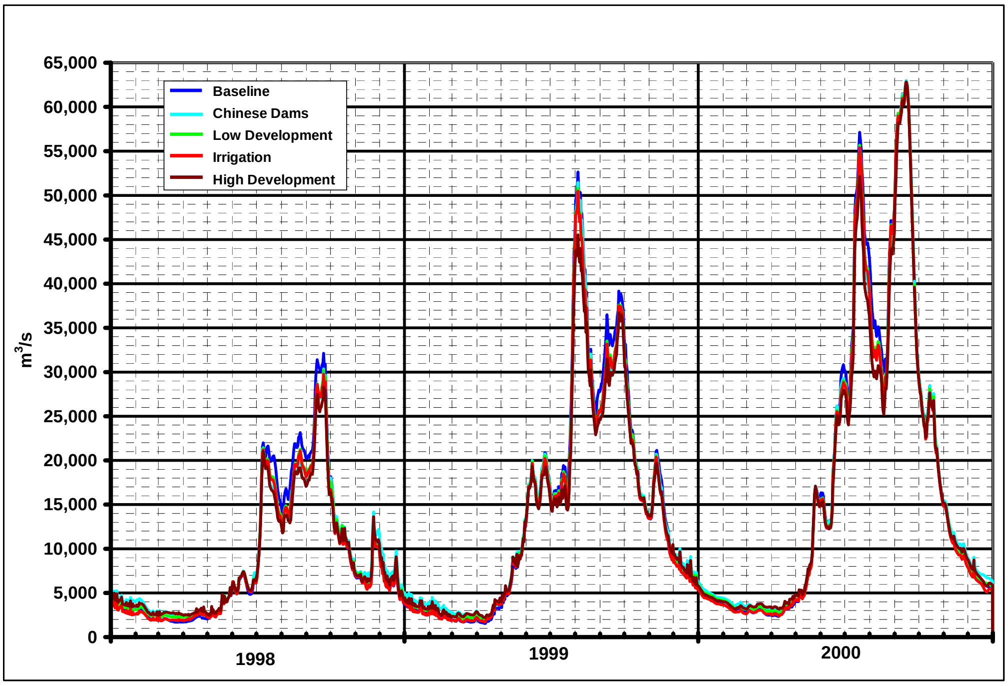
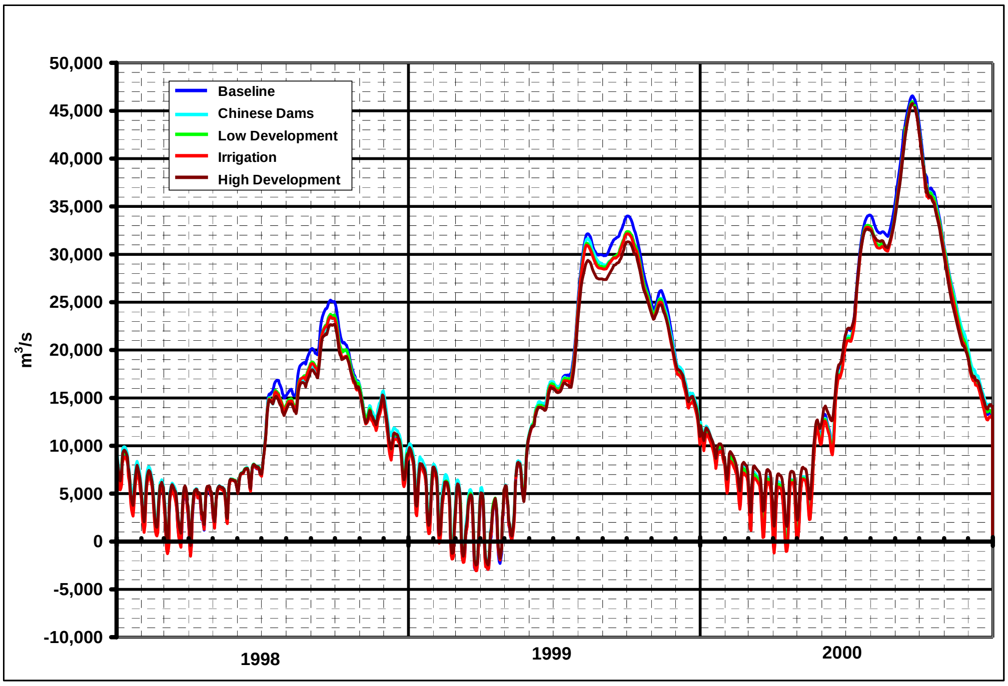


Figure 8.13: Simulated flow (1998-2000) for five scenarios across Vietnamese border.



The following table summarises the changes in flow between scenarios.

Table 8.17: Changes in mean annual minimum and maximum annual water levels

Station	Parameter	Baseline mean gauge height	Changes in gauge height (m)			
			Chinese Dams	Low Development	Irrigation	High Development
Luang Prabang	*min*	3.06	1.00	0.50	0.50	0.99
	max	15.59	-1.81	-1.16	-1.16	-1.93
Nakhon Phanom	*min*	-0.33	0.29	0.11	0.04	0.26
	max	4.48	-0.24	-0.23	-0.23	-0.41
Pakse	*min*	0.48	0.37	0.24	0.05	0.33
	max	11.01	-0.34	-0.32	-0.36	-0.56
Kratie	*min*	6.39	0.60	0.41	0.09	0.66
	max	22.37	-0.14	-0.18	-0.24	-0.60
Tan Chau	*min*	0.09	0.08	0.03	-0.02	0.09
	max	4.65	-0.11	-0.10	-0.12	-0.17

Mean Monthly Dry Season Flow

Article 6a requires that mean monthly dry season flows not be reduced below that which occurs naturally. A working definition of this was proposed by the MRC[i] and is currently under consideration by the Joint Committee (JC) (March 2005) (Table 8.18). For planning purposes, the 1:5 year monthly mean flow is proposed to form the lower bound of "acceptable".

Table 8.18: Illustrative Draft Technical Guidelines for planning and monitoring/management of mainstream flows

Purpose	Zone Colour Code	Average monthly flow / water level		Data Source	Actions / Responses
		Upper criterion	Lower criterion		
Planning	1	2000 Baseline Scenario estimates of average monthly flow	Above 1:5 year flow / water level	DSF Simulations	Evaluate impact of development scenario

For each scenario the mean monthly flow are determined from DSF simulations for the dry season months of December through May.

The illustrative draft *Technical Guidelines* propose that the above analysis be performed for each of the mainstream hydrological stations listed below:

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[i] MRC (December, 2004). DRAFT for illustrative purposes only: "Technical Guidelines for the implementation of Procedures for the Maintenance of Flows on the Mainstream".

- Chiang Saen
- Luang Prabang
- Chiang Khan
- Vientiane
- Nong Khai
- Nakhon Phanom
- Mukdahan
- Kong Chiam
- Pakse
- Stung Treng
- Kratie
- Phnom Penh
- Tan Chau
- Chau Doc

Results at many of these stations are likely to be very similar, therefore as the purpose of this report is to demonstrate the major differences between the scoping scenarios, the results are restricted to five locations, Luang Prabang, Nakhon Phanom, Pakse, Kratie and Tan Chau/Chau Doc (+floodplain). These are shown graphically in Figures 8.14 to 8.18.

The most upstream station at Luang Prabang shows two basic sets of impacts, either an increase of 600-800 m^3/s or an increase of 250-400 m^3/s, above a mean flow during dry season months of 1100-2200 m^3/s. This effect can be almost totally attributed to releases from the large Chinese dams. The impacts of irrigation are very small in this region, however, the impact of the inter-basin diversion can be detected in December as the difference between the Chinese Dams scenario and the High Development scenario.

The picture at Nakhon Phanom is more diverse as the impacts of other dams, as well as irrigation and intra-basin diversions come into play. In most cases the flows are higher for the development scenarios compared with the Baseline. Significant is that large off-takes for diversions as well as the diversion of releases of Nam Theun 2 to a tributary downstream of Nakhon Phanom station cause flow for the Irrigation scenario to be lower than the Baseline scenario. Nam Theun 2 also moderates the increases in dry season flows for all scenarios.

A similar pattern of impacts is seen at Pakse station, except that the relative size of these is lower. The flows in the later part of the dry season appear to have increased, and maybe because the intra-basin diversion coming through Mun-Chi was not fully used by irrigation. Releases from additional dams in the High Development scenario has also caused a relative increase in flows months compared with the Irrigation scenario.

This pattern is reinforced at Kratie. The impacts of the Irrigation scenario still cause the flows to be lower for months in the early part of the dry season, and a large part of this could be attributed to the large increases in dry season irrigation along the Mekong between Stung Treng and Kratie.

The Baseline hydrograph for the Vietnamese border has a different shape to the upstream stations because of the impacts of flow returning from the Great Lake to the Mekong River. For example the flow in December is almost three times that at Kratie, although by April this difference is greatly diminished. A full interpretation of the impacts of the Great Lake is complex, because the amount of flow leaving the Great Lake is also dependent on how much flow entered the previous wet season.

Nevertheless, similar conclusions can be reached, that most of the scenarios have higher dry season flows in the range 100-400 m^3/s for the Low Development scenario, and

300-800 m³/s for the Chinese Dams and the High Development scenario. The impact of the Irrigation scenario is more significant from increased irrigation included from Cambodia. The net decrease in flows crossing the border for the Irrigation scenario is in the range 100-300m³/s.

Most of the impacts from the scenarios do not cause concern within the context of reducing dry season flow relative to the Baseline, as in most cases there are increases. However, the Irrigation scenario starts to have a significant impact from Nakhon Phanom downstream, and a scenario with these characteristics would warrant closer attention in the context of any guidelines developed under Article 6A.

Figure 8.14: Mean monthly dry season flows at Luang Prabang

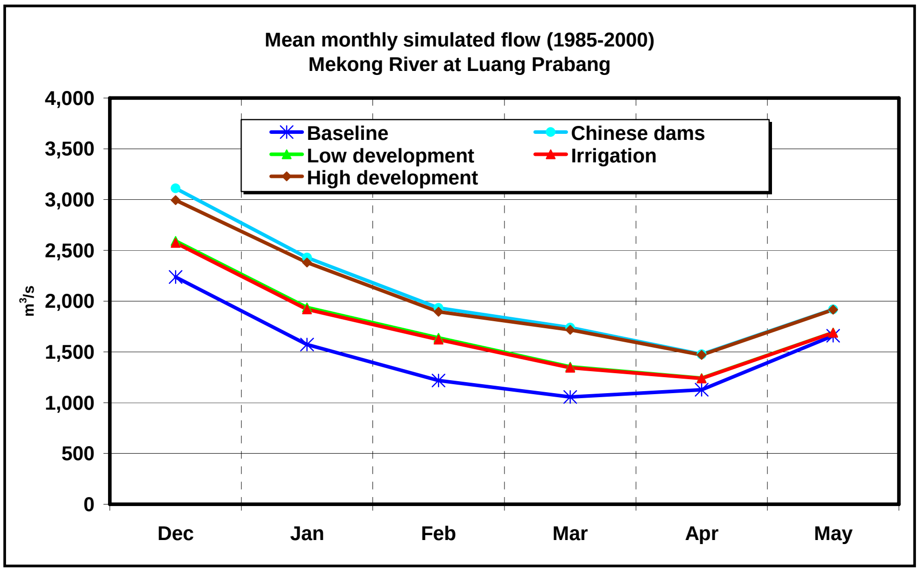


Figure 8.15: Mean monthly dry season flows at Nakhon Phanom

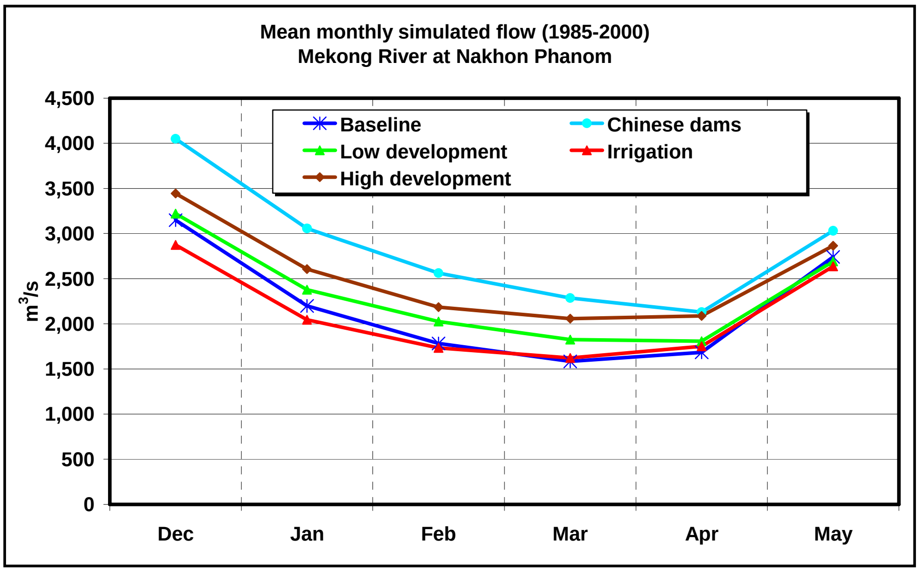


Figure 8.16: Mean monthly dry season flows at Pakse

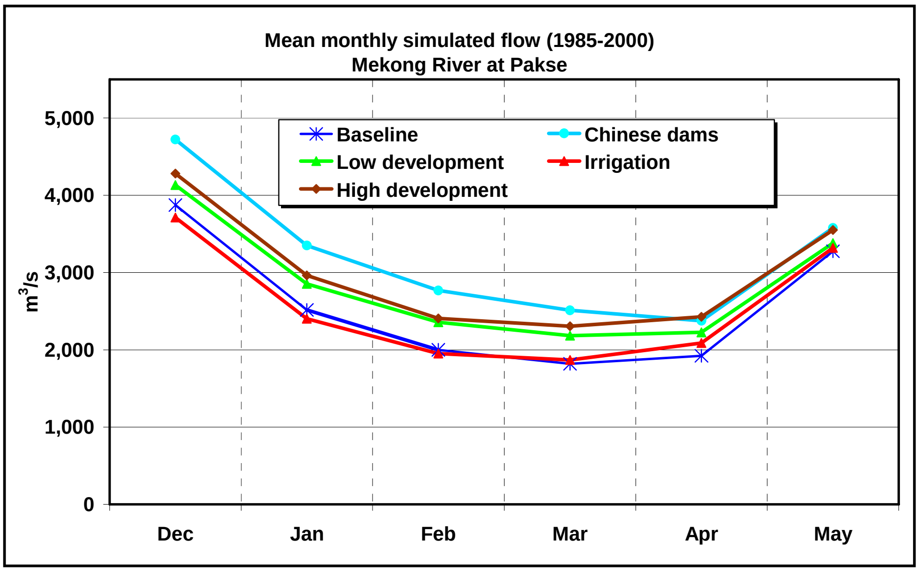


Figure 8.17: Mean monthly dry season flows at Kratie

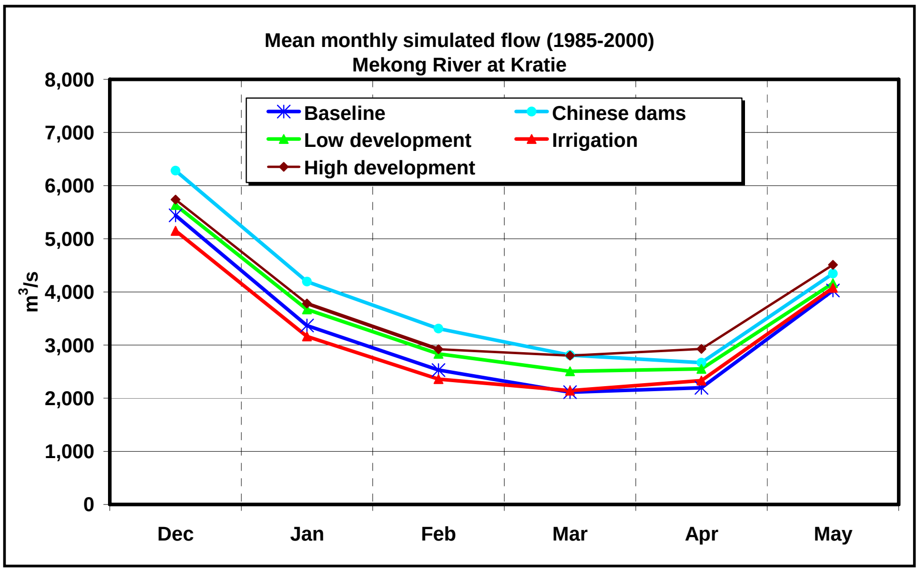
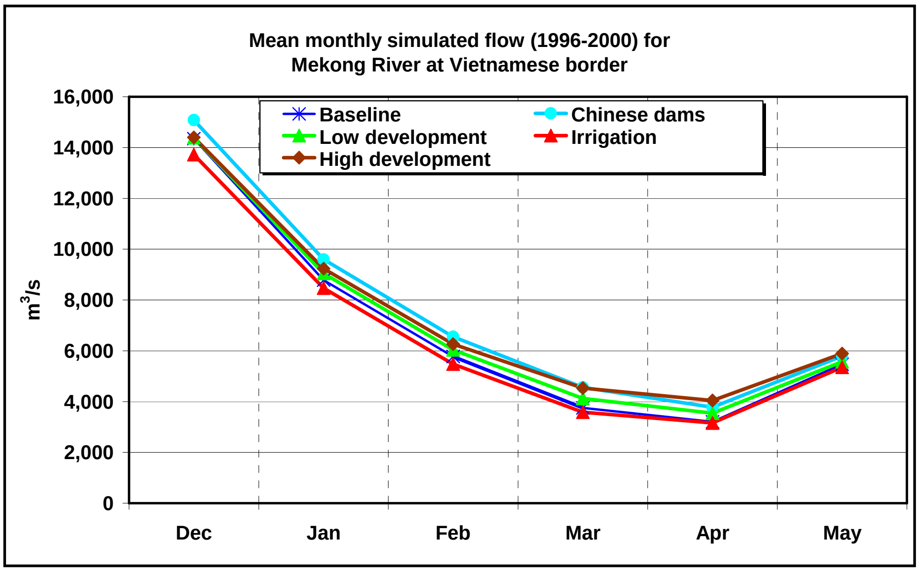


Figure 8.18: Mean monthly dry season flows at Vietnamese border.



Ton le Sap flow reversal

Article 6b requires that acceptable natural reverse flows of Ton le Sap be maintained during the wet season. 'Acceptable' is defined as the wet season flow level in the Mekong River at Kratie that allows the reverse flow of the Ton le Sap River to an agreed optimum level of the Great Lake. Thus at least the wet season flow at Kratie and the Great Lake water level have to be reported.

The most obvious indicator of "the wet season flow level in the Mekong River at Kratie", is the mean wet season water level. However, a report by the WUP-IBFM Report No.2 (MRC, 2004[i]) indicates that the monthly September volumes and wet season volumes at Kratie, both provide similar superior relationships with peak lake levels, than does the relationship with Kratie peak daily wet season flows. The report also recommends the use of the Ton le Sap total annual flow reversal volume at Prek Kdam.

These can all be reported directly from simulation results from the DSF. The DSF provides two simulated flow figures for Prek Kdam; Tonle Sap River only and Tonle Sap plus the floodplain. These floodplain flows are the sum of four floodplain nodes, in each case representing flow from one floodplain cell to another, as shown in the ISIS schematisation (Figure 8.19).

In view of the above, the following indicators have been selected:

- Mean total wet season flow volume at Kratie (1 June – 30 November);

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[i] MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figures 9.20, 9.21 & 9.22

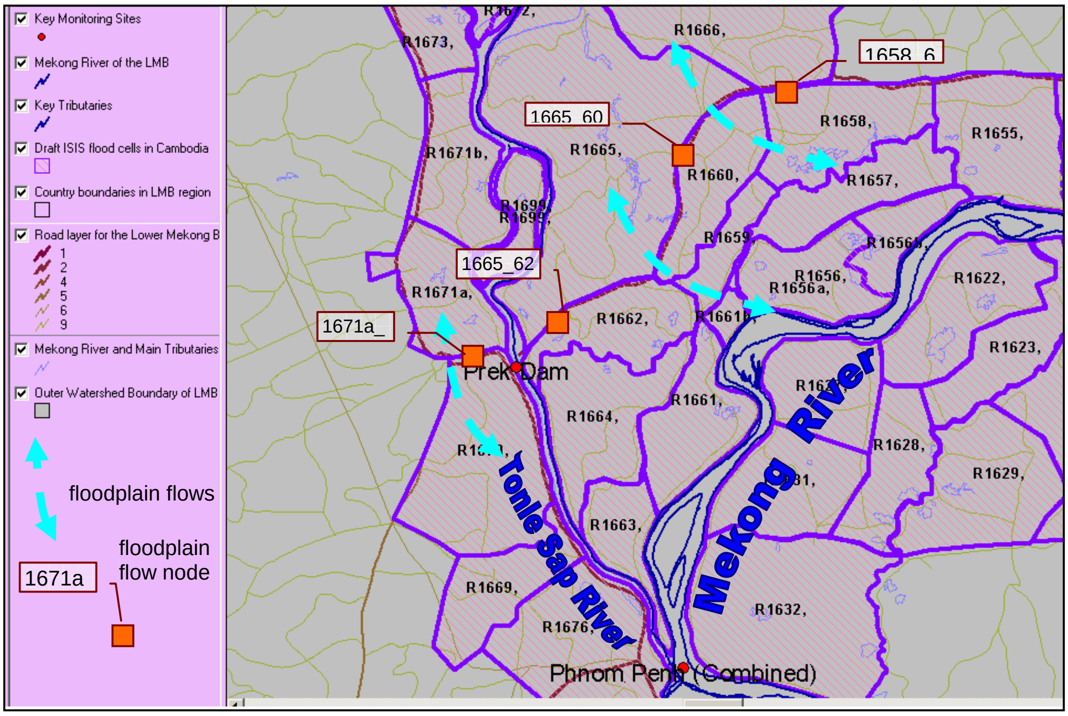
- Tonle Sap River and floodplain flow at Prek Kdam reported as the mean annual wet season reverse flow volume, i.e. the total negative (upstream) flow in the wet season;

- The mean annual peak water level in the Great Lake at Kampong Luong; and

- The mean annual flood area in the Great Lake and surrounds (i.e. to the west of Prek Kdam and National Road No.5).

These indicators are reported in Table 8.19. All these factors show consistent patterns as you would expect. Less flow at Kratie would logically result in less reverse flow in Ton le Sap and less volume in the Great Lake. The volume in the Great Lake is functionally related to both water levels and flooded areas.

Figure 8.19: ISIS floodplain schematisation in the vicinity of Prek Kdam on the Tonle Sap River showing the Prek Kdam River node & adjacent floodplain nodes



The mean annual wet season volumes at Kratie were reduced by 3% for the Chinese Dams and Low Development scenario, up to 7% for the High Development scenario. This resulted in between 2,500 mcm and 4,300 mcm entering the lake on average. Water levels in the Great Lake dropped by between 0.2-0.37 m, and peak flooded areas decreased by 260-430 km^2.

Table 8.19: Changes in flow reversal indicators

Scenario	Mean annual simulated values (1996-2000)			
	Wet season volume at Kratie	Reverse flow volume at Prek Kdam	Peak water level at Kampong Luong	Maximum flooded area for Great Lake
	mcm * 1,000	mcm * 1,000	m	km²
Baseline	380	39.4	9.31	12,492
Chinese Dams	369	36.9	9.08	12,230
Low Development	368	37.4	9.11	12,265
Irrigation	363	37.3	9.07	12,216
High Development	355	35.1	8.95	12,067

Looking at a higher level of detail to see the year to year variability between scenarios, reported in Table 8.20. The general pattern is that the Chinese Dams, Low Development and Irrigation scenario have similar impacts for average and higher than average wet season flows. The High Development scenario has almost double the impact, and all scenarios have a greater impact for the below average flow years (1998-1999).

One anomaly in these results is the result for 2000 for High Development. The 2000 event was interesting as it had two major peaks during the wet season (See Figure 8.12), and the second event had the greater volume. The large reduction for this reverse flow occurred during the early part of the wet season.

Table 8.20: Changes in flow reversal volumes at Prek Kdam

Year	1996	1997	1998	1999	2000	Average
*Baseline reverse flow volume (mcm * 1000)*	44.6	41.7	19.7	31.8	59.1	
Scenario	% change compared to baseline					
Chinese Dams	-4.5	-5.1	-19.6	-7.6	-3.4	-8.0
Low Development	-4.5	-3.7	-13.8	-7.6	-2.1	-6.3
Irrigation	-4.8	-4.0	-13.7	-8.0	-2.1	-6.5
High Development	7.0	-8.8	-21.9	-14.9	-19.8	-11.6

8.5 Flood levels

Wet season water levels indicate both the socio-economic benefits of reduced extreme flood levels, as well as environmental impacts that can arise if the extent and depth of flooding is reduced, thereby reducing the lateral connectivity of rivers and wetlands with their floodplains. In particular, Article 6C of the Mekong Agreement requires that "peak flood flows that are not higher than those which occur naturally during the wet season".

Changes in simulated mean water levels are reported at the same locations as those for dry season mean monthly flows, with the addition of Kampong Luong to represent conditions in the Great Lake. Water levels downstream of Kratie are simulated by the ISIS model in the DSF. Due to time restrictions (the ISIS model requires 4 hours to simulate one year), only 5 years were simulated. Consequently:

- Water levels at Luang Prabang, Nakhon Phanom and Pakse were calculated from IQQM simulated flows, using the appropriate rating curves for the period 1/1/1986 – 31/12/2000.
- Water levels at Kratie, Kampong Luong and Tan Chau were simulated directly by the ISIS model for the period 1/1/1996 – 31/12/2000.

Mean monthly wet season levels

The differences in mean monthly water levels for each scenario are compared with the Baseline Scenario for each wet season month, June to November, for Luang Prabang, Nakhon Phanom, Pakse, Kratie and Tan Chau, and are shown graphically in Figure 8.20, 8.21, 8.22, 8.23 and 8.24 respectively. All have been plotted at the same scale for comparison.

Figure 8.20: Mean monthly water level differences during the wet season at Luang Prabang (1985-2000)

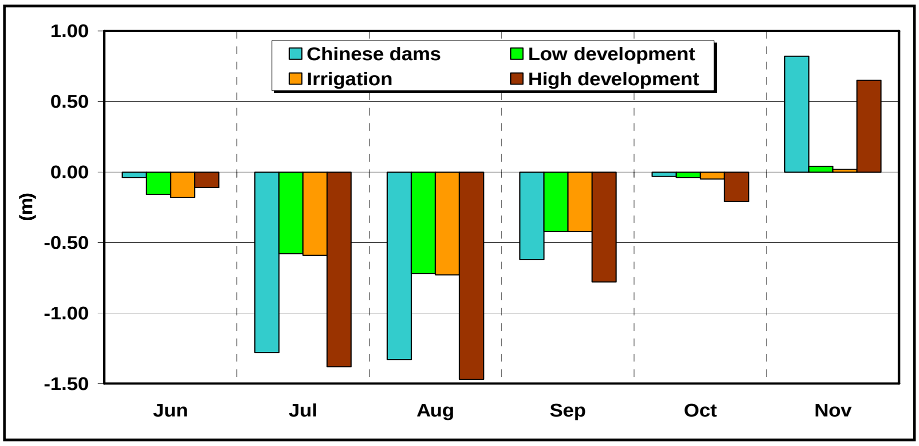


Figure 8.21: Mean monthly water level differences during the wet season at Nakhon Phanom (1985-2000)

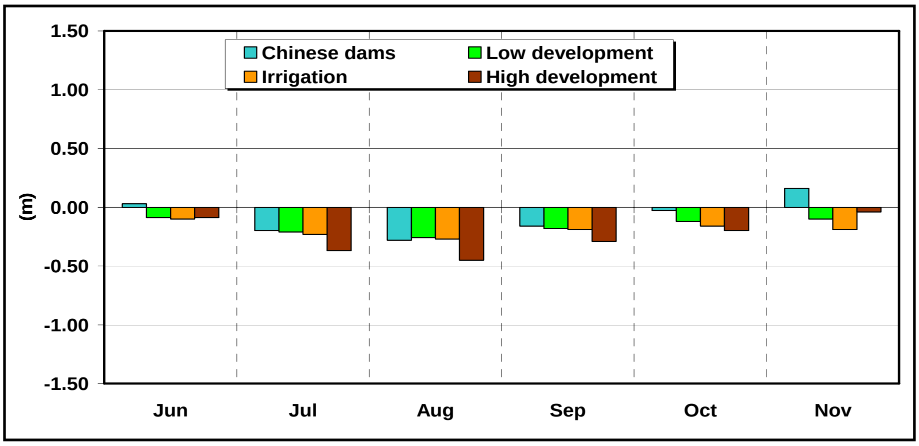


Figure 8.22: Mean monthly water level differences during the wet season at Pakse

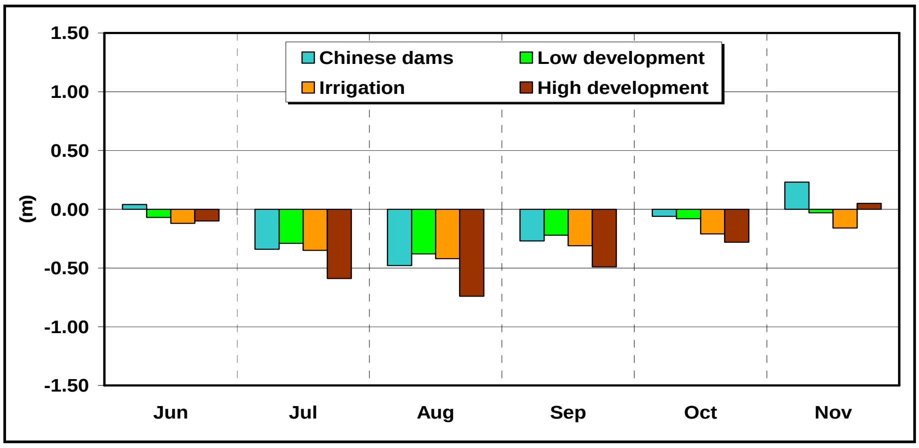


Figure 8.23: Mean monthly water level differences during the wet season at Kratie

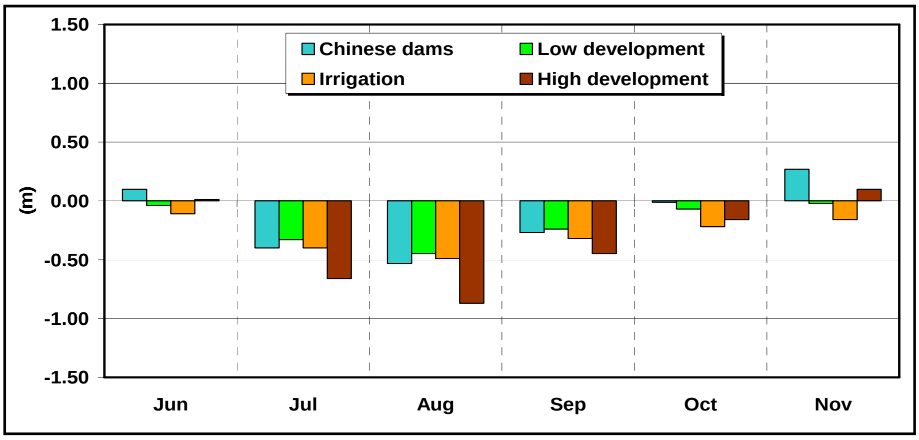
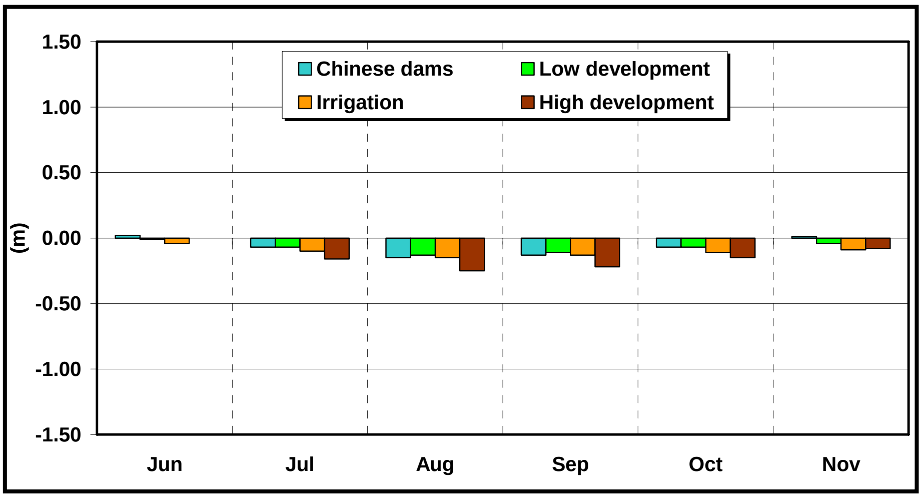


Figure 8.24: Mean monthly water level differences during the wet season at Tan Chau



The largest changes in water levels occur at Luang Prabang, with reductions in mean water levels in the range between 1.3-1.5 metres for the early wet season months, when the large Chinese Dams are filling. This size reduction reduces by September to 0.6-0.8 m. The slightly higher value for the High Development scenario compared with the Chinese Dams scenario is caused by the Kok-Ing-Nam inter-basin diversions. The lower development and irrigation scenarios have a smaller effect, in the range of 0.4-0.6 m for the main wet season months. Increases in mean water level during November can be attributed to the large Chinese Dams, moderated by the inter-basin diversions for the High Development scenario.

The mean water level differences are less dramatic at Nakhon Phanom, presumably because of channel flood plain geometry, and are in the range of 0.2-0.3 m. The Nam Theun 2 diverting water downstream appears to have a similar impact to the second large Chinese Dam, as the water level differences for the Low Development scenario are similar to the Chinese Dams scenario. The High Development scenario has both these dams as well as Nam Theun 2, and has a significantly greater impact, with mean water levels in the range 0.3-0.5 m lower.

A similar pattern with slightly higher differences are apparent at Pakse, with water level changes in the range 0.3-0.5 m lower for the Chinese Dams, Low Development and Irrigation scenarios, and 0.5-0.8 m for the High Development Scenario. Again as similar pattern is apparent at Kratie (Figure 8.23), which is impacted by all the dams, with water levels in the range 0.3-0.5 m lower for all scenarios, except for the High Development which is between 0.5 to 0.9 m lower

As the water spreads over a large area in the floodplain around the Great Lake and Mekong Delta, the absolute reduction in water level is decreased compared with the more channelised flow upstream. The changes at Tan Chau are in the range 0.1-0.15 m for the Chinese Dams, Low Development and Irrigation scenario, and in the range 0.15-0.25 m for the High Development scenario.

Peak annual water levels

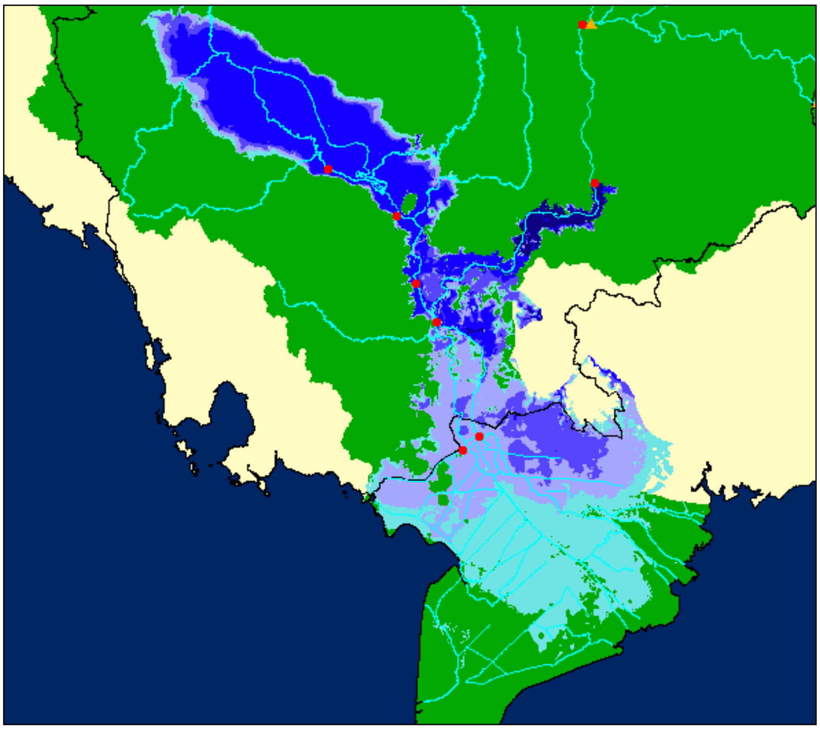
These are reported in Table 8.21, along with the highest and lowest annual peak differences from the Baseline scenario.

The differences in mean peak water levels for Luang Prabang are impacted mostly by the dams in China. Where there is one dam only (Xiaowan), the changes in mean peak flood levels are above 1 metre, whereas when Nuoazhadu is also in place, the comparable changes would be closer to 2 metres. The differences in mean peak water levels decrease for stations further downstream as other unregulated tributaries join, and are in the range 0.2-0.6 m for Kratie upstream, and 0.1-0.2 m at Tan Chau. The relativities between scenarios are maintained for all the stations above Kratie. The higher value for Kratie for the High Development scenario maybe because of the inclusion of large dams on the Se Kong, but is also calculated for a shorter period. The differences in mean peak water levels decrease

The changes in for the highest peak water level are greater than the mean for Luang Prabang, and the lowest peak water level is less than the mean. These results are similarly dominated by the large dams upstream at China. This pattern is not maintained at downstream stations, and the year of occurrence of the highest varies, although the lowest is consistent for the consistent evaluation periods. The differences in highest peak annual levels are consistently less than the mean for all stations below Luang Prabang, and are much lower, with virtually no effect at Nakhon Phanom, and less than 0.05 m at Tan Chau. The differences in the highest peak water level is also generally less than the differences in the lowest peak annual water level.

Table 8.21: Scenarios changes in peak annual flood levels

Station	Parameter	Baseline		Change in height (m)			
		Gauge height (m)	Year	Chinese Dams	Low Development	Irrigation	High Development
Luang Prabang	Lowest	9.40	*1992*	-0.99	-0.81	-0.81	-1.18
	Mean	15.59	*1985-2000*	-1.81	-1.16	-1.16	-1.93
	Highest	19.06	*1995*	-2.68	-1.70	-1.70	-2.78
Nakhon Phanom	Lowest	2.92	*1992*	-0.08	-0.16	-0.17	-0.27
	Mean	4.48	*1985-2000*	-0.24	-0.23	-0.23	-0.41
	Highest	5.33	*2000*	0.00	-0.04	-0.04	-0.03
Pakse	Lowest	8.86	*1992*	-0.10	-0.15	-0.19	-0.24
	Mean	11.01	*1985-2000*	-0.34	-0.32	-0.36	-0.56
	Highest	13.70	*1991*	-0.22	-0.11	-0.13	-0.40
Kratie	Lowest	18.17	*1998*	-0.35	-0.36	-0.47	-0.79
	Mean	22.37	*1996-2000*	-0.14	-0.18	-0.24	-0.60
	Highest	24.41	*1996*	-0.01	-0.17	-0.26	-0.47
Tan Chau	Lowest	3.59	*1998*	-0.21	-0.18	-0.20	-0.29
	Mean	4.65	*1996-2000*	-0.11	-0.10	-0.12	-0.17
	Highest	5.30	*2000*	-0.05	-0.04	-0.05	-0.05



9 Impacts of flow changes

by Richard Beecham and Hugh Cross,
March 2005

9.1 Navigation potential

Two types of factors affect the volume and efficiency of navigation along the Mekong. First are National and international rules pertaining to customs, immigration and navigation logistics. These are not modelled by the DSF and are not considered here.

Second, is the hydraulics of river flows, i.e. the depths and velocities that result from the interaction of the physical channel form at a particular location and prevailing river flow. Whilst high velocities increase power consumption and hence cost for upstream river transport, most notably during the wet season, it is shallow water depths that physically prevent vessels from transiting a river reach at all.

Lower flow result in lower river depths. In any one reach of the Mekong, the typical dry season flow has lead to the use of vessels that are capable of navigating it most, but not all, of the time. Thus river reaches that have shallow river depths in the dry season are typically used by smaller vessels than in deeper reaches; larger ones being un-economic due to long periods when they can not be used.

In many reaches of the Mekong, navigation of goods and people is subject to restriction in the dry season as the depth of water approaches and becomes less than the safe depth for the size of vessels using that reach. However, only in one area, the Khone Falls, does navigation remain impassable at all flows and at all times of year for any sized vessel. The safe depth is a function of the average vessel's (loaded) tonnage and design, which define its "safe draught", i.e. the depth of the vessel below the water surface, plus a safety allowance. The safety allowance in the Mekong is typically 0.5m.

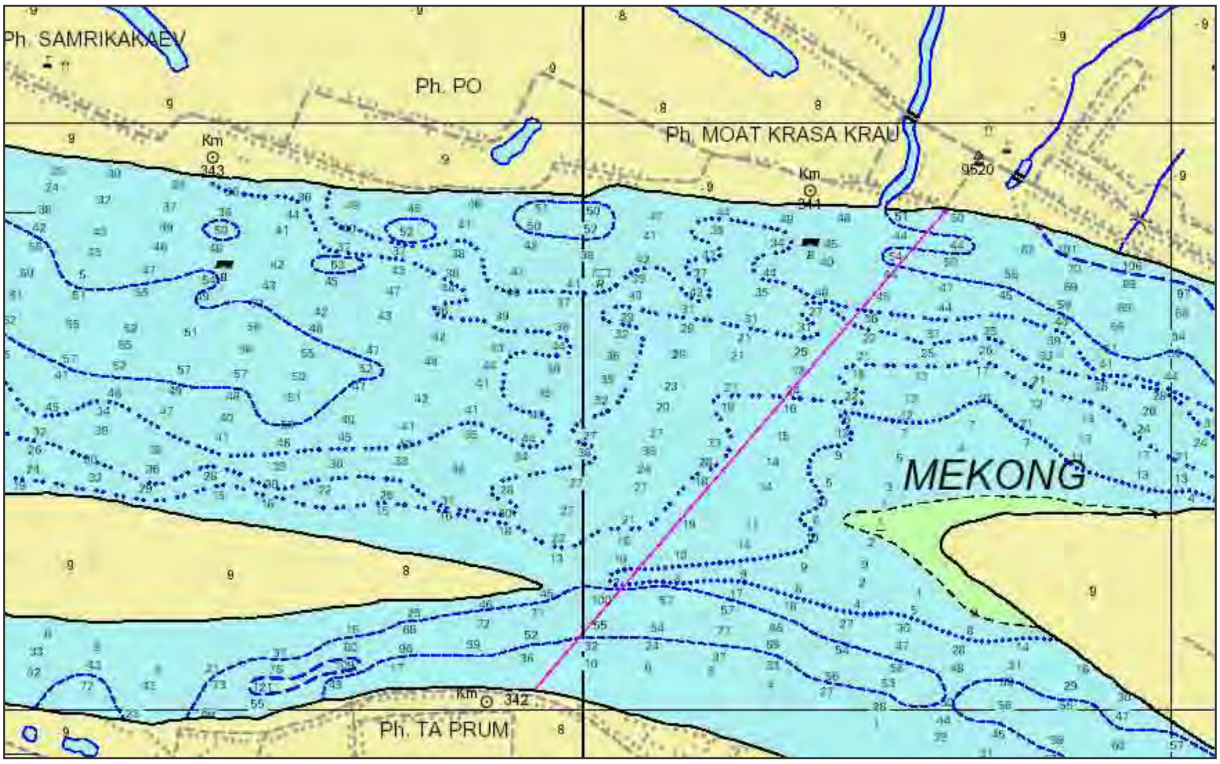
Differences in vessel design, used upstream and downstream of Kampong Cham, results in the different safe draught – tonnage relationships, as shown in Table 9.1 (source: MRC Navigation Programme).

The Navigation Programme has interpreted these safe draft requirements for each major reach of the Mekong. Maps 9.1 and 9.2 show the current limits of navigation in terms of minimum depths and corresponding maximum vessel size. The minimum depths are determined by the lowest low water (LLW) level, as indicated on each of the Mekong Hydrographic Atlas charts (produced by bathometric survey for the MRC Navigation Program), an example of which is presented as Figure 9.1.

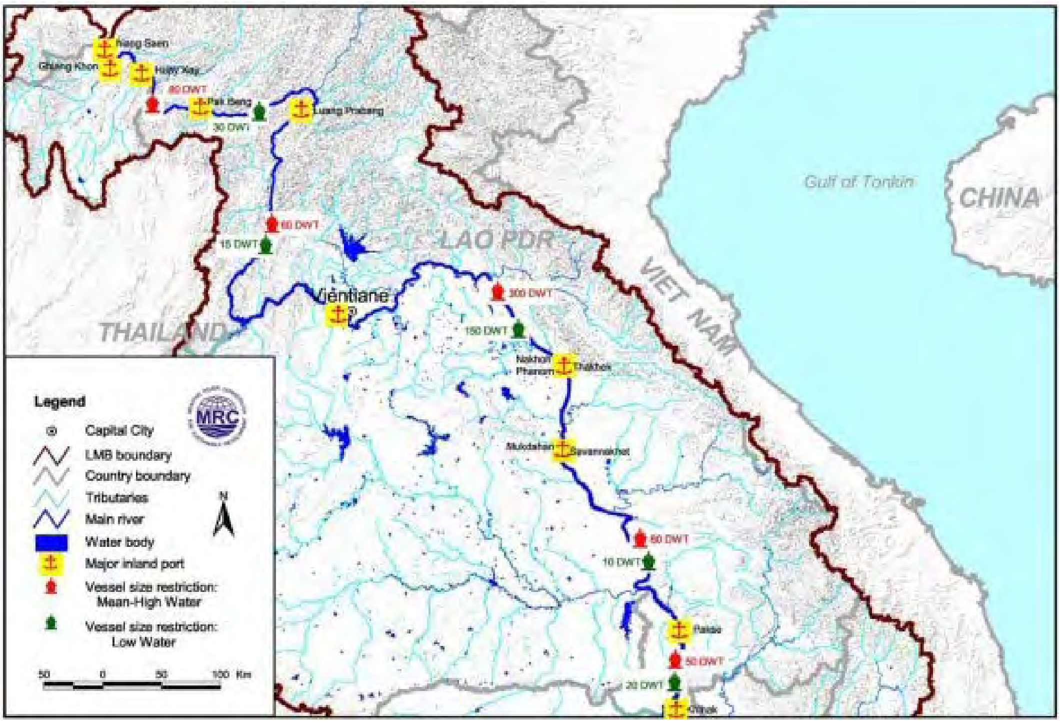
Table 9.1: Safe draught – tonnage relationships in the 'lower' and 'upper' Mekong.

Upper Mekong Navigation			Lower Mekong Navigation					
China, Myanmar, Lao PDR, Thailand, Cambodia upstream of Kampong Cham			Cambodia, downstream of Kampong Cham, including waterway canals in the Mekong Delta			Maritime Accessibility (sea-going vessels)		
No	Type of vessel	Ts (m)	No	River Vessels	Ts (m)	No	Sea-Going Vessels	Ts (m)
			1	Tug boat 135 (hp)	1.5			
2	Tug boat 150 (hp)	1.4	2	Tug boat 150 (hp)	1.4			
3	Tug boat 200 (hp)	1.4	3	Tug boat 200 (hp)	1.4			
4	Boat of 10 DWT	0.6	4	Boat of 10 DWT	0.8			
5	Boat of 30 DWT	0.7	5	Boat of 30 DWT	1			
6	Boat of 50 DWT	0.9	6	Boat of 50 DWT	1.3			
7	Boat of 70 DWT	1.2	7	Boat of 70 DWT	1.3			
8	Boat of 100 DWT	1.2	8	Boat of 100 DWT	1.5			
9	Boat of 150 DWT	1.4	9	Boat of 200 DWT	1.5			
10	Boat of 200 DWT	1.6	10	Boat of 300 DWT				
11	Boat of 300 DWT	2.2	11	Boat of 400 DWT				
12	Boat of 400 DWT	2.5	12	Boat of 500 DWT		1	general cargo vessel of 500 DWT	3.2
13	Boat of 500 DWT	2.8	13	Boat of 1000 DWT		2	general cargo vessel of 1000 DWT	3.6
14	Boat of 1000 DWT	3.2	14	Barge of 100 DWT	1.6	3	general cargo vessel of 1500 DWT	4
15	Barge of 100 DWT	1.2	15	Barge of 200 DWT	1.6	4	general cargo vessel of 2000 DWT	4.5
16	Barge of 200 DWT	1.4	16	Barge of 500 DWT		5	general cargo vessel of 3000 DWT	5.1
17	Barge of 500 DWT		20	Self Propelled Barge of 120 DWT	1.8	6	general cargo vessel of 5000 DWT	5.9
18	Push-convoy of 4 x 500 DWT		21	Self Propelled Barge of 200 DWT	2	7	river-sea vessel of 2000 DWT	4.5
20	Passenger vessel 200 pax	1.4				8	river-sea vessel of 4000 DWT	4.8
						9	container vessel of 3000 DWT	5.1
						10	container vessel of 5000 DWT	5.9
						11	container vessel of 7000 DWT	6.8
						12	container vessel of 10000 DWT	7.3
						13	bulk carrier of 5000 DWT	6.4

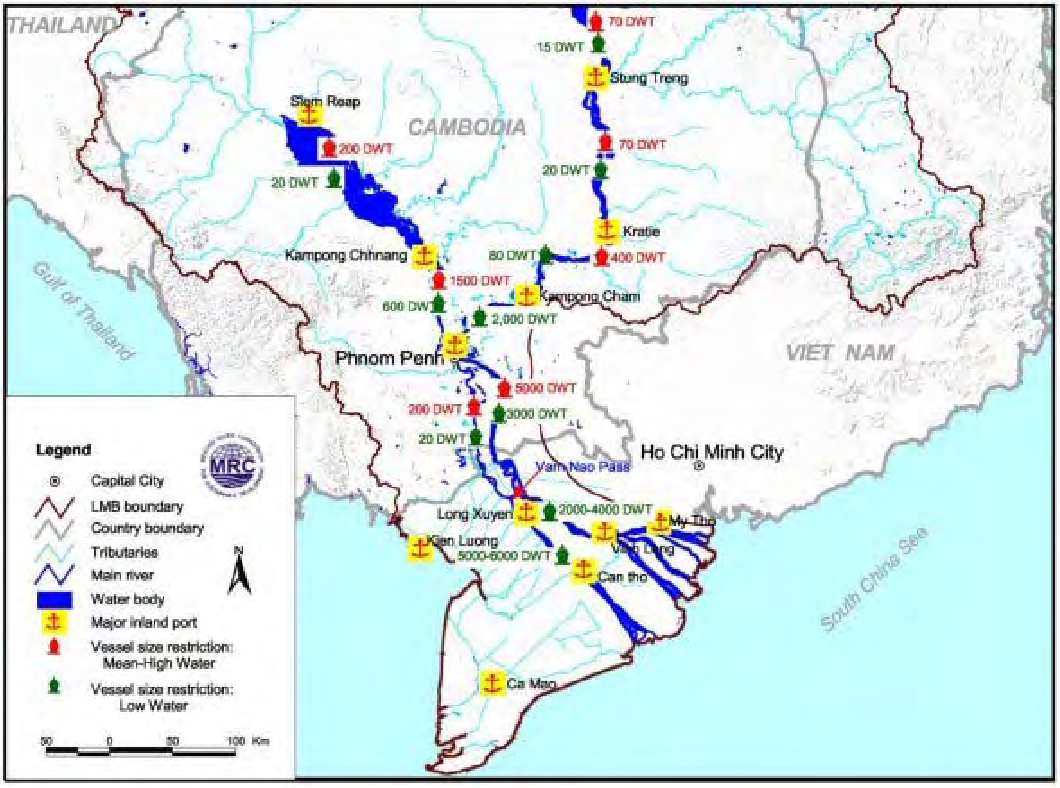
Figure 9.1:   *Example chart from the Mekong Hydrographic Atlas (depths in decimetres)*



Map 9.1: Current (2003) navigation potential in the 'Upstream' Mekong (upstream of Kampong Cham)



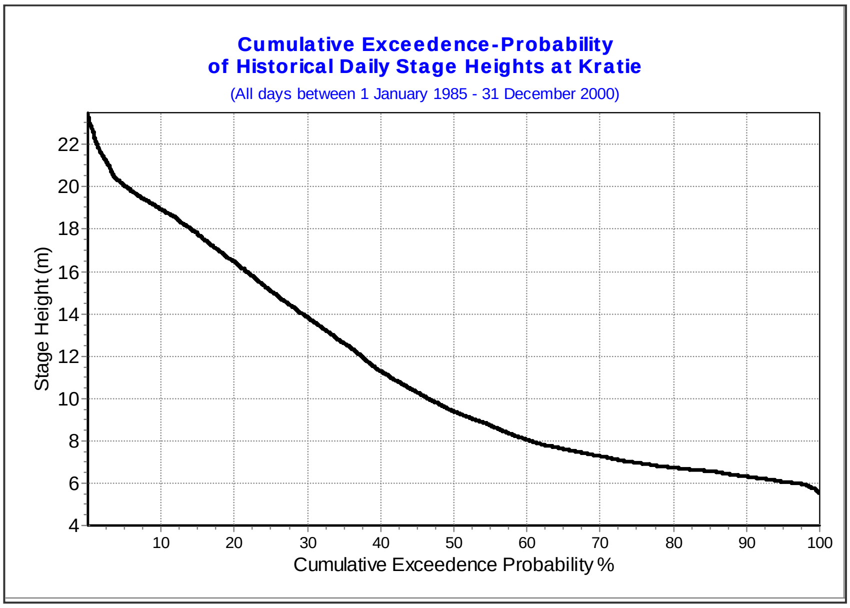
Map 9.2: Current (2003) navigation potential in the 'Downstream Mekong (downstream of Kampong Cham)



Appendix E of the World Bank (2004[i]) reports that the MRC Navigation Programme objective is 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 m) and therefore can only use a limited portion of the inland waterway network, seaward from Kampong Cham.

In view of this objective, the adopted navigation indicator is the mean annual duration (in days) when river depths in the critical (i.e. shallow) portions of each river reach are >4m downstream of Phnom Penh and >3m upstream of Phnom Penh, averaged across all years (16 years from Kratie upstream and 5 years downstream of Kratie). This is computed by summing all occasions in each year that meet the criteria at the mainstream flow monitoring station located towards, or at, the bottom of each reach. In practice this can be achieved by reading off the percent time equalled or exceeded on a cumulative plot of flow frequencies against time, i.e. a stage height duration curve, an example of which is shown in Figure 9.2. These durations are then converted into the number of days per year.

Figure 9.2: Example of a stage-height duration curve (cumulative time equalled or exceeded)



Simulated river levels can only be provided at mainstream flow monitoring stations, not at the shallowest areas within a river reach. However, river flow monitoring stations are not typical of the critical shallow portions of river reaches, as they are selected for being narrow, constrained sections where sediment deposition is minimal. This is to reduce changes in the rating relationships over time due to varying levels of sedimentation and erosion. Fortunately, the Mekong Hydrographic Atlas mentioned above also provides the means by which these levels can be reconciled.

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[i] World Bank (November, 2004). Modelled Observations on Development Scenarios in the Lower Mekong Basin. A technical report for the World Bank's Mekong Regional Water Resources Assistance Strategy.

For each chart in Viet Nam and Cambodia, the chart datum, from which depths are measured, is set at the level of the lowest historical flow in the 20 years to the year 2000. Similarly, the charts for Lao PDR and Thailand present tables of LLW at each 'Mekong kilometre' for the period of the bathometric survey, i.e. 1959 – 60.

By making the assumption that the lowest low water (LLW) level (i.e. the minimum depth) at the critically shallow sections within a reach, correspond to the LLW levels at the stream flow monitoring stations, the corresponding gauge height can be computed (Table 9.2).

Table 9.2: Lowest low water (LLW) levels at critically shallow sections and representative monitoring stations within each river reach

Reach represented	Critical Section	Monitoring station				
	LLW (m depth)	Gauging Station	Chart Number	Chart Datum LLW (m above MSL)	Gauge Zero relative to MSL	Gauge Height at LLW
Chiang Saen to Nong Khai	1.4	Nong Khai	2-039	154.18	153.648	0.53
Nong Khai to Mukdahan	2.5	Mukdahan	2-094	124.68	124.219	0.46
Mukdahan to Pakse	1.6	Pakse	2-094	86.54	86.49	0.05
Pakse to Stung Treng	1.2	Stung Treng	3-067	38.00	36.79	1.21
Stung Treng to Kampong Cham	1.7	Kratie	3-044	3.97	-1.08	5.05
Kampong Cham to Phnom Penh	4.0	Kampong Cham	3-028	0.95	-0.93	1.88
Phnom Penh to the sea	6.0	Tan Chau	TG4003	-0.57	-0.001	-0.57

The LLW levels for stations in Cambodia and Viet Nam (Tan Chau, Kampong Cham, Kratie and Stung Treng) are for the last 20 years to 2000, whereas those for Laos and Thailand (Pakse, Mukdahan and Nong Khai) represent the lowest levels at the time of the bathometric survey in those reaches (1959 – 1960). The vertical height datums for mean sea level (MSL) are the Ha Hein and Ko Lak datums, respectively.

Table 9.3: Gauge heights at key monitoring sites required to meet minimum target water depths at the critical river sections

Flow Monitoring Site	Reach represented	Current Depth at LLW	Gauge Height at LLW	Target Minimum Depth	Target Gauge level
Nong Khai	Chiang Saen to Nong Khai	1.4	0.53	3	2.13
Mukdahan	Nong Khai to Mukdahan	2.5	0.46	3	0.96
Pakse	Mukdahan to Pakse	1.6	0.05	3	1.45
Stung Treng	Pakse to Stung Treng	1.2	1.21	3	3.01
Kratie	Stung Treng to Kampong Cham	1.7	5.05	3	6.35
Kampong Cham	Kampong Cham to Phnom Penh	4.0	1.88	4	1.88
Tan Chau	Phnom Penh to the sea	6.0	-0.57	4	-0.57

Using the relationships established by the MRC Navigation Program between vessel class and minimum safe draft requirements for each river reach, Table 9.4 presents the average annual number of days that these navigation requirements are met. Values less than 300 days/year are highlighted, as the long term goal is for the average navigability to exceed this duration.

Table 9.4: Number of days target navigation requirements met (> 4 m draft downstream Kampong Cham & > 3 m safe draft upstream Kampong Cham)

River Reach	Flow Monitoring Site	Threshold Water Level at Gauge Height (m)	Average Annual Navigable Days				
			Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario5
Chiang Saen to Nong Khai	Nong Khai	2.13	**253**	341	**287**	**282**	337
Nong Khai to Mukdahan	Mukdahan	0.96	**288**	361	339	301	358
Mukdahan to Pakse	Pakse	1.45	**223**	**263**	**237**	**223**	**245**
Pakse to Stung Treng	Stung Treng	3.01	**195**	**207**	**196**	**191**	**200**
Stung Treng to Kampong Cham	Kratie	6.35	347	365	365	349	365
Kampong Cham to Phnom Penh	Kampong Cham	1.88	343	362	356	342	363
Phnom Penh to the sea	Tan Chau	-0.57	365	365	365	365	365

Values < 300 days **shaded & highlighted in bold**

Downstream of Kratie the number of navigable days exceeds 300 for all scenarios. Conversely, none of the scenarios provide sufficient flows in the river reaches from Mukdahan to Stung Treng. Between these two extremes are the two upper reaches spanning Chiang Saen to Mukdahan. In the first of these, from Chiang Saen to Nong Khai, only Chinese Dams and High Development meet the 300 day target. In the second, from Nong Khai to Mukdahan, only the Baseline fails, but by the relatively small margin of 12 days.

Changes relative to the Baseline condition (Scenario 1) are presented in Table 9.5. In all but one case, Irrigation Development at Stung Treng, the navigable number of days increases relative to the Baseline or stays the same. That result can be explained by the large amount of additional irrigation upstream of Stung Treng, with the compensatory benefit of dry season hydropower releases from only one additional dam in China, rather than the two additional Chinese dams assumed in the China Dams and High Development scenarios. The Low Development scenario also comes close to a negative result in this reach; the irrigation demand, whilst considerably greater than the Baseline, is not sufficiently large to lower the navigable days.

Table 9.5: Change in average annual navigable days

River Reach represented	Flow Monitoring Site	Baseline	Change in Average Annual Navigable Days			
		Navigable Days	Chinese Dams	Low Development	Irrigation Development	High Development
Chiang Saen to Nong Khai	Nong Khai	253	88	34	29	84
Nong Khai to Mukdahan	Mukdahan	288	72	51	13	69
Mukdahan to Pakse	Pakse	223	40	15	0	22
Pakse to Stung Treng	Stung Treng	195	12	2	-4	5
Stung Treng to Kampong Cham	Kratie	347	18	18	2	18
Kampong Cham to Phnom Penh	Kampong Cham	343	20	14	0	20
Phnom Penh to the sea	Tan Chau	365	0	0	0	0

Shaded cells achieve target 300 navigable days

The greatest changes, however, are in the upstream reaches where the affect of the additional Chinese Dams is greatest. Navigable days improve by more than 10% for all development scenarios in the reach from Chiang Saen to Nong Khai (as indicated by the shaded cells). From Nong Khai to Mukdahan, the result is similar, with only Scenario 4 failing to reach a 10% improvement, for the above mentioned reasons relating to the very large increase in irrigated area under this scenario. Therefore it can be seen that the release of hydropower from the additional Chinese dams in the dry season clearly improves navigability.

No improvement is possible from Phnom Penh to the sea because the baseline already experiences 100% navigability for the target minimum safe drafts (4 m in this reach).

9.2 Salinity intrusion

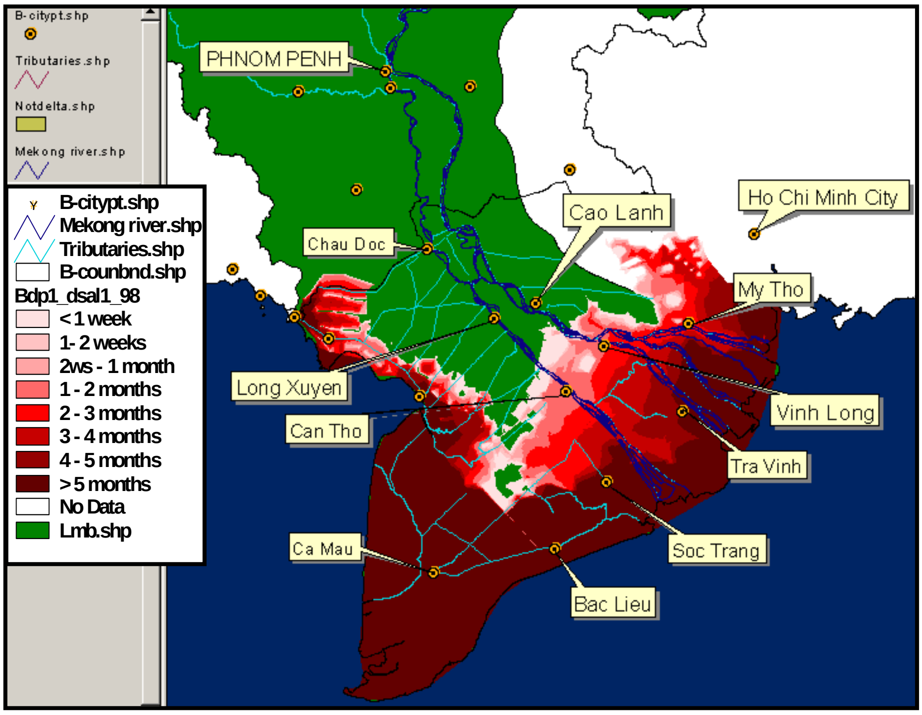
The iSIS model uses the flow and water level results from the hydraulic simulation and tidal and salinity measurements from 1998 to simulate a time series of salinities in the Mekong Delta at hourly time steps. The results from this simulation should be able to give an indication of the relative effects of the different scenarios. However, there are a two main issues with the configuration and operation of the iSIS model that will have an impact on results before the absolute salinity levels can be considered reliable.

The first is that the configuration and operation of salinity intrusion barriers needs to be updated to reflect current conditions. Comments from a presentation of results were that salinity intrusion barriers in the region about Tra Vinh have not yet been included in the configuration. Also, the operation of the salinity intrusion barriers, that is when they are opened and closed does not necessarily take into consideration the operation of these to cater for brackish water requirements of shrimp farms.

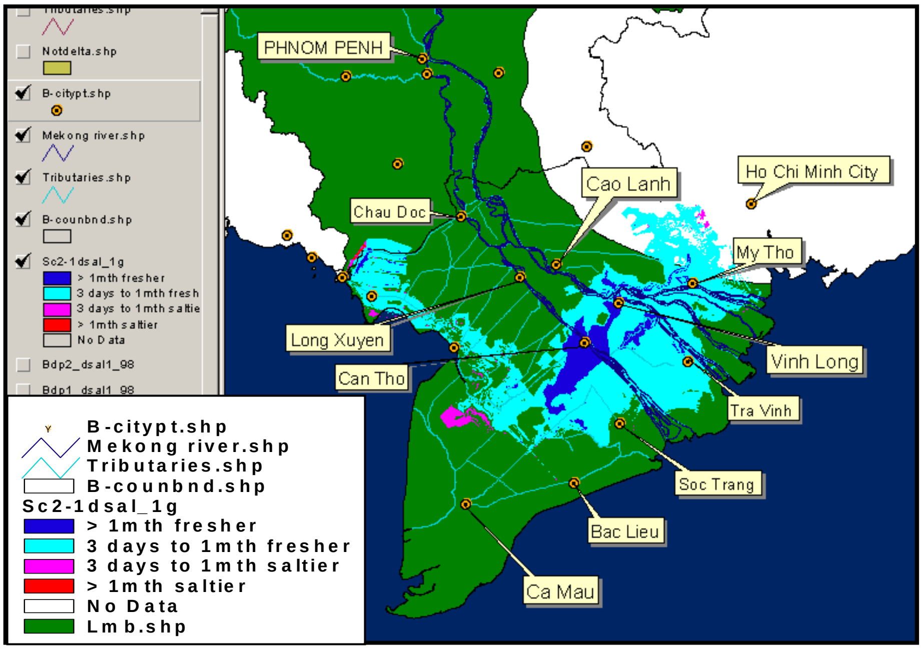
The second key issue is that the irrigation diversions had to be averaged over a 90 day period to make the hydraulic simulation stable. Consideration of the diversion patterns in the Mekong Delta region show that this 90 day averaging removes some important variability. This is necessary, in part, because the dry season rice crops is modelled as starting on the same day (1 April), which results in an abrupt increase in diversions during the critical flow period. Ideally, crop calendars in the diversion model should be staggered to start planting at weekly intervals from late march to mid-April, and then irrigation diversions could be averaged over a much shorter period; in the range 1-2 weeks.

The area affected at the maximum saline intrusion (> 1 g/l) in 1998 (28,466 km²) is shown in Map 9.3; longer durations occur closer to the sea. The extent to which the duration of salinity intrusion differs in each scenario, relative to this Baseline condition, are shown in Maps 9.4 to 9.7.

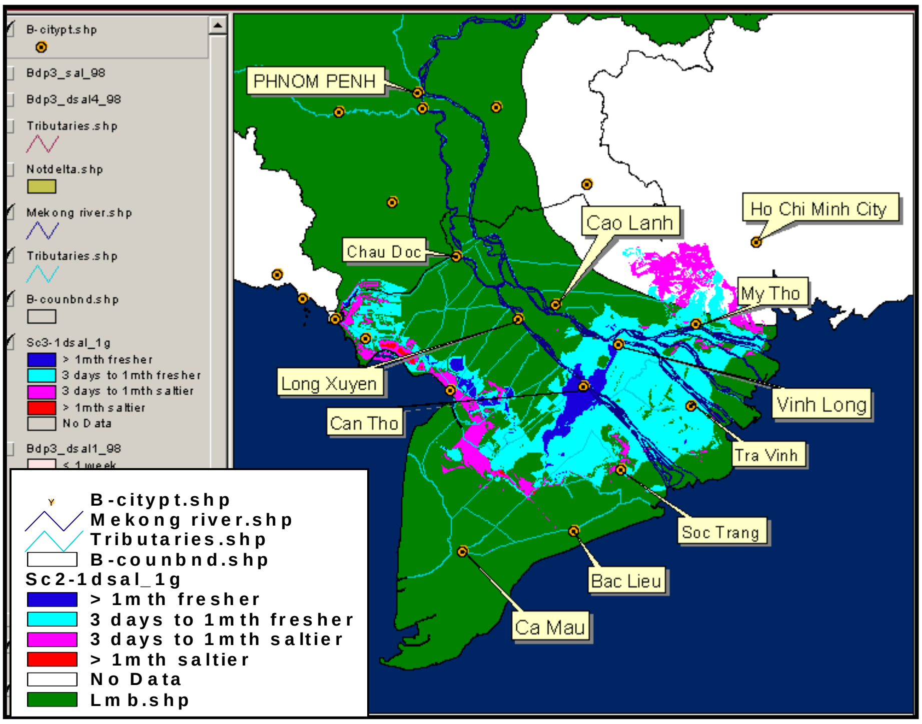
Map 9.3: Baseline Conditions (1998) - duration of salinity levels > 1 g/l



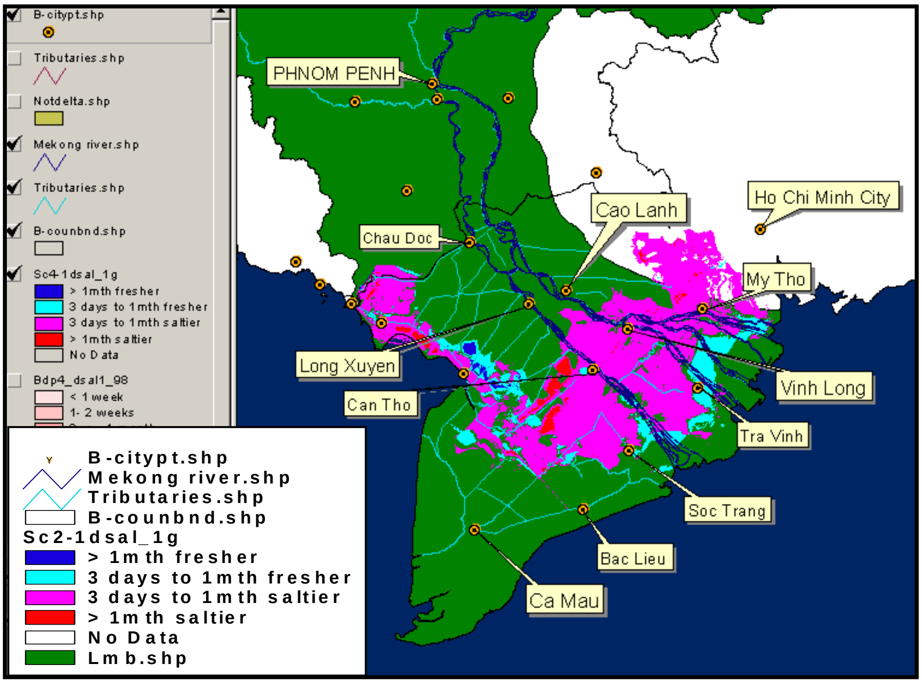
Map 9.4: Chinese Dams difference to Baseline (1998) - duration of salinity levels > 1 g/l



Map 9.5: *Low Development difference to Baseline (1998) - duration of salinity levels > 1 g/l*



Map 9.6: *Irrigation Development difference to Baseline (1998) - duration of salinity levels > 1 g/l*



Map 9.7: High Development difference to Baseline (1998) - duration of salinity levels > 1 g/l

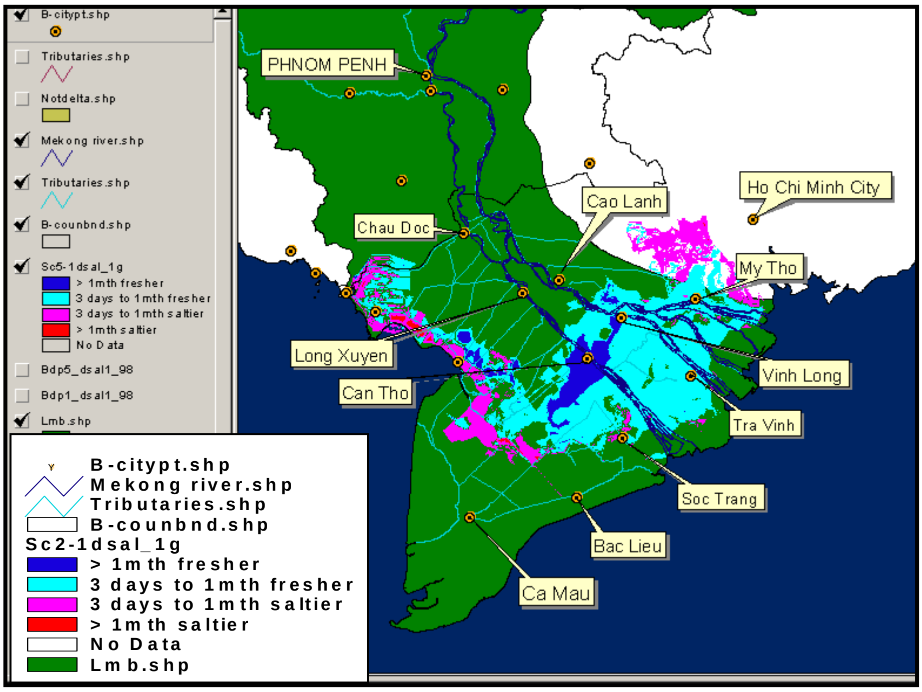
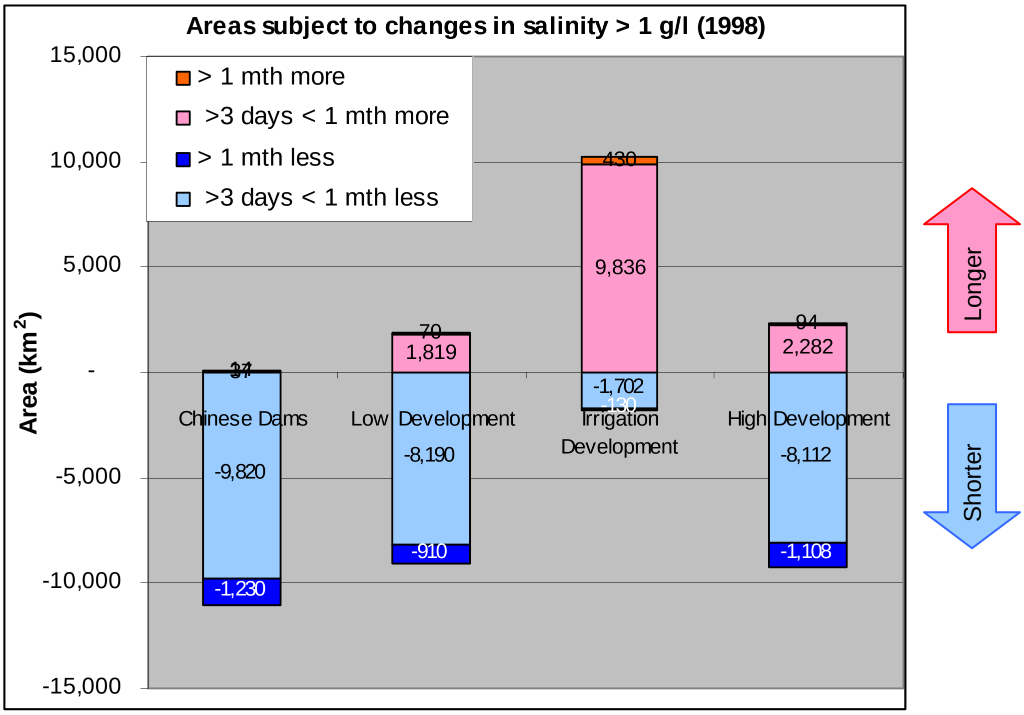


Figure 9.3 presents the changes in the areas shown in the above difference maps. The way in which the pattern of salinity durations inversely mirrors the flow duration changes clearly demonstrates the driving influence of changes in flow, with wet season flood size and duration affecting the level of flow in each subsequent dry season.

Figure 9.3: Differences in salinity intrusion relative to Baseline Conditions (1998; > 1 g/l)



Two aspects are of interest in interpreting differences presented in the above figures. First is the geographic location of the areas experiencing changes in salinity durations above 1 g/l, and secondly, the nature of those changes, both within a scenario and between them.

Geographically, the changes occur in a crescent shaped band stretching from the Cambodian-Vietnamese border in the west to My Tho in the east. Indeed changes occur further to the east outside of the LMB due to flow contributions from the Mekong to the headwaters of the Vam Co river system. Salinity durations changes in the Chinese Dams scenario are almost without exception, reductions. Those few areas displaying an increase are of less than one week duration and are most probably due to model dynamics. The reason for the shorter durations above 1 g/l is clearly the elevated dry season flows relative to the baseline. The High Development scenario shares a similar pattern to the Chinese Dams scenario, but displays a less uniform change. The shorter durations are again due to the two large additional Chinese hydropower dams, plus the additional releases from new LMB dams. However, the longer durations are a result of the very high levels of irrigation, which at the peak of the dry season, are greater than the hydropower releases.

The Low Development scenario displays a very similar pattern to the High Development scenario, because of a similar balance between additional irrigation and hydropower dams – each counter balancing the other to achieve a similar level of impact despite the large difference in the scale of the interventions themselves. This balance is not maintained in the Irrigation Development scenario. Whilst it shares the same level of LMB and Chinese dam interventions as in the Low Development scenario, the level of irrigation is the same as that in the High Development scenario. The mismatch in the additional agricultural water use and elevated dry season flows contributed by hydropower dam releases, is clearly evident in the majority of changes being towards longer salinity durations, including considerable areas which experience more than 1 month longer salinities over 1 g/l.

9.3 Flood management

At the very least, management of the positive and negative aspects of flooding needs to take account of the areas affected by different flood depths and durations. Large floods of long duration and/or depths cause more flood damage, but conversely are beneficial for fish production. Small floods result in fewer fish.

To be comprehensive flood management should also consider other factors that contribute both to flood risk and ecological functioning. Examples of the former include flood velocities, island formation and drown-out, distance to flood free areas, flood debris and sedimentation. Ecologically important variables share some of those factors, as well as needing to consider water quality, inundated habitat type, short-term water level fluctuations, soil oxidation states, sources of drift, and many other factors. However, current knowledge levels are inadequate to support quantitative analysis of many of these additional criteria, therefore the factors for quantitative flood management analysis are confined to flood depth – duration.

As mentioned previously, downstream of Kratie daily water levels are directly computed by the ISIS model in the DSF over the whole floodplain, not just the river channel. From these data, flood depths can be computed for each day by comparison to a digital elevation model (DEM) of the floodplain surface. Of primary interest are the peak flood extent, peak annual flood depths at each location and the annual duration of flooding above particular depth thresholds. These parameters are generated from maps of maximum annual flood depth and annual depth-duration maps. Standard DSF depth thresholds for the depth-duration maps are 0.5m, 1.0m or 2.0m.

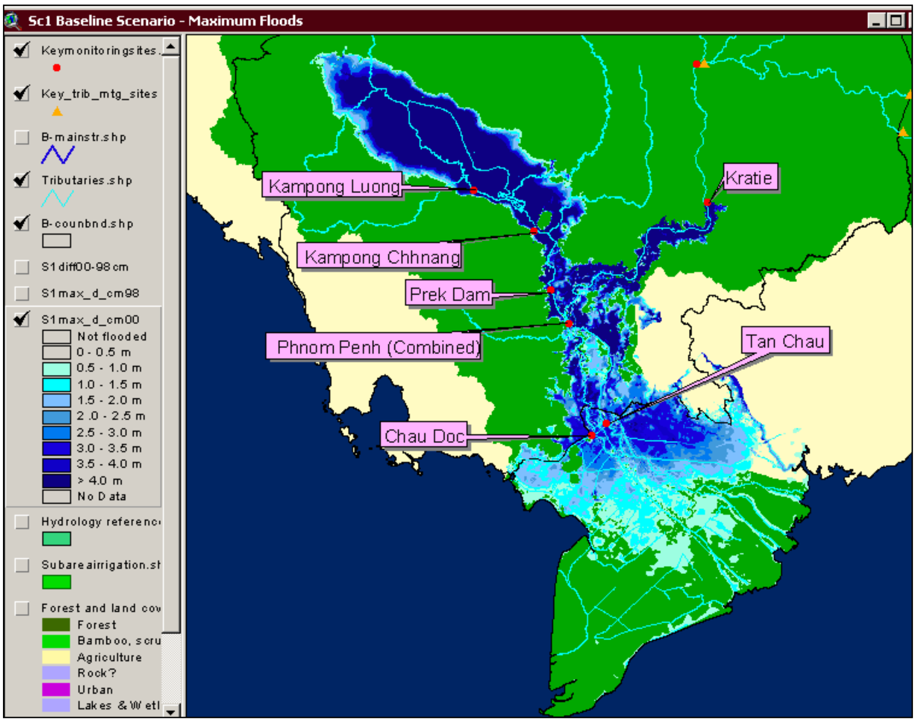
Maximum area inundated > 0.5 downstream of Kratie

Peak annual depths and flood durations less than 0.5 m are generally not of real concern to people, as access is not significantly impeded and duration is very short. In addition, even small embankments can easily block such shallowing flooding, thus limiting the extent of flooding. The short durations and shallow depths also make these areas of limited utility to fish. Therefore, as a general indicator the 0.5m level is adopted for comparison of maximum flood and flood durations between scenarios.

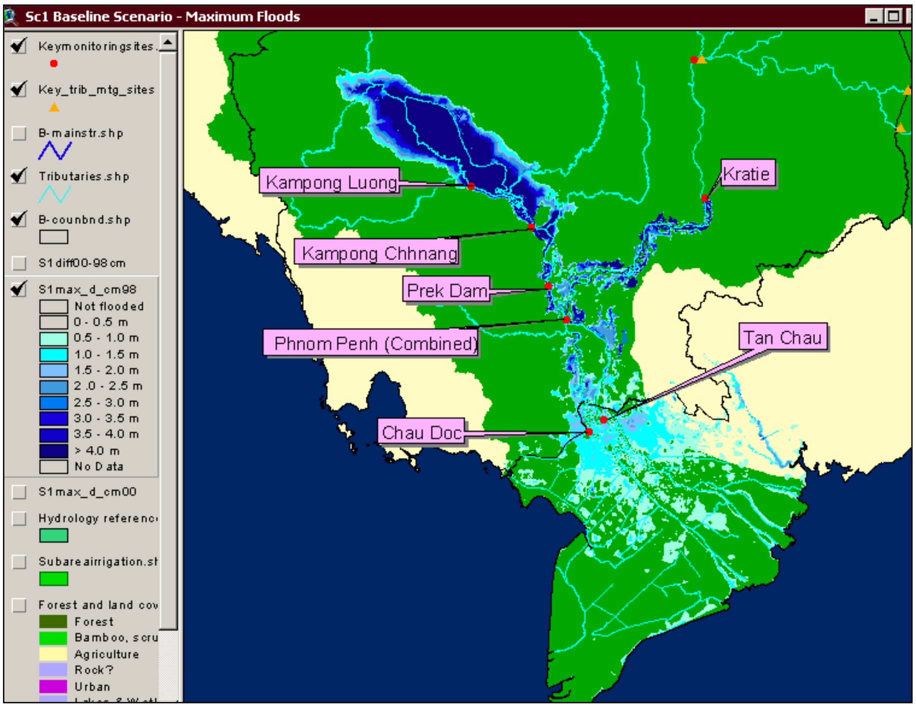
Maps 9.8 and 9.9 provide examples of maximum annual flood extent maps for Scenario 1 (Baseline conditions), year 2000 and 1998 respectively. Areas inundated to less than 0.5m are not shown. The depth categories represent the maximum depth that occurred at each location over the period of the simulation, i.e. in the whole year. Thus the map displays flood depths and extent that are a consequence of the whole wet season, not a particular day of the year.

This is important to note, as in practice not all areas are flooded to their peak annual depths at the same time; the flood peak travels down the floodplain, creating peak flood depth conditions in the upper areas long before they occur in the lower parts. Conversely, areas in Viet Nam experience their annual peak flood levels and flood extent when flood levels are already beginning to fall in the upper areas near Kratie. Therefore comparison between these annual maximum flood extent maps and those generated by satellite imagery on a particular date, is not possible. If such comparisons are needed, the DSF can generate a flood depth-extent map for just that day, which inherently, will be a lesser extent that what is shown in maps of the whole 'envelope' of wet season peak flood depths.

Map 9.8: Baseline conditions peak flood depth-extent map for year 2000

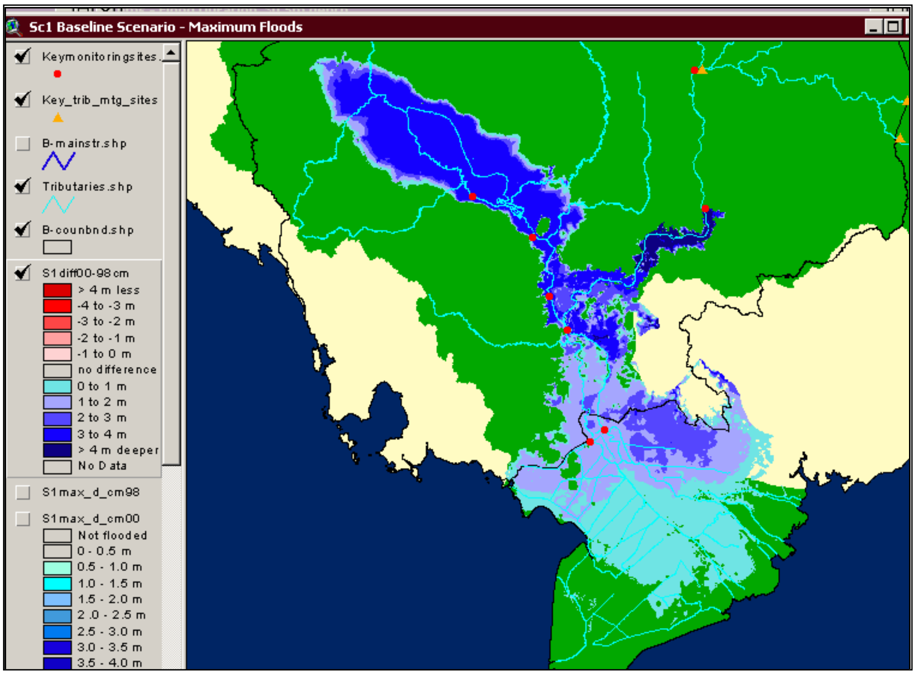


Map 9.9: *Baseline conditions peak flood depth-extent map for year 1998*



Map 9.10 presents the difference in depths between the Baseline year 2000 and 1998 flood depth maps, to give an indication of the between-year variation in flood depths and extent.

Map 9.10: *Baseline conditions – difference in peak flood depth-extents between year 2000 and 1998*

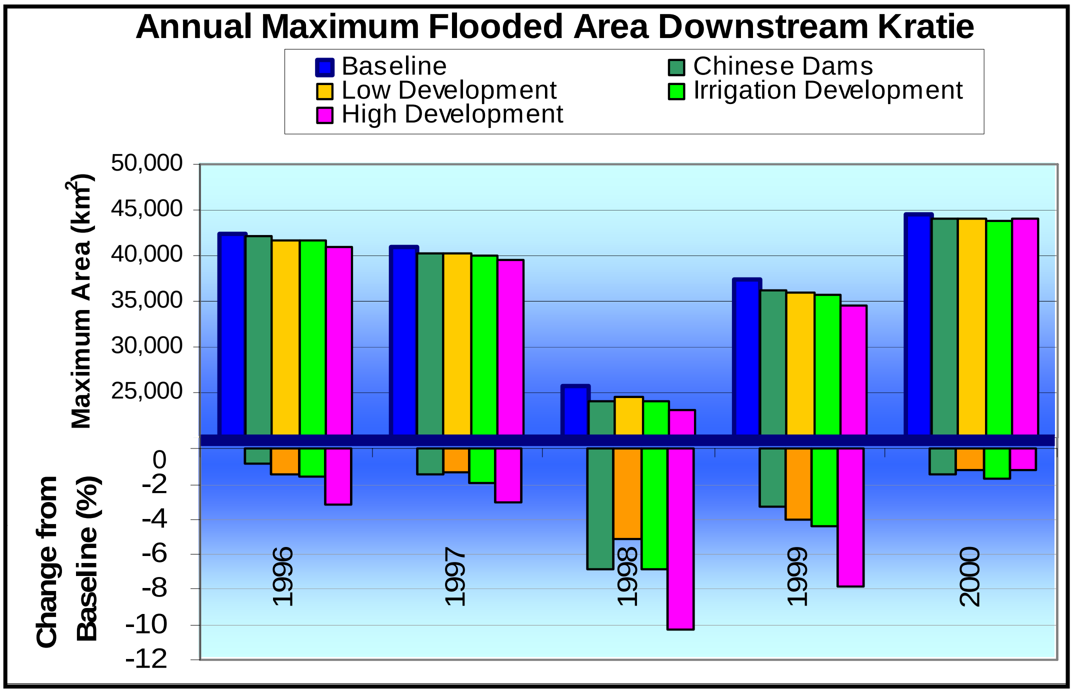


Data exported from the simulated flood maps for each scenario provide the maximum annual flood extent values in Table 9.6. Differences relative to the Baseline are shown in Figure 9.4.

Table 9.6: Scenario maximum annual flood extent ('000 km^2)

	Downstream Kratie: Maximum Annual Flooded Area ('000km^2)						Average Change (%)
Year :	1996	1997	1998	1999	2000	Average:	
Baseline	42,385	40,854	25,803	37,406	44,638	38,217	
Chinese Dams	42,029	40,284	24,032	36,179	44,000	37,305	-3
Low Development	41,785	40,315	24,476	35,923	44,126	37,325	-3
Irrigation Development	41,709	40,076	24,048	35,762	43,894	37,098	-3
High Development	41,047	39,617	23,141	34,469	44,090	36,473	-5

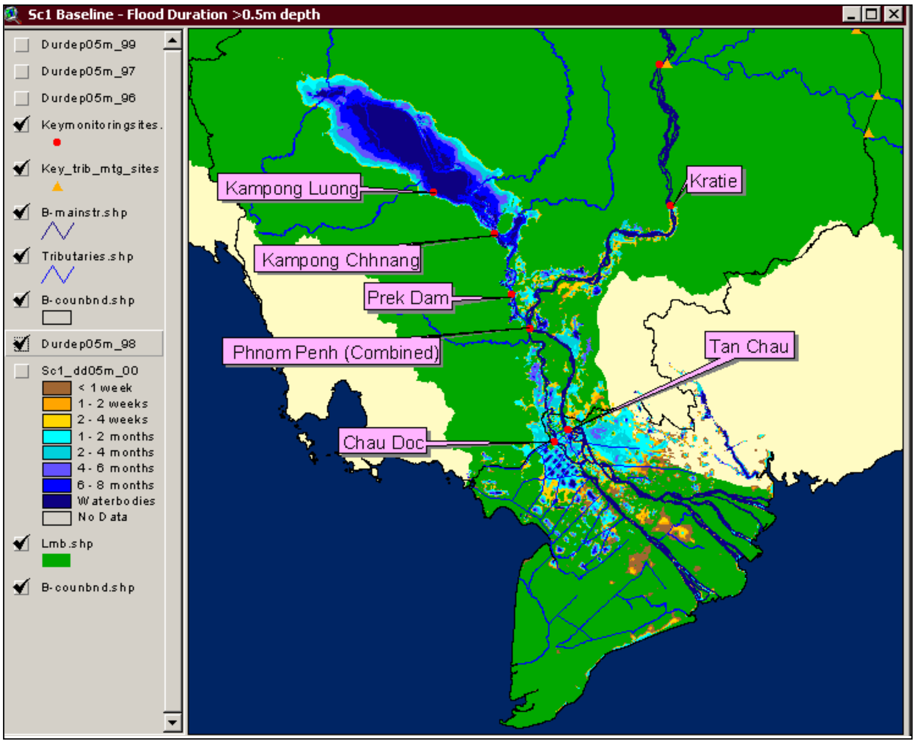
Figure 9.4: Maximum annual flooded areas and changes from Baseline



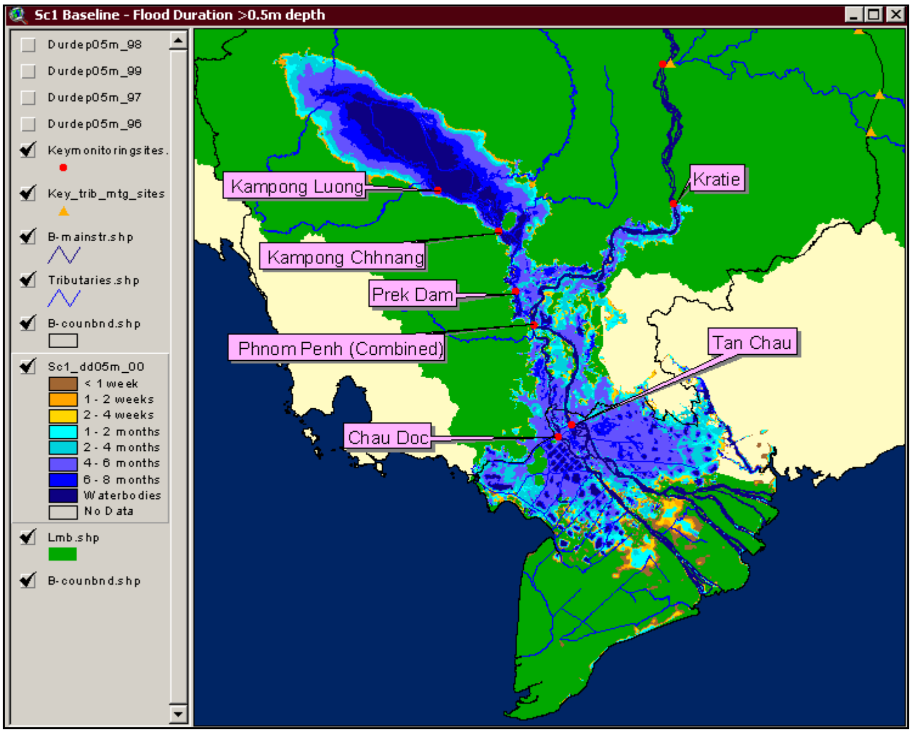
Duration of area inundated > 0.5 m downstream of Kratie

The largest flood in the five year period from 1996 to 2000, was in the year 2000. Although peak depths in that year were relatively large, it was the long durations that really set this flood apart from other recent events. The driest of the five simulated years was 1998, although over the longer period of 1985 – 2000, it was only slightly less than the median flood (on the basis of annual peak flood levels). Therefore, the report presents scenario difference maps for both the 1998 and year 2000 floods, based on the >0.5m flood-duration maps. The actual Baseline flood-duration maps for 1998 and 2000 are presented in Maps 9.11 and 9.12 to illustrate the range of between year differences over the period 1996 – 2000.

Map 9.11: *Baseline year 1998 flood-duration map for areas flooded > 0.5m*



Map 9.12: *Baseline year 2000 flood-duration map for areas flooded > 0.5m*

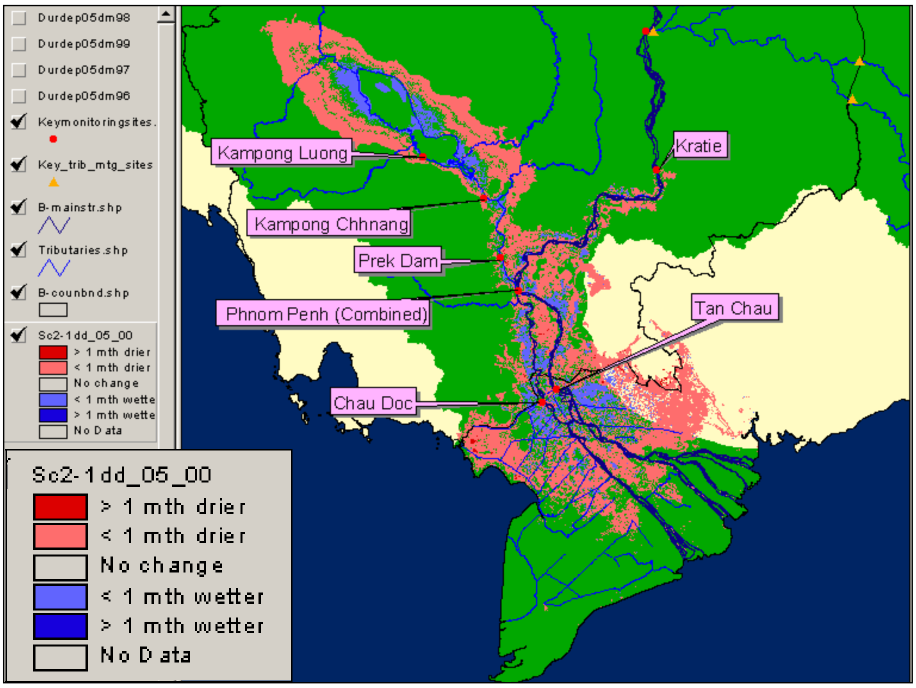


Baseline and development scenario values are compared using GIS software, with differences in the areas in each duration category reported in tabular form. Duration difference maps are also produced, but for ease of interpretation showing only two categories:

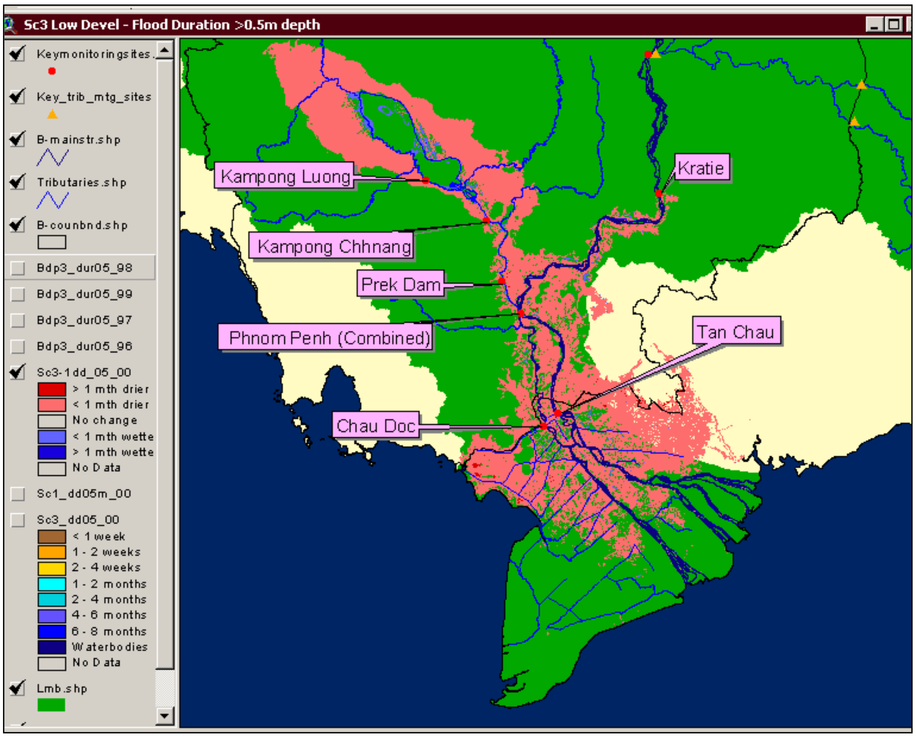
- Areas where the flood duration changes by more than one week, but less than one month; and
- Areas where flood duration changes by more than one month.

Flood-duration difference maps were calculated between each development scenario and the Baseline scenario (Maps 9.13 to 9.16).

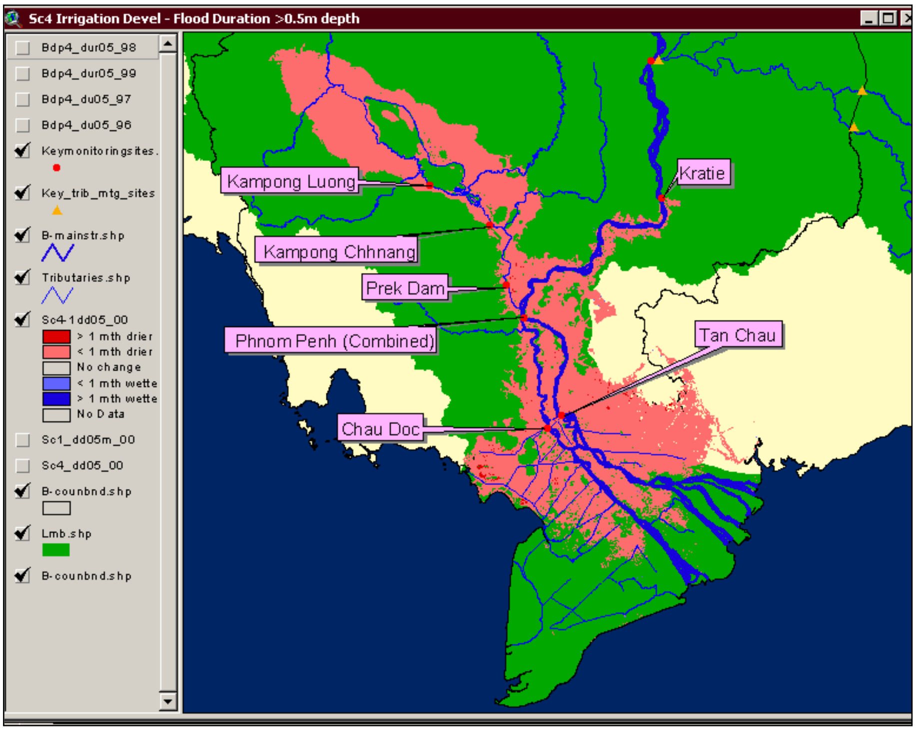
Map 9.13: Change in flood duration between Scenarios 1 & 2 (0.5m exceedance)



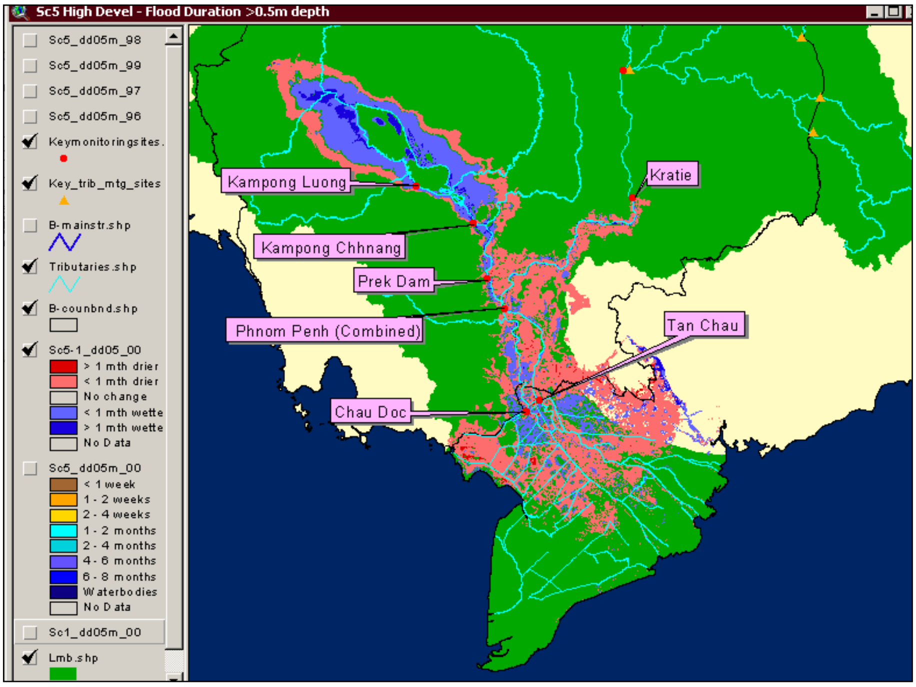
Map 9.14: Change in flood duration between Scenarios 1 & 3 (0.5m exceedance)



Map 9.15: Change in flood duration between Scenarios 1 & 4 (0.5m exceedance)



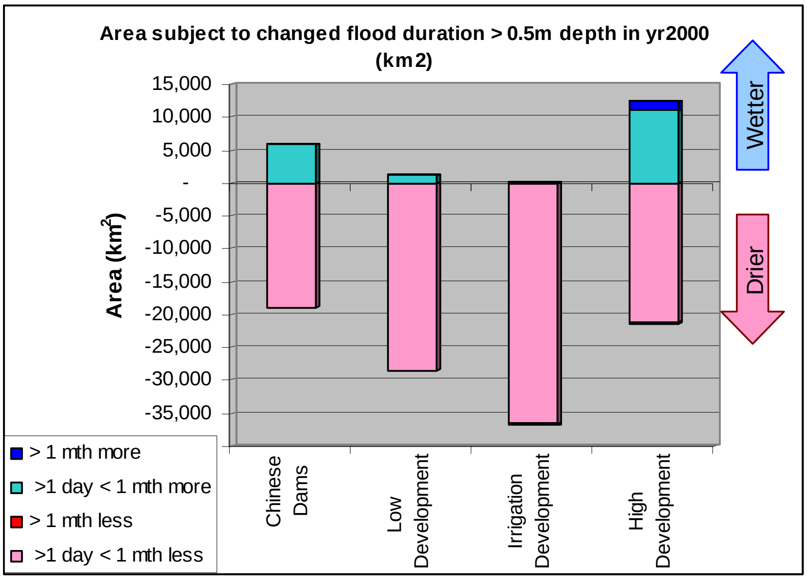
Map 9.16: Change in flood duration between Scenarios 1 & 5 (0.5m exceedance)



From the above maps, the areas subject to category of change were calculated and presented graphically in Figure 9.5.

Compared to the minimal changes in mean (annual) maximum flooded area presented previously in Table 9.6 and Figure 9.4 (averaging around 3% for most scenarios and only 5% for the High Development scenario), there are significant differences in flood durations between the scenarios.

Figure 9.5: Areas subject to changes in year 2000 flood durations from Baseline > 0.5 m depth



With the exception of longer durations in High Development scenario, almost all changes are less than one month. All but the Irrigation Development scenario involve both increases and decreases in flood duration over 0.5 m depth, although the Low Development scenario only displays a very small area subject to longer flood durations. The additional dams in China and the LMB, combined with the much higher levels of irrigation diversion in the Irrigation Development scenario, reduces flood durations (in higher parts of the floodplain), largely through its impact on the beginning and end of the wet season flood levels. The dams reduce flood levels, particularly at the commencement of the wet season whilst they re-fill after being drawn down in the dry season, thus shortening the duration of the flood in higher areas of the floodplain.

Whilst this is also true of the other development scenarios, what sets the Irrigation Development scenario apart is the lack of any increase in flood durations in low lying floodplain areas (and therefore subject to long flood durations), such as is exhibited most strongly by the High Development scenario and to a lesser extent by the Chinese Dams scenario. Those increases occur due to the elevation of mainstream river flows in the dry season and transition months (i.e. the beginning of the wet and dry seasons) that are caused by hydropower dam releases and irrigation tail-water return flows. These two scenarios have two additional large dams in China (rather than one) that appear to be the main drivers of the elevated dry season flows and hence longer flood durations in low lying areas.

Any such elevation of flows in the Irrigation Development scenario are more than equalled by the high level of extractions and losses associated with the inter-basin and intra-basin transfers. A similar, but slightly less extreme pattern is exhibited by the Low Development scenario.

9.4 Crop flood damage

Cambodia

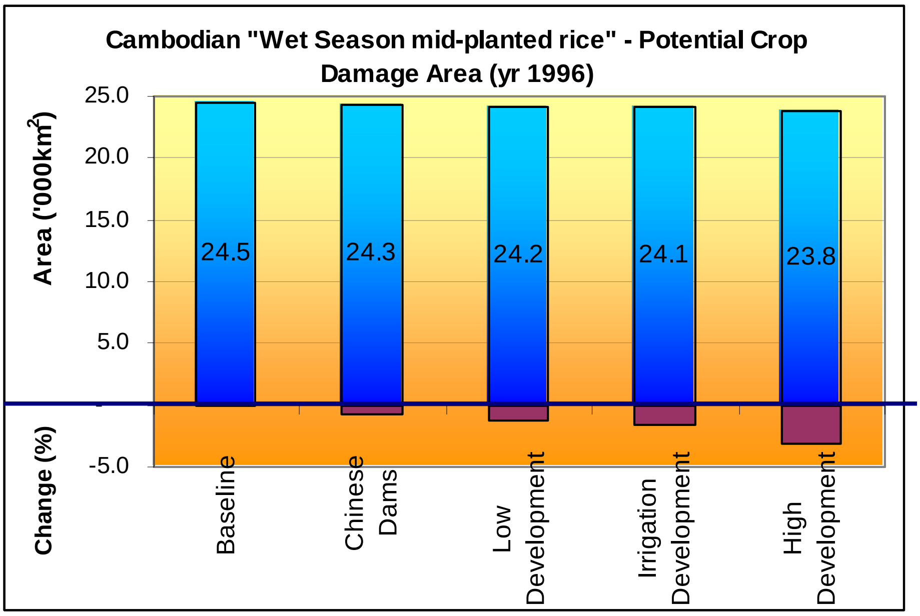
Of the three predominant crop periods, "wet Season – mid planted" rice crop covers the largest area (52%). The most vulnerable period for this crop is the pollination (flowering) period which ranges from about 25 September to 15 October. Scenario differences in potential crop damage in this period, caused by flooding in excess of 0.5m for more than one day in 1996, are shown in Figure 9.6. The year1996 was chosen for analysis as it was a very large flood that occurred later than normal. It is therefore typical of the type of flood year that will cause the most damage to this particular crop.

All development scenarios result in marginally smaller areas of potential crop damage for this year (1996), relative to the Baseline scenario. The High Development scenario shows the greatest reduction in potential crop damage, because of its higher level of impact on flood durations in August.

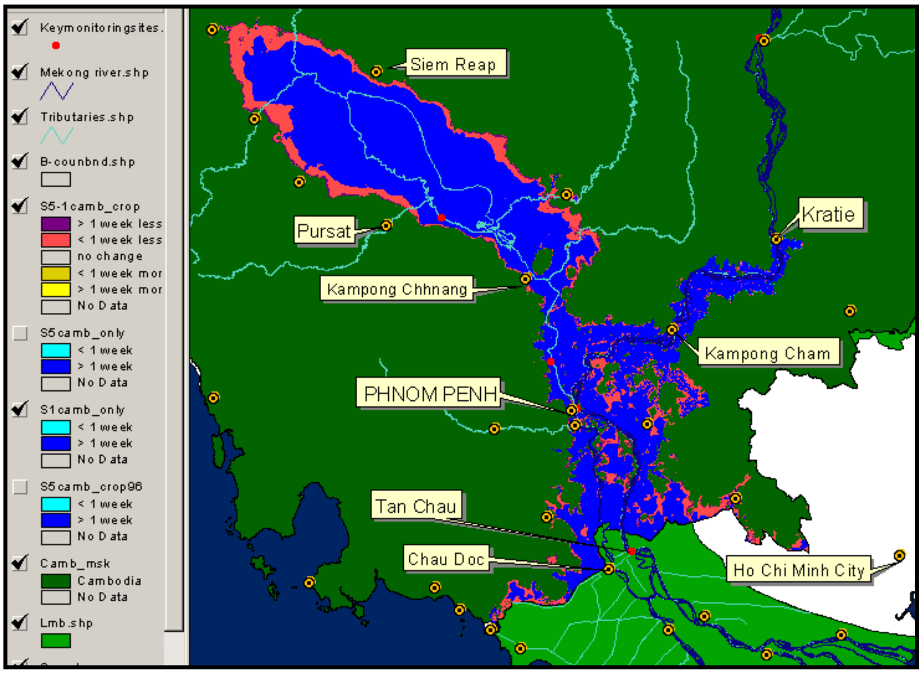
The geographic distribution of those changes between each scenario are very similar, as would be expected for such small changes. As an example, Map 9.17 shows the Baseline area affected by flooding over 0.5 m deep in the period 25 Sept to 15 Oct (blue colours); those areas shaded in red experience reduced flood durations under High Development conditions.

Because the location of "wet Season – mid planted" rice crop is not known, it is not possible to calculate with accuracy the potential increase in yields.

Figure 9.6: Potential area impacted by flood damage relative to Cambodian "wet season mid-planted rice" (depth > 0.5m for > 1 day between 25 Sept & 15 Oct, 1996)



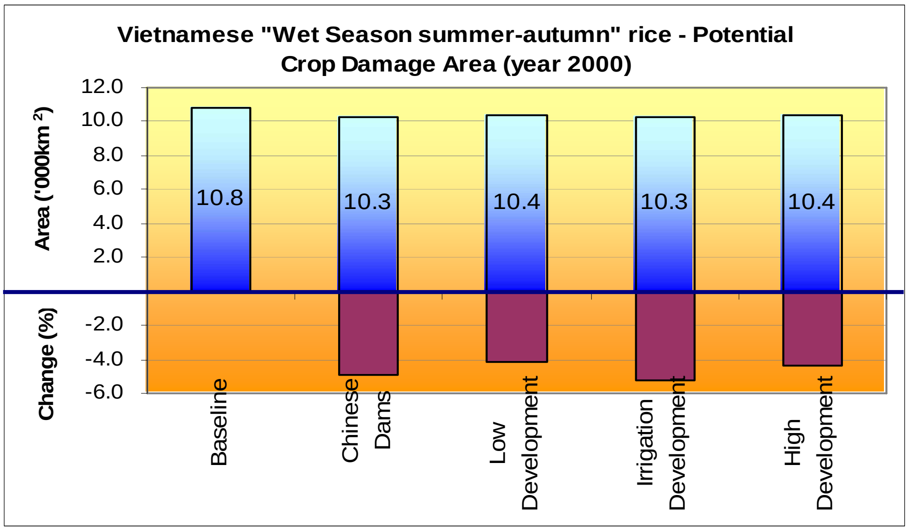
Map 9.17: Cambodian area potentially impacted by flood damage relative to Cambodian "wet season mid-planted rice"; Baseline versus High Development



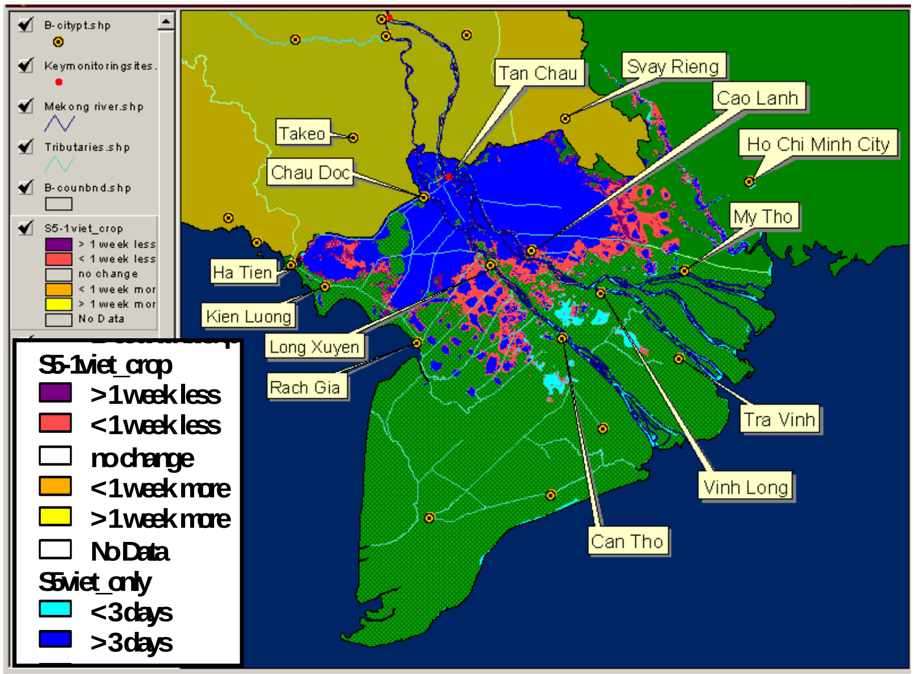
Viet Nam

The wet season “summer-autumn crop” is the largest seasonal rice crop in Viet Nam, averaging 44% of the total annual crop area . Its most vulnerable period is the harvest period spanning the whole of August. Scenario differences in potential crop damage in this period, caused by flooding in excess of 0.5m for more than 3 days in the year 2000, are shown in Figure 9.7. The flood in the year 2000 is representative of a long large flood, starting earlier than average, with a consequent potential to impact on this crop type.

Figure 9.7: Potential area impacted by flood damage relative to the Vietnamese “summer-autumn wet season rice” crop (depth > 0.5m for > 3 days between 1 – 31 August, yr2000)



Map 9.18: Map of Vietnamese area potentially impacted by flood damage relative to Vietnamese “summer-autumn wet season rice” crop; Baseline verses High Development (yr2000)



All four development scenarios provide a greater level of crop exposure to damage than was determined for the Cambodian crop analysis. Evidently, the unique features of the year 2000 flood and/or the more downstream location subject to tidal factors, are responsible for the greater reductions, which in every case are 4% or more less than the areas in the Baseline. The lack of correspondence between the impact of the 1996 flood on the Cambodian crops and the year 2000 flood on the Vietnamese crops highlights the complexity of flood behaviour between years and the subsequent changes induced by development. Clearly, further analysis of potential flood damage on different crops using depth and duration criteria is warranted.

The Baseline August 2000 flood extent is shown in blue in Map 9.18, overlaid with red areas showing the reductions in flood duration under High Development conditions. As with the Cambodian crops, because the location of "summer-autumn rice crop" is not known, it is not possible to calculate with accuracy the potential increase in yields arising from the reduced potential flood damage.

9.5 Fish habitat availability

Fish Habitat Availability Index

Capture fisheries utilise the naturally occurring wild fish populations of the LMB that is comprised of more than 1,500 species. Total annual LMB catches range between one and two million tonnes, making it one of the largest freshwater fisheries in the world. One study in the LMB near Phnom Penh by Dubeau *et al* (2001[i]), indicates that the unit area productivity is likely to lie between 243 – 281 kg/ha/year (based on their more accurate method). Whilst there are caveats on this estimate, it does indicate that the Mekong fisheries are very productive.

Sustainability of the fishery, however, is dependent on many factors, including fishing practices, total fishing effort, river flows, barriers to river migration, access to and from floodplain habitats and habitat changes. One of the most important is the area flooded each year and the duration for which it is inundated. For the area downstream of Kratie, for which flooded areas can be simulated, this can be captured in a single index.

The "Fish Opportunity Feeding Index" used in the World Bank (2004) report (referenced previously) has been relabelled to "Fish Habitat Availability Index" (HAI) to be more reflective of what it actually measures. There is no change in the way that it is calculated. It is computed as the product of area inundated to more than 0.5m and the number of days this area is inundated in each year. Areas that are flooded less than one month (30 days), and/or more than six months (183 days) are excluded. This total area – duration is representative of total amount of habitat that is available to fish over the year; the more habitat available, the more fish that can survive, grow and/or reproduce. Figure 9.8 shows the relationship between incremental flooded area and area-duration days for all duration classes.

Differences in the mean HAI are shown as difference maps and tables of differences in areas, for each development scenario compared to the Baseline.

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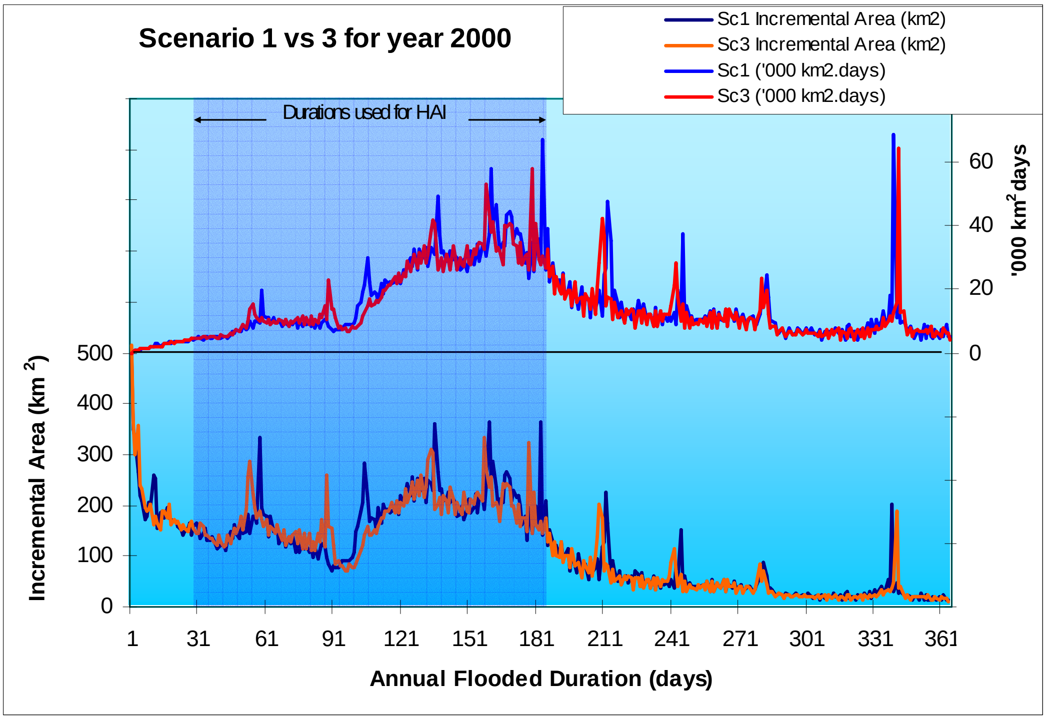
[i] Dubeau P, Poeu O & Sjorslev J (2001). Estimating Fish and Aquatic Animal Productivity/Yield per Area in Kampong Tralach: An Integrated Approach. Sourced from MRC website; Mekong Info 14-5-2004; http://www.mekonginfo.org/mrc_en/doclib.nsf/ByCat_Fisheries?OpenView&Start=1&Count=30&Expand=5.2#5.2

Figure 9.8: Relationship between incremental flooded area and HAI for Scenario 1 (Baseline) & Scenario 3 (Low Development)



Changes in Habitat Availability

Upstream of Kratie changes in flow volume above an assumed floodplain threshold is used as an indirect indicator of habitat availability, otherwise referred to here as the "partial flood volume". This indicator captures elements of flood duration and flood peak and consequently mirrors the Fish Habitat Availability Index (HAI) used downstream of Kratie. At each site, the flow level equivalent to the 20th percentile flow exceedance is used as the threshold.

Table 9.7 presents the changes in the partial flow volume, whilst Table 9.8 presents the changes in mean annual flood duration above the assumed floodplain threshold. The fact that the reductions in the partial flood volume are close to double the reduction in flood durations, indicates that those volume changes are caused almost equally by reductions in flood duration and peak flood levels.

Table 9.7: Changes in flow volume above assumed floodplain threshold (20th percentile flow exceedance)

MONITORING LOCATION	Luang Prabang	Nakhon Phanom	Pakse	Kratie
Baseline scenario volume above floodplain threshold (mcm):	*18,871*	*34,833*	*47,850*	*76,263*
SCENARIO	*% change in volume above assumed floodplain threshold*			
Chinese Dams	-47	-27	-19	-11
Low Development	-28	-26	-15	-10
Irrigation	-29	-27	-18	-12
High Development	-51	-42	-29	-23

Table 9.8: Changes in number of days above assumed floodplain threshold (20th percentile flow exceedance)

Monitoring location:	Luang Prabang	Nakhon Phanom	Pakse	Kratie
SCENARIO	*% change in number of days above assumed floodplain threshold*			
Chinese Dams	-28	-14	-10	-4
Low Development	-15	-16	-7	-4
Irrigation	-15	-17	-9	-6
High Development	-32	-28	-17	-8

As might be expected, the reductions are largest for the most upstream sites and for the Chinese Dams and High Development scenarios. For the Chinese Dams scenario, the volume reduction of 47% at Luang Prabang, is entirely due to the impact of the new dams in China, there being no additional irrigation or new dams in the Lower Mekong Basin. The additional 3% impact in the High Development scenario is due to a small amount of additional irrigation upstream of Luang Prabang. The impact for the Low Development and Irrigation Development scenarios is very much less as only one new large Chinese dam is assumed in those scenarios.

Moving downstream, the impacts of the large Chinese dams are diminished by the contributions of tributaries joining the Mekong from Lao which are less affected by either irrigation or dams, albeit both are present in various scales in each development scenario. However, because a number of large tributaries between Luang Prabang and Nakhon Phanom are subject to a number of new LMB dams and irrigation, the reductions in partial volumes at Nakhon Phanom for the Low Development and Irrigation Development scenarios are almost identical to those at Luang Prabang. Only at Pakse does the impact lessen. By Kratie, the partial volumes reductions are of the order of 10% for all scenarios but the High Development scenario, which because of two large dams on the lower Sre Pok and Se San, still exhibits a 23% reduction.

Fish access to inundated floodplains down stream of Kratie is assumed to be the product of flood duration and area of each flood duration class, i.e. the Fish Habitat Availability Index (HAI). Table 9.9 presents the changes in the fish HAI for the flooded area downstream of Kratie, year by year and overall, for each scenario relative to the Baseline.

Table 9.9: *Changes in the Fish Habitat Availability Index (HAI) for the flooded area downstream of Kratie*

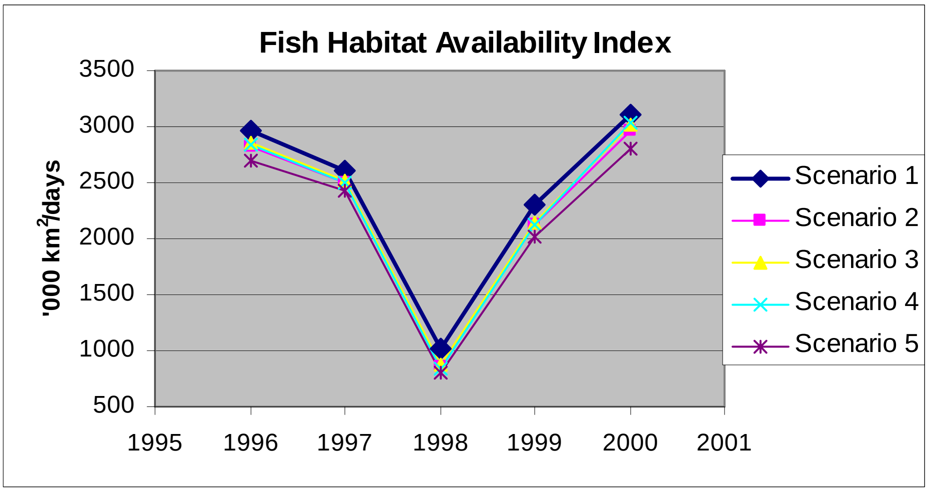
Downstream Kratie: Change in Fish Habitat Availability Index ('000km^2 days)									
	Baseline	Chinese Dams		Low Development		Irrigation Development		High Development	
Year	Total '000km^2 days	'000km^2 days	%	'000km^2 days	%	'000km^2 days	%	'000km^2 days	%
1996	2,972	-144	-5	-119	-4	-131	-4	-282	-9
1997	2,603	-98	-4	-83	-3	-101	-4	-171	-7
1998	1,023	-167	-16	-140	-14	-184	-18	-226	-22
1999	2,308	-183	-8	-169	-7	-185	-8	-294	-13
2000	3,100	-140	-5	-76	-2	-65	-2	-292	-9
Average:	2,401	-146	-7	-117	-6	-133	-7	-253	-12

In all cases, the development scenarios result in reduced HAI values, averaging -6% to -7% for Scenarios 2 to 4, and -12% for Scenario 5. On a year by year basis, the greatest reductions are in 1998. Whilst this was the driest year simulated, it is only marginally below the median peak annual flood for the 16 years 1985 to 2000.

Considered in the context of that longer time-period, the 1998 HAI values, ranging between -14% and -22%, assume a greater importance than the average values over the five simulated years. Reductions of this magnitude can be expected to have direct consequential impacts on the productivity of capture fisheries downstream of Kratie, including the Great Lake. Impacts on fish biodiversity are less certain, as HAI values might be expected to have a less direct relationship to the type of habitat and changes relative to the particular habitat needs of particular species or species groups.

The year by year changes in HAI by year are presented graphically in Figure 9.9.

Figure 9.9: *Changes in HAI by year for all scenarios*



9.6 Fisheries productivity

Capture fisheries upstream Kratie:

In common with other tropical ecosystems, many fish in the LMB have been observed to undertake seasonal migrations in response to hydrologic cues, most particularly corresponding to the beginning and end of the wet season. At these times, various fish species migrate upstream and downstream, between dry season refuges in the main rivers, and flooded floodplains and wetlands in the wet season.

In the Mekong, areas of deep holes have been identified by local fishers and scientists alike, as being points of high fish density during the dry season, relative to shallower and faster flowing areas. Similar refuges are known to exist in at least some of the major tributaries. Satellite imagery, topographic information and anecdotal reports, indicate that wet season flooded areas upstream of Kratie are largely associated with tributary floodplains. Flooding in the lower areas of these tributaries, near their confluences with the Mekong, is significantly contributed to by backwater flooding from Mekong mainstream as much as by the tributarys' own flows.

For many species, the migrations undertaken at the commencement of the wet season are an essential component of an annual breeding cycle, the success of which is determined by at least the following two factors:

- The ability to move upstream along the Mekong mainstream and tributaries, without impediment by physical barriers; and

- The extent of inundation in the wet season 'destination' areas to which the migrations are directed towards.

In view of these two factors, an index is proposed that computes potential LMB fish yield, upstream of Kratie, for different scenarios on the basis of impacts per linear length of stream. Impacts affecting the first factor are those that physically block fish, such as the construction of weirs, dams and barrages. Where such structures are built it can be assumed that no fish migration is possible upstream of that location and that the habitat that was once available is no longer accessible during migrations. Natural capture fisheries upstream of new dams can be assumed to be much reduced because of the lack of migration. A 90% reduction upstream of dams is assumed.

Importantly, the potential additions to fish yield from the new reservoir fisheries themselves are not included at this time, even though they may more than compensate for the reduction in upstream river fish yields. Figures for unit area productivity of reservoirs differ markedly for different dams and in any case are generally expressed as yields per unit area. The actual areas of the proposed storages are not known and can not be computed from the known (or assumed) active storage volumes that are included in the DSF models. This is an area of study for the future.

The second factor, extent of wet season inundation, can not be measured directly at present by the DSF or any other available tool. A surrogate indicator is the partial-volume indicator of floodplain flooding, presented in section 0 above. It measures the volume of flow above a particular threshold, the 20% exceedance level being chosen because it represents flooding that occurs, on average, for about two and half months each year; a period that is assumed to be long enough for fish to undertake migratory feeding and breeding behaviour. It also roughly corresponds with the flood durations that have been reported for a few areas, such as the lower Song Khram.

The partial volumes are computed both for primary mainstream monitoring sites, as well as for sites at the downstream end of each major tributary. The ratio of the Development Scenario partial volume to the Baseline Scenario partial volume becomes the factor by which the fish yield per unit length of river is reduced in that river reach.

Please refer to Beecham and Cross (March 2005) for details about the methodology and background information used to derive the capture fisheries values.

In summary, the only factors assumed to impact on capture fisheries are:

- The physical barrier affect of dams to longitudinal upstream fish migrations; and
- The potential changes in wet season flooded area, as 'represented' by changes in the flow volume above the 20% exceedance flow.

Table 9.10: presents the capture fisheries potential annual yields for each scenario and the difference to the Baseline conditions.

Table 9.10: Capture fisheries upstream Kratie – potential annual yields

Scenario	Capture Fisheries Effective Length Ratio (ELR)	Potential Annual Fish Yield (t/yr)	Yield relative to Baseline (t/yr)	Yield relative to Baseline (%)
BDP Scen 1: Baseline	0.720	985,289	-	0
BDP Scen 2: China Dams	0.696	951,776	- 33,513	-3
BDP Scen 3: Low Development	0.699	956,055	- 29,233	-3
BDP Scen 4: Irrigation Development	0.699	955,654	- 29,634	-3
BDP Scen 5: High Development	0.584	799,142	- 186,147	-19
Natural annual fish yield:	(985,289/0.720) =	1,367,842		

Reservoir fisheries upstream Kratie

As for capture fisheries, the assumptions used to estimate the annual fish yield for reservoir fisheries are simplistic; being the product of fish yields per unit area (kg/ha/yr) and the maximum surface area of the storages. Only for a few reservoirs were fish data available, for the others an average value was adopted from the average unit-area yields determined by Nguyen Quoc An (2001[i]) for different regions in Viet Nam (derived from 768 reservoirs). For each reservoir, these unit-area values were multiplied by the maximum reservoir surface area, which without exception could be expected to be reached every year at some point during the wet season. This maximum area is therefore assumed to be the 'driving factor' for annual reservoir fish production.

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[i] Nguyen Quoc An (2001). Effectiveness of Stocking in Reservoirs in Viet Nam.. ACIAR Proceedings 98, Reservoir and Culture-Based Fisheries: Biology and Management, p235 – 245. Workshop held in Bangkok 15-18 February 2000. 384 pages. Table 1, p236

Table 9.11: Reservoir fisheries upstream Kratie – potential annual yields

Scenario	Reservoir Fisheries			
	Total Reservoir Area (ha)	Potential Annual Fish Yield (t/yr)	Yield relative to Baseline (t/yr)	Yield relative to Baseline (%)
BDP Scen 1: Baseline	89,997	14,917	0	0
BDP Scen 2: China Dams	89,997	14,917	0	0
BDP Scen 3: Low Development	150,457	22,474	7,558	51
BDP Scen 4: Irrigation Development	150,457	22,474	7,558	51
BDP Scen 5: High Development	396,457	53,224	38,308	257

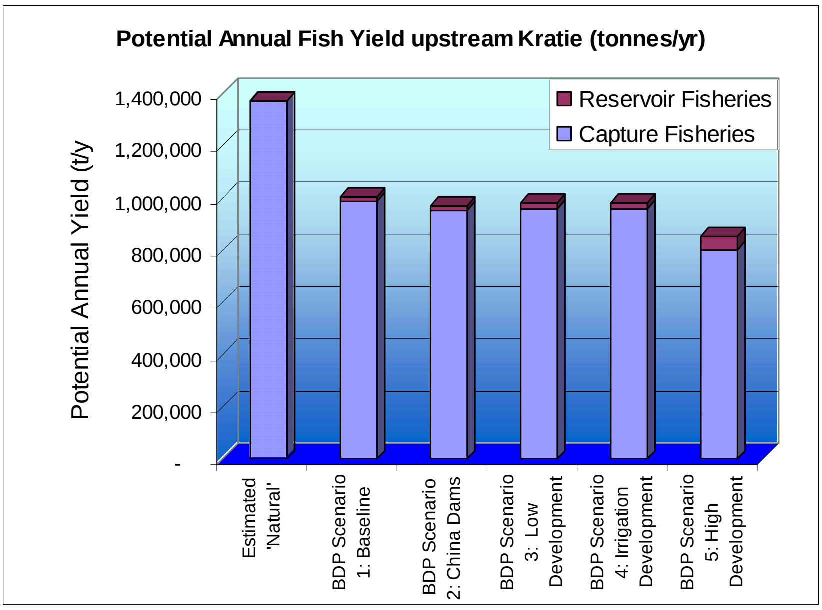
Total fisheries upstream Kratie

The total estimated potential annual yield is the sum of the capture and reservoir fisheries yields. Figure 9.10 demonstrates that of the two components, it is the capture fisheries that dominates the fish resource upstream of Kratie and that reservoirs have limited capacity to replace diminished yields from capture fisheries.

Table 9.12: Total potential annual fish yield – upstream Kratie

Scenario	Total Potential Annual Fish Yield		
	Potential Annual Fish Yield (t/yr)	Yield relative to Baseline (t/yr)	Yield relative to Baseline (%)
BDP Scen 1: Baseline	1,000,756	-	0
BDP Scen 2: China Dams	967,243	- 33,513	-3
BDP Scen 3: Low Development	979,080	- 21,676	-2
BDP Scen 4: Irrigation Development	978,679	- 22,077	-2
BDP Scen 5: High Development	852,917	- 147,839	-15

Figure 9.10: Potential annual fish yield upstream Kratie; sum of capture and reservoir fisheries



Potential annual fish yields downstream Kratie

If certain assumptions are made, a measure of changes in potential fish production can be made. Such a measure requires that a functional relationship be proposed between the key drivers of production and fish production.

The study by Dubeau *et al* (2001) referred to in the previous section provides estimates of annual fish productivity per hectare. This indicates that an indicator of fisheries annual productivity might be derived that is the product of flooded area and fish productivity per unit area.

The study used two methods to estimate the annual fish and aquatic animals yield per hectare, based on catch data from Fishing Lot No.18 and Piem Chumniek Canal, on the Tonle Sap River floodplain in Kampong Tralach District which covers 82.5 km^2 (8,252ha). First, an estimated mean catch per fisher was calculated from a sample of fishers that kept diaries of their catch amounts each day for a year. These were then applied to estimates of the total number of small-scale fishers in the study area to compute an estimate of the total annual catch of the small-scale fisheries. To these values were added the annual catches from two commercial fishing lots, to give the total annual fishing catch for the study area.

Using these assumed total catch figures and considering all areas flooded more than 0.1m deep, including "flooded upland rice", produced the following estimates:

- Estimate A: 392 – 532 kg/ha/year "rough" estimate
- Estimate B: 243 – 281 kg/ha/year "more accurate" estimate

The range in each estimate is a function of differences in assumed number of fishers, ranging from the lowest to highest values. Estimate A used less accurate fish catch estimates based only on the number of active fishers on an annual basis, whilst Estimate B used more sophisticated methods that reflect numbers of active fishers by month, and seasonal variations in fishing practices, including fishing effort. Accordingly Estimate B values provide a more accurate and conservative set of production values, which according to Dubeau *et al* (2001) are comparable to productivity values in Bangladesh.

The authors of the study in comparing these values to other tropical areas, such as Bangladesh, indicate that the high productivity may not be solely a function of the inundated area analysed, but that fish may enter from adjacent areas. Given that the study area is on the floodplain of the Tonle Sap River and subject to flows exiting Tonle Sap Lake, this would appear to be a valid concern. Additional weight to this concern is that depths as low as 0.1m were used (flooded rice areas), which may not be useful to many fish. In fact Dubeau *et al* (2001) report that Bangladeshi studies have shown greater productivity for deeper areas (>1.8m). Rather than depth per se being important, this might indicate a relationship with flood duration, as deeper areas at the peak of the flood are naturally also those areas that are flooded the longest.

Advice from Hortle (pers com), however, indicates that there may be a degree of over estimation in even the lower Dubeau *et al* values; the fishers surveyed apparently are "above average fishers" and therefore may not be appropriate to use as examples of "typical fishers" from which to extrapolate to the whole population of fishers in the study area.

Hortle proposes a set of alternative average yield values, based on the spread in the literature:

- Low: 75 (50-100) kg/ha/yr
- Medium: 125 (100-150) kg/ha/yr
- High: 200 (150-250) kg/ha/yr

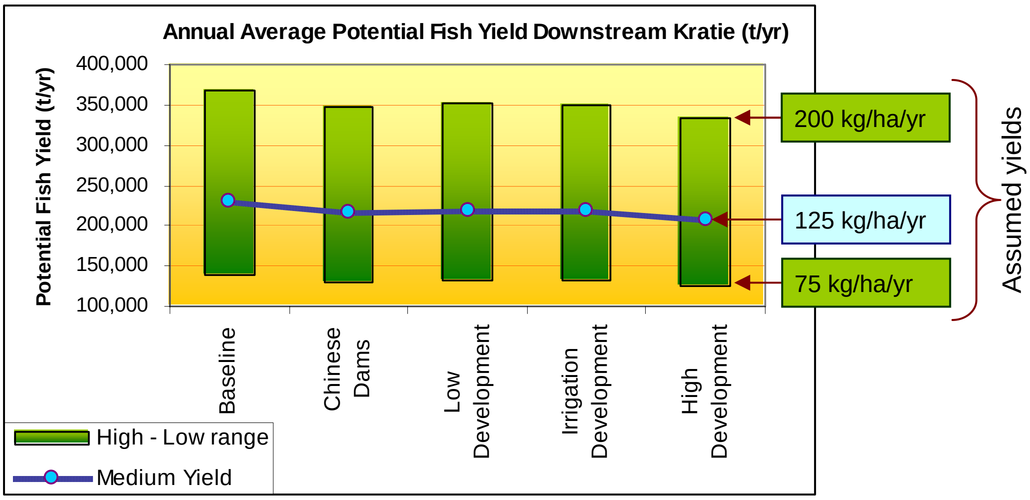
Application of this value to the whole inundated area downstream of Kratie could therefore provide a measure of total potential fish yield. Changes in this value between scenarios could then be used as an indicator of the scale of changes in fish (and aquatic animal) catch. Attachment of money values could extend the assessment to changes in the value of the fishery if the average value per kg of capture fisheries can be determined. Importantly, Dubeau *et al* (2001) observe that the peak flood levels, used in the calculation of their unit area productivity rates, occurred for not more than about 2 – 2.5 months.

The indicator of changes in potential annual fish catch downstream of Kratie are therefore based on:

- The average annual area flooded to greater than 0.5m depth for more than two months each year, but excluding areas flooded for more than 6 months (183 days); and
- Average yield values of 75, 125 and 200 kg/ha/yr for low, medium and high estimates respectively.

Changes in potential annual fish catch downstream of Kratie are presented in Figure 9.11 based on the annual area flooded greater than 0.5m depth for more than two months each year, but excluding areas flooded for more than 6 months (183 days).

Figure 9.11: Annual average potential fish yield downstream Kratie (t/yr); 1996 – 2000



There is relatively little change between each development scenario; Chinese Dams and High Development show the largest reductions at 5.8% and 9.7%, respectively. The impact of the second of the two additional dams in these scenarios (which is not present in the other scenarios) are the cause of the high impact through there greater reductions in flood peaks and duration.

9.7 Environmental maintenance

Wetlands in Cambodia

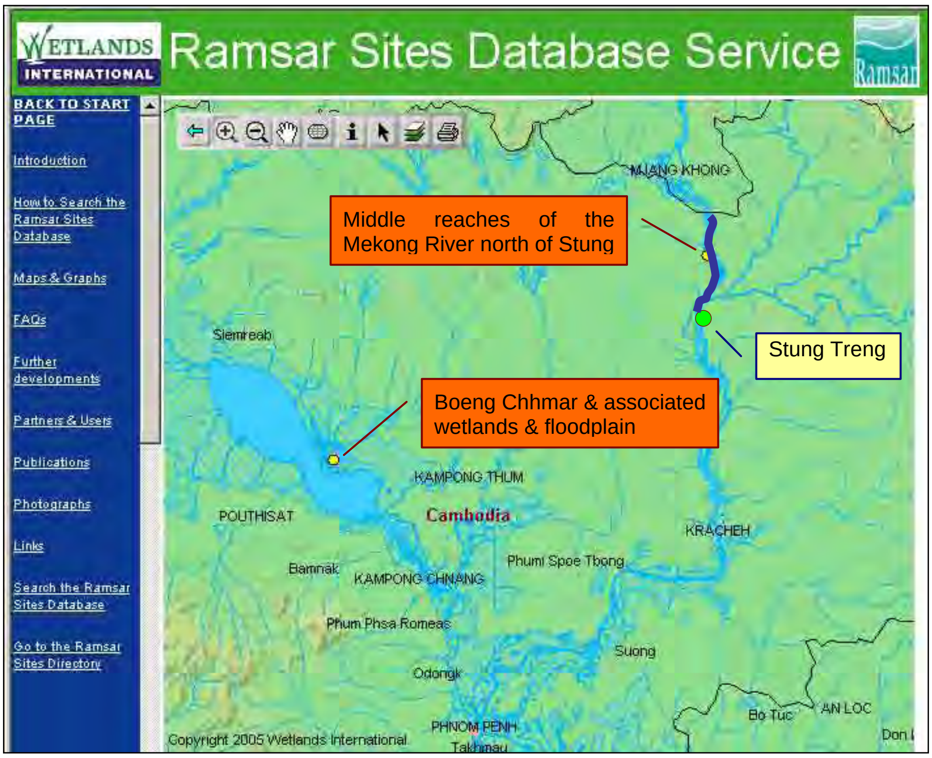
Within each of the four member countries are wetlands of national and/or international significance, including some that are listed under the *Convention on Wetlands of International Importance*, i.e. the 'Ramsar' convention, and the "Convention on Biodiversity".

Two of the three Cambodian listed Ramsar sites are associated with the Mekong River and floodplain. The "Middle reaches of the Mekong River north of Stung Treng" is the first of these and covers the river reach between the Lao – Cambodian border downstream to Stung Treng, at the confluence of the Se Kong and Mekong. The other is "Boeng Chhmar & associated wetlands & floodplain", located on the northern side of Tonle Sap Lake.

Issues relating to the hydrological regime of the Stung Treng site can be resolved by reviewing the results of the hydrological analyses, particularly the changes associated with the dry season months which are likely to be of greater consequence for the ecological functioning of this area.

Similarly, changes the hydrology of the Boeng Chhmar site are driven by water level changes in Tonle Sap Lake. Both the peak wet season water levels (depth and duration) and the dry season water levels will impact the its ecology. Consequently, review of changes to those parameters in the relevant sections of this report will provide an indication of the relative impacts of each scenario.

Map 9.19: Location of Ramsar listed wetlands of international importance in Cambodia



Middle reaches of the Mekong River north of Stung

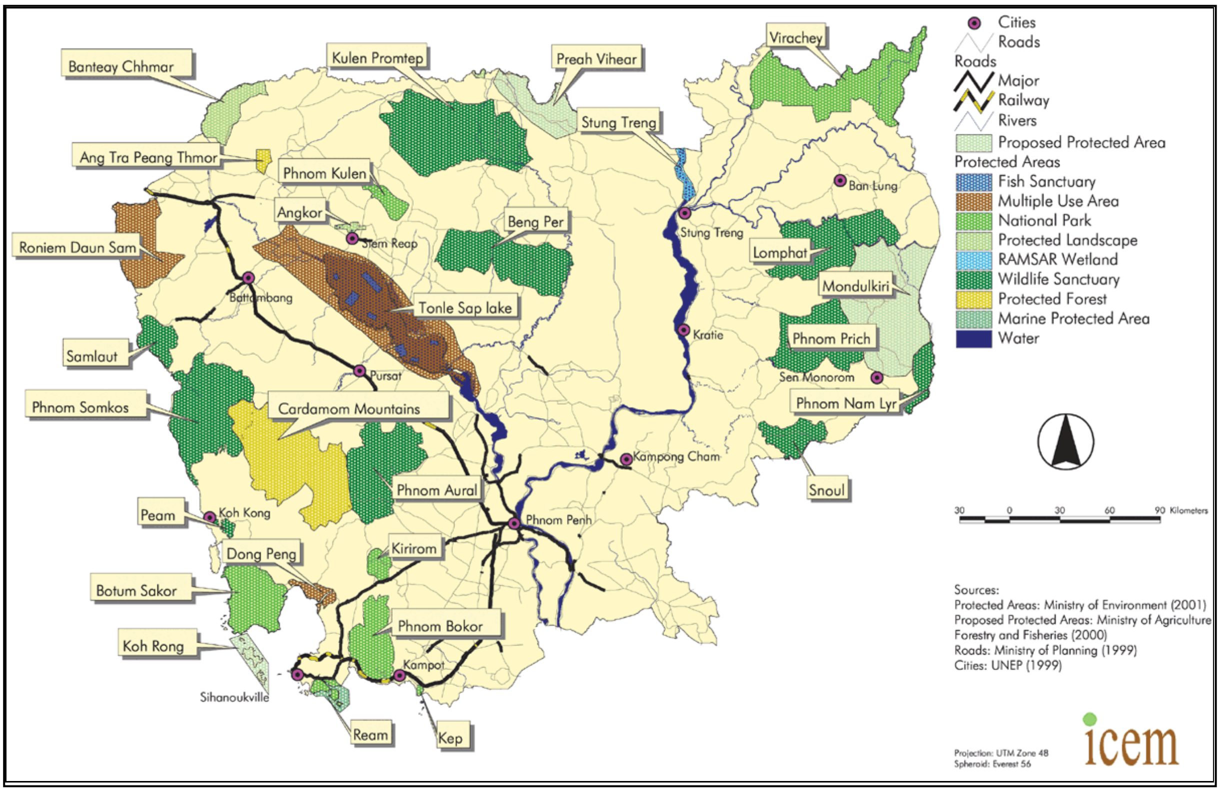
Stung Treng

Boeng Chhmar & associated wetlands & floodplain

(http://www.wetlands.org/RSDB/Default.htm)

Cambodia has other conservation sites of national significance shown in the protected areas system map in Map 9.20. These include the Ramsar sites, as well as fish sanctuaries in the Mekong River and in Tonle Sap Lake, as well as a multiple use area over the whole of Tonle Sap Lake, including much of the area that becomes flooded in the wet season. As indicated above, impacts on these areas can be explored through the hydrologic indicators used for the wet and dry seasons.

Map 9.20: Protected area system in Cambodia



Sources:
Protected Areas: Ministry of Environment (2001)
Proposed Protected Areas: Ministry of Agriculture Forestry and Fisheries (2000)
Roads: Ministry of Planning (1999)
Cities: UNEP (1999)

Projection: UTM Zone 48
Spheroid: Everest 56

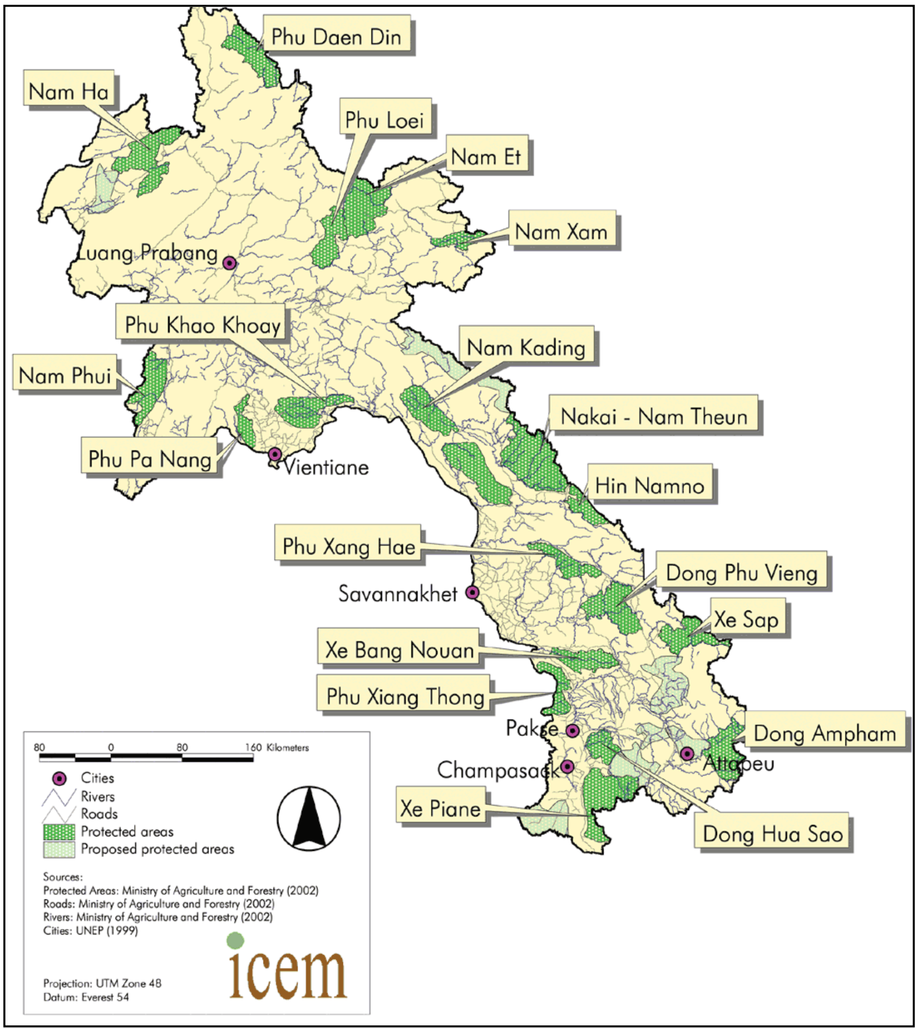
(http://www.mekong-protected-areas.org/cambodia/pa-map.htm)

Wetlands in Lao PDR

The protected area system of Lao PDR is shown in Map 9.21. For the most part, the Mekong River forms the left hand side of the country, except in the north west and extreme south west portions.

Nam Phui, Phu Pa Nang, Phu Xiang Thong, Dong Hua Sao and Xe Piane all front the Mekong River and thus are potentially subject to some impact from alterations to river flow, flooding and secondary geomorphic and ecological impacts. The hydrologic indicators for the mainstream monitoring stations can be used to establish the quantum of the hydrologic changes and to some degree the potential fish productivity changes reported for the whole area upstream of Kratie.

Map 9.21: Protected area system in Lao PDR

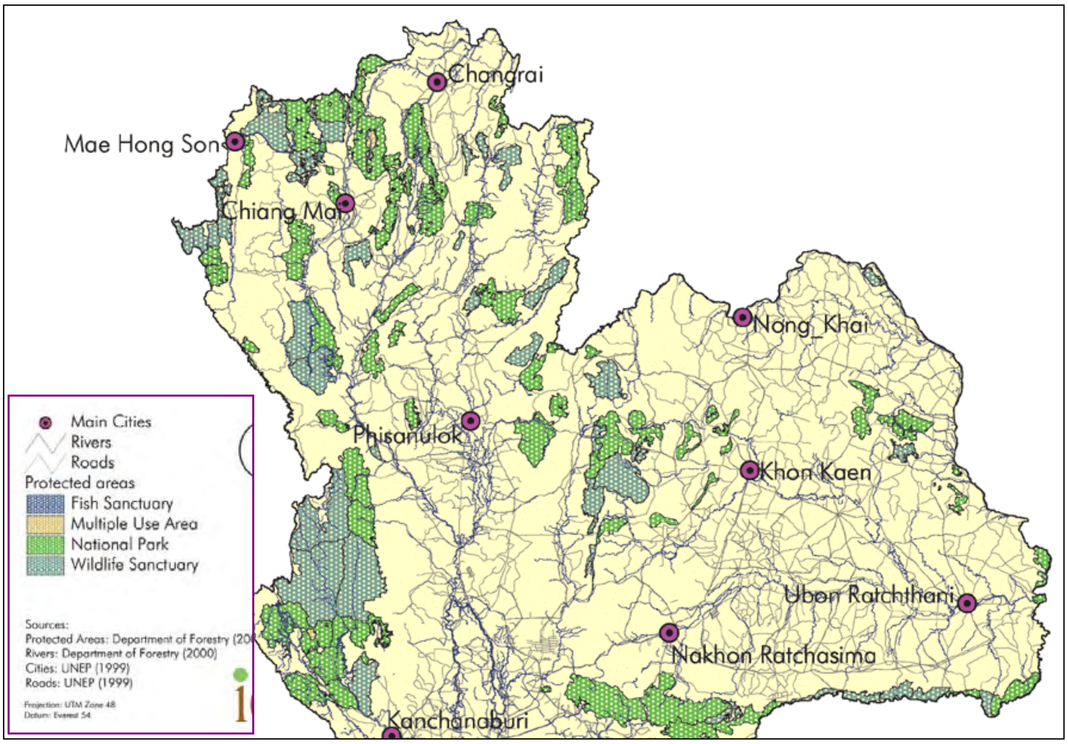


(http://www.mekong-protected-areas.org/lao_pdr/maps/pas.gif)

Wetlands in Thailand

The protected area system in the north east of Thailand is shown in Map 9.22. As with Lao PDR, a number of wildlife sanctuaries and national parks are located along the Mekong River for which the wet and dry season hydrologic indicators will provide an indication of the scenario impacts.

Map 9.22: Protected area system in Thailand



(http://www.mekong-protected-areas.org/lao_pdr/maps/pas.gif)

Wetlands in Viet Nam

A map of the protected area system in Viet Nam is not available. However, one of the main conservation areas in southern Viet Nam is the "Plain of Reeds", located towards the Ho Chi Minh side of the upper delta. It has a high significance for water bird conservation, being one of the few remaining areas not converted to agriculture or other landuses.

Water management in the plain of reeds, whilst dependent largely on flows from the Mekong River in the wet season, to maintain its surface and groundwater hydrology, also can be manipulated via various control structures. Hence a detailed analysis of changes in its natural hydrology has limited utility without a commensurate account of the "typical' operational parameters. It is understood that water levels are deliberately maintained at high levels by the managers of the area to thwart dry season fires that otherwise would enter from adjoining lands. Concerns are held for the long term impact of such a constantly wet regime on the wetland vegetation that is central to its value for water birds and other bio-diversity conservation goals.

9.8 Wetland impacts

Impacts on the above wetlands can be assessed by reviewing the results of the hydrologic analyses.

Impacts on the riparian ecology of the Stung Treng Ramsar riparian wetland, composed of many islands, gravel bars and braided channels from Stung Treng to the Lao-Cambodian border, might be expected to be most keenly felt in the dry season. For example, under the High Development scenario, the flow level increase of 0.66m at Kratie is of greater scale relative to the prevailing flow level of 6.4m, than the 0.60m decrease in the wet season, when flows are on average some 16m higher (Table 9.7). Such increases in dry season flow levels can directly inundate low lying gravel bars that might otherwise be used by wading water birds, or support vegetation that becomes a habitat and food resource when flooded in the following wet season. They are also accompanied by higher velocities and therefore stream power, which can change sedimentation patterns and prevent benthic spawning fish from breeding.

Minimum flow levels are elevated by similar levels for the Chinese Dams scenario and by 0.41m under the Low Development scenario. However, the higher level of irrigation extractions under the Irrigation Development scenario make nearly full use of the dry season hydropower releases, so that flows are increased only marginally (0.09m). Wet season changes for all the other scenarios are less than that for the High Development conditions. The Irrigation Development scenario has the next largest impact (-0.24m), presumably due to the impact of irrigation extractions, as it has the same level of dam development as the Low Development scenario and less than the Chinese Dams scenario.

The Boeng Chhmar wetlands on the north side of Tonle Sap Lake are similarly affected by both dry and wet season lake level changes. The duration and extent of flooding are critical to fish productivity and to the maintenance of wetland vegetation patterns. Firstly, it is noted from Table 9.9 that all development scenarios lead to a reduction in wet season peak annual lake levels, averaging as much as -0.36m for the High Development scenario, but generally about -0.20m for the other scenarios. However, reductions in dry years are much greater, as reflected in the higher level of reduction in flood area in the dry year of 1998 verses the wet year of 2000, shown in Table 9.10.

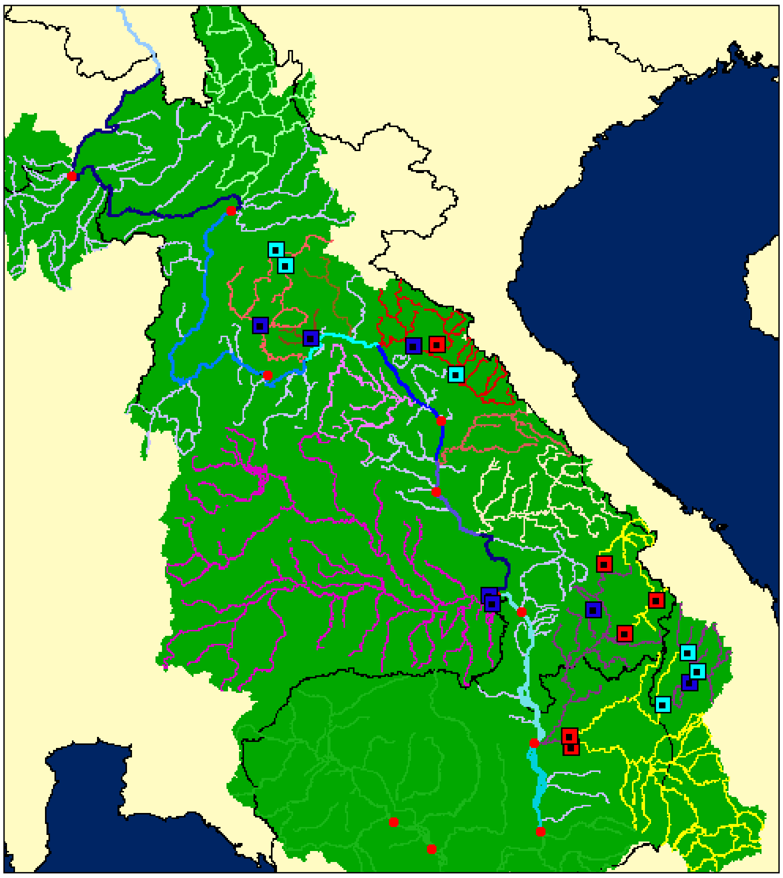
As can be seen from the maps showing scenario changes in flood durations (Maps 9.13 to 9.16) some scenarios (Irrigation Development) result in shorter flood conditions at the Boeng Chhmar wetland site, whilst others created longer flooding (Chinese Dams and High Development). The Low Development scenario creates a border line situation at the site; slightly wetter on the lake side and drier on the landward side. The histogram of year 2000 flood duration changes in Figure 9.5 summarises the scale and direction of changes in flood duration; High development creates the wettest conditions and Irrigation Development, the driest. Whilst these figures are for the whole area downstream of Kratie, the changes are indicative of what would be experienced at the Boeng Chhmar site.In the scenarios having shorter flood durations, the effect will be to lead to a gradual shift in wetland vegetation structure from wetter types to those more typical of the drier conditions. The type of vegetation that may eventually arise could be interpreted from an analysis of existing wetland vegetation at a location which currently experiences similar durations to those that would be created by the scenario. The converse is true of wetter conditions.

Research and modelling by the WUP-FIN project indicate that sediment inflows to Tonle Sap Lake, from the Tonle Sap River annual flow reversal, are vital to the level of primary productivity and hence fisheries productivity and environmental maintenance generally.

Boeng Chhmar wetland is located sufficiently far east to benefit from this plume of suspended sediment and conceivably would be negatively impacted by any reductions in the reverse flow volume.

All four development scenarios reduce the flow reversal volume at Prek Kdam (Table 9.9), in the case of the High Development scenario, by as much as 11.6% relative to the Baseline. The least change, around 6% is caused by the Low Development and Irrigation Development scenarios, whilst the Chinese Dams scenario reduces the reverse flow volume by 8%. Nutrient bearing sediment loads could be expected to decreases in a more or less linear way with these flow reductions.

Changes in flood duration in the Vietnamese Plain of Reeds wetlands share a similar pattern to those at Boeng Chhmar. As mentioned in section 2, however, those changes will be ameliorated or exacerbated by the ability to regulate local water levels. In this regard, the reductions in flood durations are likely to have a greater impact, as longer flood durations are effectively being overwhelmed by the ability, and general practice, of holding water in the area for longer than naturally occurs. Shorter flood durations may lead to less water, reducing the managers' ability to maintain the higher than natural dry season water levels. Whether this is good or bad for the wetland depends not only on the direct effects of altered hydrologic regime on vegetation and ecological processes, but also on the success or otherwise of fire management.



10 Implications of development scenarios

by Richard Beecham and Hugh Cross,
March 2005

10.1 Implications for sustainable development

10.1.1 Defining sustainability

Significantly, the "Agreement of the cooperation for the sustainable development of the Mekong River Basin" (5 April 1995) contains the term "sustainable"; unambiguously and inseparably linked with the goal of development. By that action, and in the specific provisions of the Agreement, the four member countries have agreed to further each other's goals for national development in a cooperative manner through developments that will provide sustained benefits in the long term, whilst avoiding or mitigating detriments, as well as protecting the environment.

Elsewhere in the agreement, there are numerous, and at times, overlapping, provisions for the protection of the environment, founded on one of the core tenants of the Agreement, the recognition that the natural resources and environment of the Mekong River Basin "are of immense value to all the riparian countries for the economic and social well-being and living standards of their peoples".

Sustainability then, in the context of the riparian countries aspirations and needs for development, might be defined as:

- Developments that deliver benefits over the long term without diminishing the natural resource base; and

- Development that do not significantly damage or degrade the environment, including maintenance of the ecological balance.

In short, the benefits of development overall, in the long term, should be greater than any losses that might be caused. How might this concept of sustainability be implemented in the assessment of the level of future basin development plans? In practical terms such planning assessments require the application of agreed criteria to selected indicators. Indicators that are relevant to the key issues of concern, such as the maintenance of particular flow characteristics set out in Article 6 of the Agreement, or the maintenance of fisheries and navigation potential. Agreed criteria that represent the limits of acceptable change; either for socio-economic reasons, or because of the assumed level of tolerance of natural ecosystems to particular changes. These criteria, collectively, might be interpreted as defining the "sustainable space".

It is beyond the purpose and scope of this report to define the criteria by which to judge the sustainability of developments. That is for the riparian countries to decide. However, it is the purpose of this report to provide descriptions of the key environmental impacts that are likely to arise from different levels of basin development. These descriptions can be used by basin planners to guide their assessment of particular developments or basin development plans. Whilst separately, and in aggregate, those developments will be unlikely to match the scenarios presented here, planners need only "map" the level of development associated with their planning scenarios to these scoping scenarios. The likely environmental impact can be assumed to have a similar level of correspondence, providing the nature of those interventions are truly similar.

10.1.2 Water management requirements

Water management can be supported by the following essential components:

(i) An agreed set of measurable management objectives that address the needs of all relevant stakeholders

(ii) A scientific factual understanding of the systems to be managed

(iii) Free and open exchange of information on system condition, usage levels and impacts

(iv) Clearly established property rights and good governance of those rights, with respect to the major natural resource assets, including land, water, fisheries/ wildlife/ forests, and minerals

(v) An ability to monitor system condition and respond in a timely manner through shared collective responsibility by different agencies and stakeholders

(vi) An ability to adapt management and usage levels, to respond to system condition and changing levels or types of resource use

It is the purpose of this report to assist with the second and third of these requirements by providing descriptions of some of the core environmental impacts of concern to the riparian countries and their constituents. Indirectly, the report may also assist in setting targets and monitoring criteria that are relevant to timely monitoring and response (point “v”).

Actual implementation of integrated water resource management involves a more detailed set of considerations, including:

- Integrated assessment by multiple specialist disciplines related to water and water related resource management
- A minimum level of knowledge about current system condition
- A minimum level of understanding about how the system responds to changes imposed externally or that arise from internal processes
- An assessment of the apportionment and nature of property rights to establish who as the legal ability to make decisions about the use of particular resources or areas
- Identification of stakeholders and their needs, particularly those needs relating to the existing pattern of river flows and resources dependent on those flows
- Processes for engaging stakeholders to obtain information, ideas and needs, and to provide feedback
- Agreed mechanisms and criteria by which to assess the benefits and impacts of future developments
- Assignment of management responsibilities amongst stakeholders, both government and non-government

- Mechanisms for integrating management responses, including coordination of government agencies and other bodies, such as industry groups or community organisations, as well as owners of land, water or other property rights who have the ability to make resource use decisions

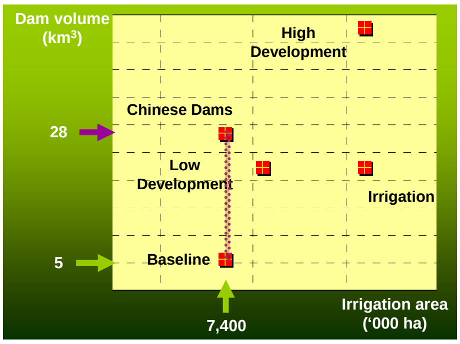
- Consistent application of good governance in effecting decisions at all levels

Again the methods and findings of this report can be seen to have potential for addressing a number of these matters.

10.2 Overview of implications

Commensurate with the scale of interventions assumed in each development scenario, the analyses reveal a level of impact that is clearly different in each case. For each scenario, the sections below provide a distillation of the analyses presented in Chapter 8.

10.2.1 Chinese Dams



Recalling that this scenario differs from the Baseline Conditions in only one respect, the addition of two large dams (and two small dams) in Yunnan province, upstream of the LMB, the resulting impacts are correspondingly simple. They are generally greatest in the upstream reaches, reducing downstream in proportion to the additional flow contributions by LMB tributaries.

Because the only interventions are in China, there are no changes in the amount of available hydropower or irrigated area in the LMB. Neither is there any change in the reliability of water supplies.

By raising the active storage volume from 5.5 km^3 to 28 km^3, this scenario reduces average wet season monthly flow levels by about 1.3m at Luang Prabang and 0.5m at Kratie, through the storage and routing effects. In fact peak wet season flow levels can be reduced by up to 1.8m at Luang Prabang, but by only 0.24m by Nakhon Phanom.

Water stored in the wet season serves to elevate the minimum dry season flow by about 1m at Luang Prabang and 0.6m at Kratie, although interestingly by only 0.37m at Pakse upstream. Compared to the wet season impact, this dry season change at Kratie is much greater, revealing the importance of upper Mekong River snow and glacial melt water contributions to the dry season flows in the LMB. Expressed as mean monthly flow, the increases in at Luang Prabang represent increases of up to 80% in some months, and even at Kratie are typically up to 40% higher than Baseline flow levels.

Wet season storage in the new dams also impacts the commencement of the wet season through reductions in the rising limb of the wet season hydrograph. Often the first flood peak is heavily impacted, whilst the second and any later peaks are less affected as the dams are by then full and often spilling. Delays in the commencement of the wet season are or considerable concern, given that it is these flows that trigger and make possible the conditions for longitudinal fish migrations by many "white" fish species.

Reductions in flow reversal volumes at Prek Kdam (6.3%), Tonle Sap lake levels (2.5%) and maximum flooded area (2.1%), are caused by the combination of reduced wet season and elevated dry season flows. The scale of those changes is unlikely to generate significant environmental impacts in their own right, but may warrant greater concern when considered together with other changes, including floodplain embankments and vegetation clearance.

Although raising minimum dry season flows at Tan Chau by only 0.08m, the nearly 25% increase in flow rate is adequate to reduce the duration of saline intrusion > 1 g/l in 1,230km^2 of the delta by over one month, and in 9,820km^2 by less than one month (in 1998). These areas represent 4% and 35% of the maximum saline intrusion area of 28,466 km^2, respectively, with consequent advantages for agricultural production.

Navigable days are improved by more than 10% from Chiang Saen to Pakse, more than half the length of the Mekong in the LMB. Whereas the Baseline failed to provide the target 300 days per year navigable days from Chiang Saen to Stung Treng, the Chinese Dams scenario achieves the target from Chiang Saen to Mukdahan.

Capture fisheries upstream and downstream of Kratie are disadvantaged by this scenario. Mainstream partial flood volumes, corresponding to assumed floodplain thresholds of inundation and thus fish habitat availability, are reduced by nearly 50% at Luang Prabang, nearly 30% at Nakhon Phanom, nearly 20% at Pakse and 11% at Kratie. However, partial flood volumes for the tributaries within the LMB retain their Baseline values, so the impact is restricted to the Mekong's own floodplain and any areas of the tributary floodplains that are flooded by backwater from the Mekong, such as is well known for the Song Khram.

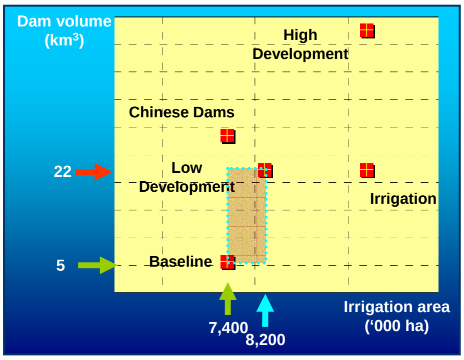
The Habitat Availability Index (HAI) downstream of Kratie displays similar, albeit smaller, changes. The average reduction of 7% can be as much as 16% in a year such as 1998, which over the 15 years from 1985 to 2000, represents slightly less than the median flood year. This despite the maximum average annual flood extent downstream of Kratie being reduced by only 3%. Such large changes in inundated floodplain habitat availability can only have negative consequences on capture fisheries both upstream and downstream of Kratie.

Based on simple assumptions about the impact of hydrologic changes and the barrier effect of dams, the potential annual fish productivity analysis suggests a relatively minor 3% reduction in capture fisheries upstream of Kratie. The combined length of numerous un-impacted tributaries ameliorate the impact of mainstream flow changes, as measured by the partial flood volumes discussed above.

Impacts on capture fisheries downstream of Kratie, due to changes in area flooded > 0.5m for more than two months (but less than 6 months), suggest a slightly greater reduction in mean annual fish yield of 5.8%. However, the period of the analyses differ; upstream of Kratie the period 1985 – 2000 is used, whilst downstream of Kratie, the productivity estimate is based on the period 1996 – 2000 only. Therefore direct comparison is not appropriate. It is also worth noting that in a drier year, such as 1998, the reduction in fish yield can be 18%, very much higher than the average change over the six years.

Finally, potential flood impacts on crops within Cambodia and Viet Nam, as assessed against their predominant crop type, are reduced by only 1% (1996) and nearly 5% (year 2000), respectively. With the exception of the Irrigation scenario, the Chinese Dams scenario offers the greatest reduction in potential crop damage.

10.2.2 Low Development



Compared to the China Dams scenario, the Low Development scenario has only one extra large dam (Xiaowan; 9.85km^3) in China, rather than two. However, it also assumes an additional 6.18 km^3 active storage from new dams in the LMB, bringing the total to 22 km^3. Irrigation, which in the Chinese Dams scenario was unchanged from the Baseline, is increased by another 800,000 ha, or 11%. These conditions simulate what might be the most probable level of development in the year 2010.

Hydro-power generated under this scenario trebles in Lao to 12,194 Gwh (giga-watt hours) per year, whilst it doubles to 5,974 Gwh in Viet Nam. These benefits are augmented by an increase in irrigation diversions of 13% overall. Only in two areas were the reliability of supply reduced due to an excess of demand over river flows; north east Thailand in sub-area 2T and in the Great Lake area. However, both these results are subject to strong qualification, the first due to lack of information on existing dams in Thailand and in the second, due to model limitations in representing all available water sources.

The elevation of minimum monthly dry season flows at Luang Prabang (+14% in March) is typically only half compared to that caused by the Chinese Dams scenario; commensurate with the smaller amount of additional active storage. However, the increases at Kratie (+19% in March) are somewhat larger due to receiving hydropower releases from the additional LMB dams further down the system. Changes in the minimum mean annual water levels reflect a similar pattern, ranging from +0.5m at Luang Prabang to + 0.41m at Kratie. By Tan Chau, however, the increase is only +0.03m, due both to the wide floodplain and the flood storage function of Tonle Sap Lake.

At Luang Prabang mean maximum annual flood levels are reduced by a smaller amount than in the Chinese Dams scenario; -1.16m (some 0.65m less). However, at all sites from Nakhon Phanom to Tan Chau the changes are almost identical, being within one to three centimetres.

Mean wet season volumes are reduced by about 3.2% at Kratie, slightly more than in the Chinese Dams scenario (-2.9%). Despite this, the reductions in mean Tonle Sap flow wet season reversal volume (-5.1%), peak lake levels (-0.2m) and maximum inundated lake area (-1.8%), are slightly smaller. None of these changes are likely to be of major concern in themselves.

Conversely, changes in the duration of flooding are larger. Some 64% of the total flooded area (Baseline conditions, year 2000) experiences flooding that is up to one month shorter in duration, compared to 43% under the Chinese Dams. And whilst the latter increased flooding by up to one month in 13% of the area, the Low Development only increases it in 3%. The higher levels of irrigation extraction in the dry season and transition months explain both these reductions.

The effects of these dry and wet season flow changes on saline intrusion is similar to the Chinese Dams impacts, but the reduction in salinity durations >1 g/l affects a smaller area; 29% of the total area subject to saline intrusion, than in the Chinese Dams (35%). And whereas the latter did not increase salinity durations, this scenario does; in over 6% of the area, but by less than one month.

Navigability in the upper reaches of the Mekong benefit from the higher flows, but to a lesser extent than in the previous scenario. The target of 300 days is still not achieved in the reach from Chiang Saen to Nong Khai and whilst the improvement in the next from Nong Khai to Mukdahan is smaller, it does achieve the target duration. In the reach from Pakse to Stung Treng, there is almost no change from the Baseline condition.

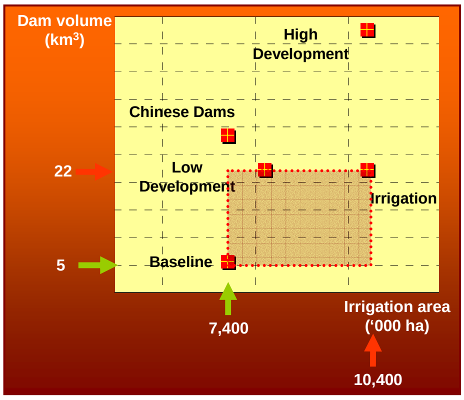
Changes in fish habitat availability, as indicated by changes in the partial flood volume, are similar to the Chinese Dams scenario at Nakhon Phanom and Kratie, but are smaller at Luang Prabang and Pakse. Impacts at the former two sites are similar, because of the effect of modified tributary flows caused by the new LMB dams countering the lower level of Chinese Dam development. Those changes are diluted further down in each case by other tributary inflows that do not have new dams on them. Downstream of Kratie, the HAI is on average 6% smaller than in the Baseline conditions and is almost identical to the Chinese Dams and Irrigation Development impacts.

The potential changes in capture fisheries upstream Kratie at -3% is the same as for all the other scenarios except the High Development scenario. Whilst offset by a 51% increase in reservoir fisheries over Baseline conditions, the total catch (capture and reservoir fisheries) still records a 2% decline (cf. -3% for Chinese Dams). Downstream of Kratie, the mean annual potential capture fisheries yield (1996 – 2000) decreases by 4.5%, compared to -5.8% for the Chinese Dams, but is -14% in 1998.

Potential crop flood damage (1998) is just 1.2% less in Cambodia and 4.1% less in Viet Nam (year 2000), than Baseline conditions; a very similar outcome to the High Development scenario.

10.2.3 Irrigation Development

This scenario explores the impacts of non-balanced development, where irrigation development proceeds in advance of commensurate increases in hydropower dam construction. To achieve this, the level of Chinese and LMB dams are held at levels assumed in the Low Development scenario, whilst the level of irrigation development is increased to very high levels, such as might correspond to high estimates for the year 2020.



With no change in LMB or Chinese dams, the level of hydropower generated is the same as for the Low Development scenario. However, benefits from increased irrigation will be markedly higher, corresponding to the 40% increase from 7.4 to 10.4 million hectares. The increase is not directly proportional, however, due to the reduced reliability of supply stemming from demand exceeding supply in irrigation projects taking water from tributaries rather than the Mekong mainstream. Such reductions in reliability are experienced in sub-areas 3T, 5T and 9C, although slight increases in reliability are also noted in some sub-areas in Lao (4L, 6L and 7L), due the improved dry season flows downstream of new dams.

Luang Prabang minimum monthly dry season flows are elevated by the same +14% in March as in the Low Development scenario because there are essentially no new irrigation areas upstream. At Nakhon Phanom, December, January, February and May, irrigation demands have lowered mainstream flows, relative to the Baseline, by up to 5%. A large part of this impact is due to the inter-basin diversions associated with the Nam Theun 2 development, that results in flows bypassing Nakhon Phanom. At Pakse the largest monthly reductions are only 3% due to the return of Nam Theun 2 flows via the Se Bang Fai and the ameliorating affect of unregulated tributaries downstream of Nakhon Phanom. The trend worsens again downstream of the confluence with the Se San – Se Kong - Se Pok system, where large scale irrigation reduces flows by up to 6%.

These reductions in monthly flows at the beginning and, to a lesser extent, end of the dry season, are not reflected in the changes occurring in the two driest months, i.e. March and April. In these months at all sites the flows are higher than the Baseline by between 2 – 8%, as a result of lower irrigation demands at these times. Dry season crops are reducing their water demands as they approach harvest and wet season crops typically are only beginning to be planted. Consequently, upstream of Kratie, March, April and May have the lowest irrigation demands in the whole year.

Changes in mean minimum annual water levels generally reflect a similar pattern, being unchanged at Luang Prabang, but are very much smaller at all sites downstream to Kratie, being only 4 – 9 cm higher than Baseline. At Tan Chau, however, levels decrease by 2 cm because of very much higher levels of Cambodian irrigation demands drawn from the mainstream.

At Nakhon Phanom and upstream, the changes in mean maximum annual water levels are almost identical to those in the Low Development scenario. At downstream sites the changes from Baseline are slightly greater, being -0.36m at Pakse and -0.24m at Kratie, some 4 cm and 6 cm lower than the Low Development scenario, respectively.

A reduction of 4.5% in the wet season flow volume at Kratie is matched by a 5.3% reduction in the mean Tonle Sap flow reversal volume, which is only slightly greater than in the Low Development scenario. Peak water levels on the other hand are reduced by a further 4 cm, bring the total reduction to 0.27m compared to the Baseline's mean annual peak water level. The peak Tonle Sap lake flooded areas is 2.2% less than the Baseline and that for the total area downstream of Kratie is 3%.

Flood durations again display greater changes than changes in peak water levels and areas, with 83% of the total inundated area in year 2000 experiencing reduced flood durations. However, as with the other scenarios, almost no areas experienced reductions greater than one month. In accord with the small elevations in dry season flows, and then only in March and April, almost no areas experienced increased flood duration.

The area experiencing increased salinity durations (> 1 g/l in 1998) is the largest of all the scenarios, i.e. 36%, including 1.5% which increased by longer than one month. This arises through the reduction in flows at the beginning and end of the dry season, as well as reduced wet season flows, particularly those at the beginning and end of the wet season which show similar trends to the aforementioned dry season months. Only 6% of the Baseline maximum saline intrusion area experienced shorter salinity durations.

A maximum increase in navigable days is achieved in the Chiang Saen to Nong Khai reach (29 days). Whilst this does not improve the Baseline situation sufficiently to meet the 300 day target, the 13 day improvement in the next reach from Nong Khai to Mukdahan, is just adequate to achieve this. From Mukdahan to Pakse there is no change, but from Pakse to Stung Treng there is a reduction of 4 days; the only reach in any scenario to achieve a negative result for navigability.

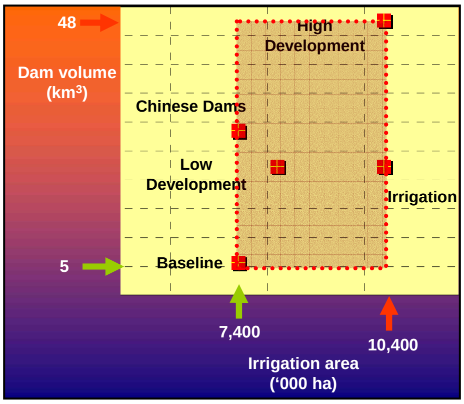
Changes in fish habitat availability from Baseline, using the partial flood volume index, differ by less than 3% from the changes note for the Low Development scenario. Downstream of

Kratie, the mean HAI for all years is worse by 1% at -7%. However, a reduction of 18% in the drier year of 1998 is noted with some concern.

Estimates of changes in capture fisheries upstream of Kratie are only -3%, unchanged from the Low Development scenario, as would be expected from the almost identical mainstream partial flood volumes. Reservoir fisheries area also unchanged, as the number and area of storages is the same. Downstream of Kratie mean annual potential fish yields are -4.9% compared to the Baseline, only slightly worse than the Low Development scenario. The largest annual reduction is achieved in 1998, where the yield is 18% less.

Reduction in the 1998 potential crop flood damage area is just 1.5% in Cambodia – midway between the Low and High Development scenario impacts. That for Viet Nam, 5.3% less than Baseline conditions (year 2000), is the best of any scenario.

10.2.4 High Development



This scenario represents the likely outer envelope of development by the year 2020. A total of 21 dams with 48 km^3 of active storage are imposed, of which 19 km^3 are from new dams on tributaries in Lao, Viet Nam and Cambodia. Irrigation development is 40% higher than in the Baseline and is the same as assumed for the Irrigation Development scenario.

Because the new dams in this scenario are largely in areas that do not benefit irrigation, there is no appreciable change in the irrigation diversion volumes and reliabilities from the Irrigation Development scenario.

LMB hydropower generation on the other hand is significantly higher, being a nearly five fold increase over Baseline levels (31,097 Gwh verses 6,945 Gwh).

Despite the high levels of irrigation, the elevation of minimum annual dry season flows under this scenario are second only to the Chinese Dams scenario, such is the level of redistribution of flows from the wet to the dry season. Indeed at Kratie and Tan Chau they are the highest at 0.66m and 0.09m, respectively. Flow increases at Luang Prabang are very similar to those generated by the Chinese Dams scenario because of the same level of dams in Yunnan province. Downstream of Nakhon Phanom, whilst March flows can be 24% – 33% higher than Baseline, the early dry season months experience smaller increases compared to the Chinese Dams scenario, a result of high irrigation demands in these months.

Of all scenarios, High Development results in the largest reductions in mean annual peak water levels. The reduction of 0.41m at Nakhon Phanom for instance is double that of other scenarios and increases to -0.56 and -0.60m at Pakse and Kratie, respectively. At Tan Chau the reduction of 0.17m is one third as great as that caused by the Irrigation scenario, the next highest. Even the impact at Luang Prabang (-1.93m) is 12cm greater than that for the Chinese Dams due to the Kok-Ing-Nam inter-basin diversion.

Wet season flow volumes at Kratie are reduced by 6.6%, some 2.1% greater than the Irrigation Development scenario. This results in a reduction of 10.9% in Tonle Sap flow reversal volumes, leading to a 36 cm reduction in lake levels and a 3.4% reduction in mean maximum Tonle Sap flooded area. For the entire floodplain area downstream of Kratie the inundated area is reduced by 5% on average.

For the year 2000, just under half the Baseline inundated area (47%) experiences flood durations > 0.5 m that are up to one month shorter than Baseline, whilst another 25% experience the exact opposite; flooding up to one month longer. The duration of flooding in another 3% is lengthened by more than one month. This pattern is similar to the Chinese Dams scenario, but the areas of both shorter and wetter durations is larger. The prime driver is the regulation imposed by large dams in Yunnan province, Xiaowan and Nuozhadu (9.9 & 12.4 km^3 active storage respectively), but augmented by additional regulation of tributary flows from another 19 km^3 of active storage in LMB dams. As was seen above, dry season flows are elevated, indicating that irrigation demands are smaller than the regulation imposed by the hydropower dam releases. This has the effect of increasing flood durations in low lying areas, whilst shorter durations in higher areas reflect the reduced flood heights towards the peak of the wet season.

Changes in salinity durations > 1 g/l match the above pattern of flood duration changes and are not dissimilar to the Low Development scenario. Year 1998 salinity durations are shorter by up to one month in 29% of the Baseline intrusion area and shorter by more than one month in nearly 4% of the area. This is offset by 8% of the area experiencing durations that are up to one month longer.

Overall, the improvement in navigable days is second only to the Chinese Dams scenario, to which it is very similar in scale and pattern. The upper two reaches spanning Chiang Saen to Mukdahan improve sufficiently to meet the 300 day navigation target, leaving only Mukdahan to Stung Treng failing. Smaller improvements are experienced in those reaches relative to the Chinese Dams scenario.

Reductions in fish habitat availability upstream of Kratie, as indicated by the partial flood volumes (1985 – 2000), are the greatest of any scenario. Reductions are never less than 23% (Kratie) and are up to 51% at Luang Prabang. Downstream of Kratie a reduction of 12% in the average annual fish HAI (1996 – 2000) mirrors the upstream impact. The drier year of 1998 displays a much higher impact, where the HAI is reduced by 22% and is perhaps more reflective of median flood conditions in the longer term, than the average of the period 1996 – 2000.

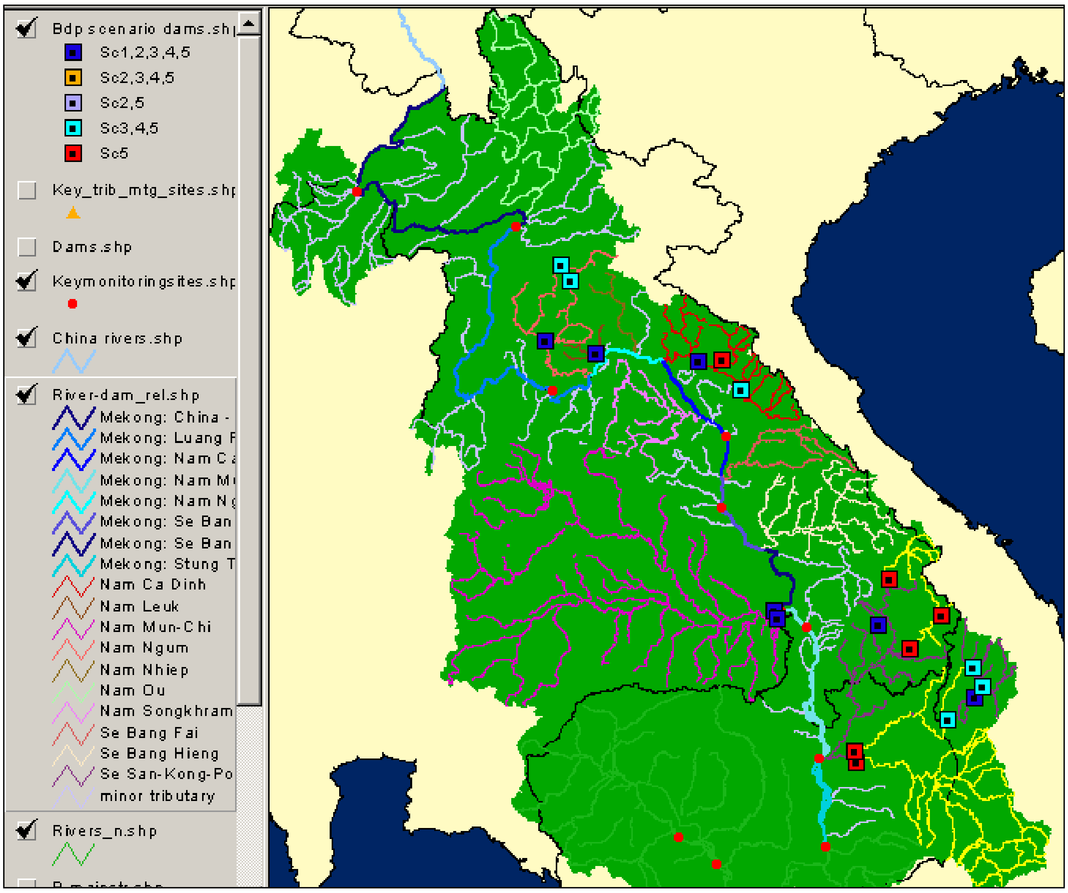
Capture fisheries upstream of Kratie exhibit a much larger reduction (19%) than any of the other scenarios (-3%) due to the large additional river length in the Se San and Sre Pok that is upstream of dams in this scenario (Map 10.1). The two large dams on the lower Se San and Sre Pok are only just upstream of their confluences with the Mekong, hence the entire tributary systems upstream are assumed to have yields just 10% of the natural yield. Additional reductions in both mainstream and tributary partial flood volumes in downstream reaches contribute to these impacts.

Although reservoir fisheries increase by 2.5 times over the Baseline, the extra 38,000 tonnes is insufficient to counter the assumed 186,000 tonne reduction in the 800,000 tonne capture fishery. The combined capture and reservoir fishery upstream Kratie is consequently 15% less than the Baseline.

Using the medium fish yield values of 125 kg/ha/yr, potential annual fish yields downstream of Kratie average 9.7% less than Baseline conditions, almost double that of other scenarios, but can be as much as 23% less in a drier year such as 1998.

Potential crop flood damage is just 3.1% less in Cambodia (1998) and 4.4% less in Viet Nam (year 2000), than Baseline conditions. The Cambodian improvement is the best any of the scenarios, whilst that for Viet Nam is a very similar outcome to the Low Development scenario.

Map 10.1 River reaches (yellow) upstream of High Development (Scenario 5) dams (red)



11 Issues and priorities

11.1 Opportunities

The following observations on development opportunities were made during the analysis:

- Elevation of dry season flows by Chinese and LMB hydropower dams provides benefits for:
    - Navigation
    - Saline intrusion in the delta
- The natural level of inter-annual variability in flow magnitude, duration and timing, provides some scope for changes in flows without generating substantial impacts on ecological processes or condition
- Return of irrigation tail water reduces the negative impacts of water extraction, if of adequate quality and if returned close the extraction point
- Changes of a particular magnitude, a 0.4m change in water levels for instance, have a greater proportional impact on prevailing dry season flow level than wet season flows, due to the greater flow depth in the latter season

11.2 Constraints

Major constraints include:

- High levels of dry season irrigation extraction, without compensating hydropower releases, which can lead to substantial reductions in dry season flows
- At the highest levels of irrigation development, the transition months, and even wet season flows, are impacted by the high level of irrigation water use
- High levels of irrigation extraction where return flows are not made close the point of extraction have a greater impact
- Inter-basin diversions can contribute in a cumulative manner to driving significant reductions in dry season flows
- Intra-basin diversions can cause significant reductions in dry season flows in the mainstream reaches by-passed by the diversion, for instance in the mainstream reaches between the diversions near Nong Khai to where return flows re-enter the Mekong at its confluence with the Nam Num near Pakse

- Tributaries will be more severely impacted than the mainstream by both irrigation extractions, and the impacts of dams on flow regimes and fish migration

- Changes in fish yield are directly linked to changes in wet season flows through the (assumed) linkages to inundated area and duration

- Salinity intrusion is closely linked to changes in dry season flows, which in turn appear to be coupled to the duration of wet season flooding

12 Solutions

No solutions are offered in the present document., which is intended for strategic decision-support as much as for specific identification of appropriate measures.

Recommendations on appropriate responses to the various hydrological and envoironmental implications will be addressed by the *'Strategic Directions for IWRM in the Lower Mekong Basin'* (in preparation, mid 2005).

13 Findings and recommendations/ lessons learnt

13.1 Adequacy of scenarios

The scenarios formulated and assessed for this study are only a small subset of a multitude of feasible scenarios. They were intended to estimate an envelope of flow and related impacts of macro level changes in water resources development that may occur over the whole Mekong Basin. The character of this work is a scoping study, i.e., to more or less define the boundaries of possible changes in the hydrologic regime, and positive and negative impacts of these changes on key sectors.

The context of this work is that it the initial comprehensive scenario analysis using the DSF done under the direction of the BDP Program, as well as with a wider involvement of the various programs in the MRCS. The information from these scenarios will hopefully be of use to the various stakeholder groups internal and external to the MRC, and will generate further interest in using and developing further details of elements of possible scenarios to fill in gaps in information they identify.

There are two aspects to possible information gaps. The first is what has not been included, and the second is what further analysis of impacts, and methods needs to be done. Some examples of the what has been included in the remainder of this section, and the second issue in Section 0.

Further elements that may impact the hydrologic regime include the following:

Land use change: The DSF was designed to be able to estimate the impact of land use change on water quantity and quality. Experience has shown that complex models claim to have this ability, but are seldom validated so that the uncertainty in the magnitude of estimated change can be reliably estimated. There are a number of reasons the affecting the DSF's capability in this area, and the use of it for this purpose needs to be undertaken with careful attention. Notwithstanding this, while the scale of afforestation or deforestation that is likely to occur in the Mekong Basin may have significant local effects, they are not likely to impact flow in the mainstream to the same extent as other scenario elements considered.

Climate change: This has the potential to significantly change runoff and crop water usage, and introduces a risk that need to be evaluated prior to making any large investment decisions. The capability of the DSF in this is affected is similar to that described for land use change. Sea level rises in the Mekong Delta may also need to be tested to test the robustness of conclusions for salinity and flood management.

Detail in North-East Thailand: Important water resources development in this region has not yet been included, and has limited the formulation of scenarios in this large part of the LMB.

Changes to irrigation management: Irrigation in the LMB is simulated as unregulated, with assumed efficiencies and return flow fractions, with no constraints on diversions apart from water availability. Changing crop mixes, improving efficiency, and regulating water partly for this purpose could be explored in parts of the LMB.

Cropping patterns in the Mekong Delta region: The level of development in the Mekong Delta is such that nearly all of the arable land is already under cultivation. Changes to crop types in parts of this region could be considered with an appropriate amount of consultation.

Impacts of small dams: Only six of the largest hydropower dams had been included by the end of the development phase of the DSF, where in reality there are hundreds or even thousands of smaller dams across the LMB that would have a significant cumulative impact, especially on dry season flows, and are important for the viability of irrigation areas

Use of groundwater: Groundwater yields and usage have not as yet been included in the DSF. These would not probably not significantly change flows in the mainstream, but may have important local effects for assessing water availability for Domestic and Industrial demands, as well as for high value crops such as horticulture and coffee.

Constraint on water usage: The various diversions in the model are operating without constraints apart from water availability. Physical access to water (i.e. pump placement) and current and potential operational restrictions (e.g., the Rules) may need to be investigated.

Provisions of instream flows: Outcomes of the IBFM may be to investigate operation of hydropower dams to store and release water taking into consideration environmental needs at key times.

Other possible scenario elements may include aquaculture requirements, large scale localised domestic and industrial water supply, and some localised water quality problems.

13.2 Scenario analysis capability

13.2.1 Technical

The DSF has adequate technical capability to undertake a scoping study. However to improve the robustness of some of answers, there is scope for improvement in the following areas.

Model calibration. As discussed in MRCS (2005), improvements were needed to the calibration of SWAT catchment inflows to the simulation model upstream of Kratie. Arithmetic modifications were made to these to improve the seasonal characteristics of the flow in the mainstream. However, these distorted tributary inflows. Model calibration needs to be reviewed.

Dry season inflow appear to be too low in some of the Great Lake sub-catchments, and should be reviewed to improve estimates of water availability for irrigation in this region.

The proliferation of small scale storages has implications for the observed hydrologic regime in tributaries, the resulting calibration, and also reliability of supply of water at crucial times. The aggregated effects of these should be considered as a process in the recalibration.

Level of detail in the Mun-Chi system needs significant upgrading to include the fifteen or so large dams and their operation, as well as other regulating and water supply infrastructure, to better estimate the regional impacts of intra-basin diversions, and impacts on reliability of water supply.

Cropping calendars in the Mekong Delta region need to be staggered to better represent the seasonal estimates of water demand, and to improve the reliability of flow related salinity estimates in this region.

The location and operation of salinity intrusion barriers in the iSIS model needs to be reviewed, and updated if necessary.

Additional years need to be simulated with the iSIS model to extend the sample size of results for flooding and salinity.

Further development of methods is needed to derive dam operation rules for hydropower operation.

Impact relationships, particularly for fisheries production need to be developed further.

Impact analysis tools used in this study, and others needed by stakeholder groups, need to be considered for inclusion in the DSF.

13.2.2 Institutional

The conduct of this study highlighted important issues other than technical. There is scope for improvement with Quality Assurance procedures as well as the relationship between the users of model results, and those producing the model results.

The simulation work necessary to analyse scenarios is quite complex. The region modelled is very large with a lot of detail of inflows, demands, diversions, storage, energy generated etc. For example, inflows are estimated at > 140 locations, and diversions at > 620 locations. The combined simulations produce literally tens of millions of numbers which were the raw results used to produce the tables, graphs and maps.

Naturally, with humans involved in the model configuration, results extractions, storing, processing and analysis, there are plenty of opportunities for mistakes. While every effort has been made to make these results mistake free, the reader should critically evaluate them before accepting them and using them for decisions.

This study has highlighted the need for developing Quality Assurance procedures in the modelling process. This naturally involves some level of documentation of sources of data used in the DSF simulation; and changes to the configuration and/or calibration of the model, and the justification for these changes. Results of the work also need to be critically checked internally prior to distributing them. Checking at the very least needs to get the direction of change and order of magnitude of the change correct, before looking at some of the finer detail or more subtle effects.

The technical person undertaking the modelling needs to be confident that the results are correct prior to distributing them, and they should take steps to make these checks internally. During the course of this work, results appeared that did not correspond with the modeller's preconceptions. In some cases these were incorrectly analysed results, in other cases the modeller's did not fully understand the complexity of the system, and the results were in fact correct. In all cases, the modeller should be able to be confident in the results, and to explain whatever changes are shown.

The second important issue is the institutional. The use of the DSF by the planners and modellers at the MRC is at a comparatively early stage. The MRC has a powerful analytical tool at its disposal which needs to be utilised and developed more to provide the information necessary for IWRM. The sustainable use of these tools requires greater involvement by MRC as a whole. The various programs need to drive the modelling process so that it meets their information needs, and to strengthen the links between the program management, and the technical capacity.

14 Relevance

14.1 Relevance for NMCs and/or line agencies

Knowledge about the present and future water availability is highly relevant to any water-related decision-making. The same is the case for knowledge about basinwide and inter-sector implications of water utilisation and water management. The better the knowledge, the better the decisions.

The DSF and the DSF-based analyses contribute to such knowledge. The modelling tools and the results of the various analyses are available to the NMCs and the various line agencies for in-house application, in support of strategic policy formulation and decision-making.

14.2 Relevance for MRCS and/or BDP Phase 2

The DSF serves as the shared platform available to the various MRC programmes for examination of inter-sector dependencies and cause-effect relationships. The DSF can indicate opportunities and constraints that would otherwise remain undetected, and is available for sensitivity analyses and parameter studies within a broad range of applications that are relevant to MRC and its programmes.

Linked with basinwide monitoring and basinwide indicators, and with incorporation of new knowledge (and new development issues), the DSF can expand into a powerful yet practical instrument for transparent and consistent analysis.

Within BDP Phase 2, DSF-based analyses can comprehensively support the consolidation of the BDP Planning Atlas. Also, DSF-based analyses are highly relevant in connection with State of the Basin reporting.

15 Concluding general outlook

The analyses presented in this report provide the best information that is available about the future water availability in the Lower Mekong Basin. This information should be maintained and developed.

The work should be done in a continued close collaboration among the MRC programmes, the NMCs, and the national line agencies. Also, there is a scope for expanded collaboration with various institutional stakeholders, as well as with development agencies that operate in the region.

This will contribute to well-informed, timely and appropriate strategic directions at all water management levels, in support of the MRC vision of *'an economically prosperous, socially just and environmentally sound Mekong River Basin'*.

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