

The MRC
Basin Development Plan

MRCS Decision Support Framework (DSF) and BDP applications

BDP Library Volume 7

March 2005
Revised September 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 The work was done from 2002 to 2005, and some information may already have been superseded by new developments and new knowledge.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 DSF-based 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 work involved comprehensive technical and financial support from the Murray-Darling Basin Commission (MDBC).

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Executive summary

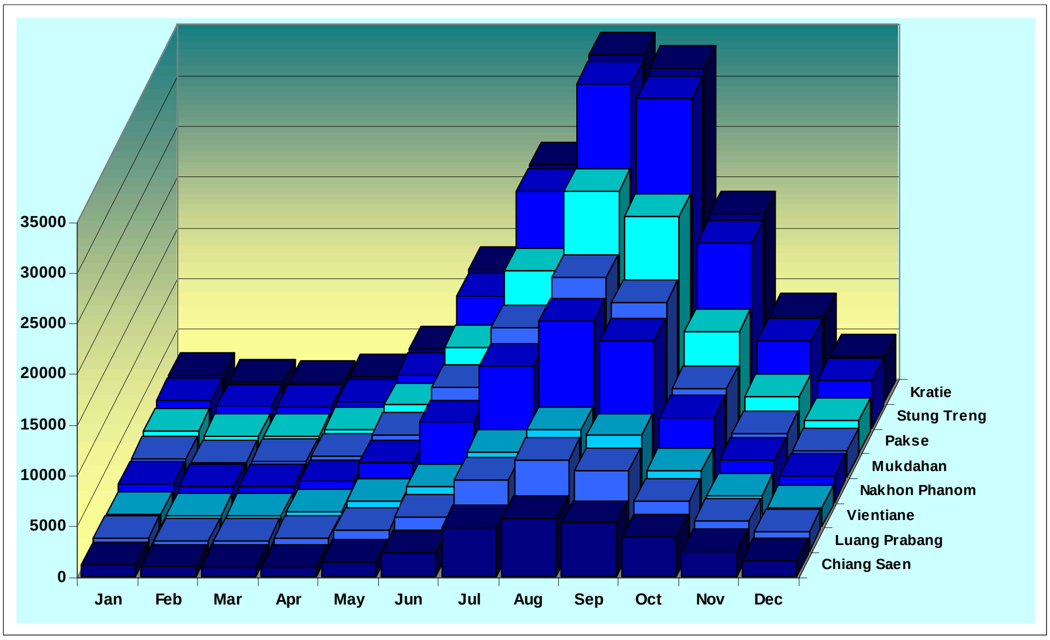
Introduction

This report presents the findings of work commissioned by the BDP of the Mekong River Commission to investigate the hydrologic and environmental impacts of a range of development scenarios.

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.

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.

Calculated monthly flow



Baseline analysis of increased storage

Manwan Dam was completed in 1993, and has a total storage of 920 million cubic meters (mcm), and an active storage of 240 mcm. It has an installed capacity of 1,250 MW, which at a head of 99 m corresponds to a release rate of 1,432m3/s (124 mcm/d). Manwan Dam is required to produce a firm power of 314 MW, which at a head of 87 m, and a utilisation fraction of 0.6, corresponds to a release rate of 245 m3/s (21 mcm/d).

Dachaoshan Dam was reported to be completed in 2003, and has similar characteristics to Manwan Dam, with a total storage of 933 mcm, and an active storage of 367 mcm. Maximum and firm release rates are calculated as 1417 m3/s (122 mcm/d) and 261 m3/s (23 mcm/d) respectively.

Analysis of the inflow data to Manwan dam show that average annual inflow is 1200 m3/s. The maximum release is exceeded 32% of the time. The lowest inflow rate to Manwan Dam is 154 m3/s, which is less than the firm release rate. However, for the period of record, inflow rates less than the release rate only occur about 0.2% of the time. This is only during the month of April, during which inflow rate less than the firm rate occurs approximately 2.3% of the time.

The conclusion from this is that Manwan Dam has a very low regulation capacity, and, even when emptied to the inactive volume, can store little more than 1-2 weeks of the flow for the dryest months. Manwan Dam could be expected to spill over 99% of the time, such that combined turbine and spillway/flood gate discharges are very similar to inflows. The geometry and hydrology of Dachaoshan is similar to that of Manwan Dam, and similar conclusions could be drawn.

River flows and dai fish catches

In the Great lake of Tonle Sap, there is a clear a relationship between annual fish catch and annual maximum lake level. On the other hand, fish catches were down in recent years, despite higher than average lake levels. This may indicate that another factors, other than peak lake levels, are becoming important in determining fish catch. It may be a reflection of a downward trend in fish catches due to over fishing, increased fish catches in other areas, or other factors, such as reduced fishing effort by people involved with the Dai fisheries.

As an alternative to the October lake water level, the Dai fish catch can be compared to other hydrologic variables, such as the Tonle Sap reverse flows during the lake's filling phase. This regression is slightly stronger than that for the October lake levels. However, if the overland flow component (from the Mekong River) is added, the regression weakens.

In conclusion, both the October lake level and flow reversal relationships, offer similar levels of prediction of Dai fish catches. Both are likely to worsen if pressures such as fishing in other locations impact on fish numbers caught at the Dai fisheries on the Tonle Sap River.

Impacts of infrastructural development on habitats and biodiversity

The changes in flows and particularly flood inundation patterns can have significant impacts on the riparian ecology. These impacts can be summarised as being as function of changes in:

- Peak flooded area and depths
- Flood duration
- Habitat type inundated
- Lateral connectivity between the river or permanent water bodies, and the floodplain
- Water quality

With respect to the first three, impacts on fish and other aquatic organisms are direct consequences of those changes, however the magnitude of the impact will depend on the species concerned. Lateral connectivity is critical to the capture fisheries of the Lower Mekong Basin. Consequently, where embankments are built along the natural levees of the Mekong, Tonle Sap and Bassac Rivers they can have adverse consequences not only on flooding, but on the movement of fish to and from the floodplain. Fish undertaking lateral migrations to and from the floodplain will often not pass through road culverts due to behavioural inhibitions associated with dark confined areas. Bridges appear to have much fewer impacts of fish migrations.

Impacts of infrastructural development on flood risk and flood exposure

Urban areas, by virtue of the prevailing population densities and value of infrastructure, are the most sensitive to increases in flood depths and durations. Urban and industrial areas are of limited occurrence in the Cambodian floodplain outside of Phnom Penh and a handful of towns, but to these areas must be added the large number of kampongs scattered across the floodplain.

Planners and inhabitants of large urban centres such as Phnom Penh assume that the flood risk must be reduced or eliminated. For the most part, Phnom Penh is protected from flooding. With the slow but gradual improvement in standards of living in rural areas comes a higher exposure of assets to the prevailing flood hazard, effectively increasing the flood risk. What was acceptable before is becoming less so and rural expectations are increasingly approximating those of city dwellers.

Rural people also need to be able to transport their agricultural, fish and other products to city and town markets, and to obtain supplies there. So whilst short duration flooding may be acceptable, longer floods begin to create hardship, as no income is generated, food supplies run short and children can not get to school.

Against this, is the current high level of poverty and dependence on natural resources directly supported by the river and its flood regime. Most significant of these functions is the widespread availability of fish and other aquatic animals that can be caught locally, or purchased at very low prices. Indeed, the prices are the lowest of any available source of protein and calcium, such that the health of many people hinges on the availability of cheap fish and aquatic products. The maintenance of capture fisheries require a certain amount of flooding, hence reductions in flood depths, extent and durations are of concern. So, on the one hand reduced flooding is desirable, but on the other, human socio-economic well being very much depends on it.

From the above, and in the absence of explicit planning that recognises and deals with the trade-offs associated with minimising flood risk, whilst maintaining the existing benefits of flooding, it might be presumed that population density and growth will be amongst the prime drivers of new and higher embankments. These factors are likely to result in new and upgraded roads to service them, as well as new agricultural projects to provide food and employment.

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 baseline conditions and implications of a range of development interventions.

1.1 Origin of document

This document is a compilation of study reports prepared by Richard Beecham, Hugh Cross (Ecosphere Solutions Pty Ltd), and Brian Haisman between December 2003 and March 2005:

Beecham, Richard (May 04): Modelling support for Basin Development Plan (with analysis of Chinese dam cascade). MRC BDP Working Paper

Beecham, Richard (Mar 04): Analysis of alternate baseline conditions. MRC BDP Working Paper

Cross, Hugh (Mar 05): A report on likely infrastructure developments on the Mekong floodplain in Cambodia and their significance in changing flow patterns. MRC BDP Working Paper

Cross, Hugh (Jun 04): Hydrologic analysis for basin planning using the MRC DSF: Spatial flood relationships to river flows, dai fish catches and inundated populations. MRC BDP Working Paper

Cross, Hugh (Mar 04): DSF outputs from ISIS model simulations for basin planning. MRC BDP Working Paper

Haisman, Brian (Dec 03): Hydrology simulation modeling in river basin planning - an introduction for non-hydrologists. MRC, BDP, MDBC Training Module 3

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, hereby providing an important basis for Stage 3.

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.

The results have formed the platform for the subsequent scenario analysis, and hereby for the strategy formulation.

The DSF-based scenario analysis is described in a set of working papers and in the consolidated report

MRC-BDP (March 2005): Scenarios for strategic planning

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 2.4 (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) and
- Output 2.3 (Development strategies for sub-areas).

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

Strategic planning at the river basin level is not entirely rational - this would require a full knowledge about the future which is not available. Still, the planning should build on realistic, if not entirely safe assumptions about the consequences of various interventions - intended as well as unintended, and positive as well as adverse.

The DSF analyses have delineated such consequences in a detailed and consistent way. Hereby, they have identified a range of consequences under a set of well-defined assumptions. Also, linkages between different interventions (within irrigation development and hydropower development) have been identified.

Hereby, the knowledge produced has contributed substantially to the formulation of strategic directions for water-related development in the Basin.

1.3.2 Significance of subject for Mekong Basin

Today and in the future, the cultures, economies and societies of the Lower Mekong Basin are closely related to water. The well-being of the Basin is related to the availability of water and will remain so for decades to come.

The DSF has been developed for the purpose of basinwide analysis of water availability.

The DSF, by its nature, is well suited for examination of the inter-sector and transboundary linkages that detemine the potential synergies and constraints within basinwide development. Detailed and consistent descriptions, on a well-defined and transparent basis, of present and future water balances and flow patterns are one of the starting points for good decision-making and fruitful water-related development.

1.3.3 Significance of subject for MRCS / BDP 1

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.
- Another 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.

2 Summary of approach

The MRC Decision Support Framework (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.

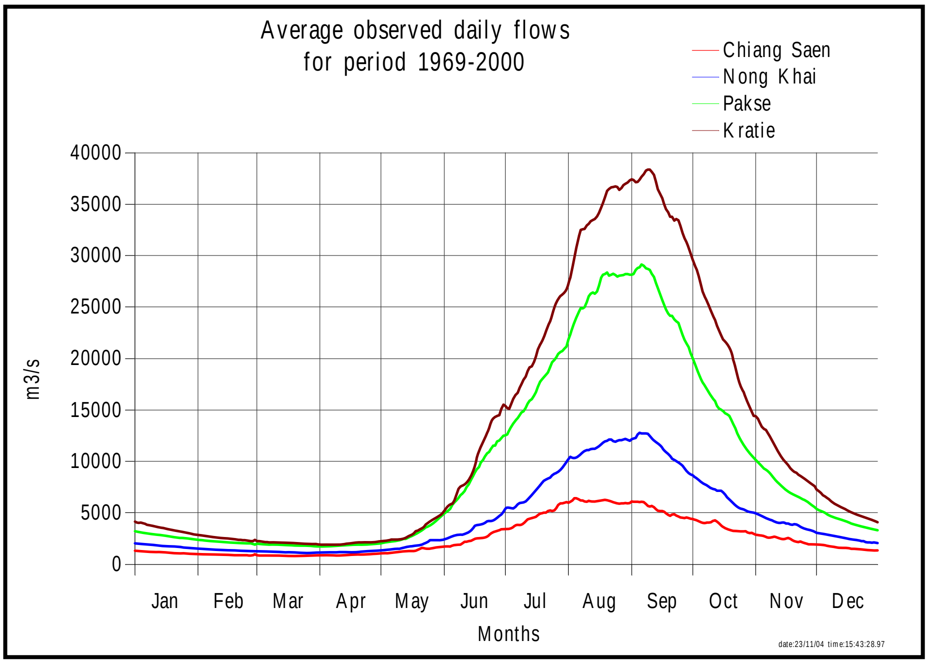
IQQM: The hydrological models provide input of runoff to a basin simulation model that uses the IQQM software developed in Australia. The basin simulation models route sub basin flows through the river system, making allowance for diversions for irrigation and other consumptive demands, and for control 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.

These models combined, are capable of estimating flows anywhere in the Mekong Basin for a range of possible interventions, including:

- Land use/ land coverage changes;
- Climate and sea level changes;
- Water supply demands;
- Aquaculture development;
- Irrigation development;
- Revised crop patterns and irrigation management;
- Changes in existing dam operation;
- New dams;
- In-stream regulation;
- Inter-basin and intra-basin diversions;
- River improvement works;
- Flood works in floodplain/tributaries; and
- Salinity intrusion barriers.

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 Flow and water quality modelling for basin planning

by Brian Haisman, December 2003,
and Hugh Cross, March 2004

3.1 Introduction to flow modelling

3.1.1 Hydrology and some of its common tems

In a simple sense, hydrology is the study of the mechanics of water flows on the surface of the Earth. It considers the nature of rainfall (or *precipitation* as meteorologists more precisely call it); what happens when rain hits the ground (how much soaks in, how much appears as a surface water flow); and how these flows of water actually move along the ground, both in river beds and over floodplains.

Hydrology is a highly mathematical discipline involving not just the physics of water movement, but also the application of statistical theory. Detailed study of the actual creation of rainfall is the field of meteorologists with whom the hydrologists work very closely. Key concepts in describing rainfall for hydrological purposes are:

<u>Depth</u> – This is used to express *amount* of rainfall and is measured as the depth of water that would be measured if rain fell on an impermeable surface. Usually described in millimetres (mm). For example: "Yesterday 25 mm of rain fell at Napakuang".

<u>Intensity</u> – This is the amount of rain falling within a chosen time duration, usually in one hour. For example: "Monsoon rains are typified by rainfall intensities of over 10 mm per hour."

<u>Duration</u> – This is simply the length of time that some event, such as a storm, continues. The product of duration and intensity is depth of rainfall.

<u>Probability</u> – This is expressed in weather forecasts as the *chance* or *likelihood* of rainfall occurring within a specified time period. For example: "There is a 20 percent chance of rainfall in the next 24 hours". Probability concepts are further extended to define the frequency of storm events or other weather events such as droughts. Often these are described as a once per so many years event. For example: "Singapore designs its urban drains to carry runoff from a 1 in 10 year storm."

This description can sometimes be misleading as it can be interpreted to mean the size of storm that occurs once every 10 years. In fact, it really means that the annual probability of occurrence is 0.1 or 10 percent every year. (For readers with a horse racing background, think of a 10 percent probability as the same as odds of 9 to 1 against.) It is possible to go 30 years or more without a "1 in 10 year storm" or to have such storms two years in succession. It is more accurate to say that it is the size of storm that occurs "1 in 10 years *on average*."

Hydrologists will also use the term *return period* for this same concept. Thus a rainfall of probability 10 percent can be described as having a *return period* of 10 years. The words "on average" should be added, but are frequently left out.

<u>Runoff</u> – This is the *amount* of rainfall that does not evaporate or soak into the ground and which therefore appears as a surface flow of water. It is typically expressed as a depth in millimetres but must be associated with a particular depth of rainfall to have any meaning. This association is often expressed as a percentage. For example: "On average, 8 percent of the rainfall in the Murray-Darling Basin appears as runoff."

The amount of surface runoff from any particular rainfall event is highly variable and is closely related to the nature of the watershed (types of soils and vegetation cover) and to how wet the ground already is. Hydrologists call this last factor '*antecedent conditions'*. Study of rainfall-runoff relationships is a major field within hydrology.

Once rainfall has appeared as surface water runoff, the forces of gravity cause the water to flow over the ground downhill towards drainage depressions and on to rivers. For the most part, the concepts and language used by meteorologists and hydrologists about rainfall will not concern basin planners. However, the concepts and language applied to river flows are highly relevant for basin planners. Key concepts in the hydrology of river flows are:

<u>Stage</u> – This is what some people might think of as water depth, although this is not necessarily strictly correct. Stage is actually water level, measured as the vertical height of the water surface of a river above some arbitrary zero. If the zero is the bottom of the river bed, then stage is indeed maximum water depth across the river channel. However, zero may sometimes be expressed as something like *mean sea level*, in which case the stage is the height of the water surface above sea level. This latter method enables the water level to be compared with heights of other things, such as the underside of a bridge for example.

<u>Flow</u> – Technically called *discharge* and generally designated by the symbol 'Q', *flow* is the amount of water passing some chosen point in a river channel within a specified period of time. The most common unit of flow used around the world is *cubic metres per second* – often abbreviated to *cumecs*.

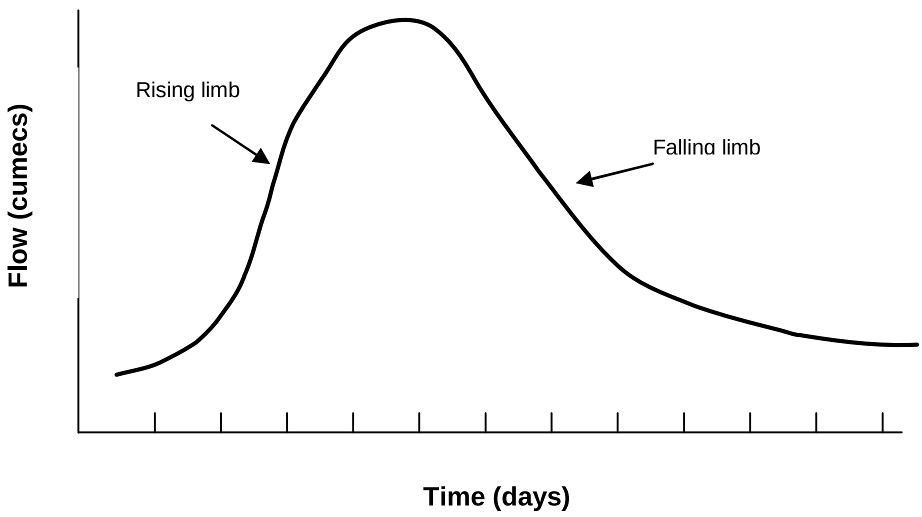
In the US where imperial units still survive, the common unit is cubic feet per second or *cusecs*, and in Australia the curious unit of megalitres (millions of litres) per day is used. This unit was chosen, among other things, to help irrigators – one megalitre will cover one hectare to a depth of 100 millimetres, which is an average application of water to pasture.

Flow data can refer to *instantaneous flow* – that is, the flow at a particular point in time, or it can be aggregated into values over a longer period of time. Typical of this aggregated flow is the *mean daily flow*, which is the average of all the instantaneous flows measured over a 24-hour period. All kinds of aggregations are possible. Thus we can refer to *annual average flows* and so forth. Sometimes it is useful also to refer to *median flows*. This is the flow value that lies in the middle of the range of observed flows. It is used because single major flow events such as floods can unduly influence and, in effect, distort the average.

In passing, it is important to note that surface runoff is not the same thing as the amount of water or flow that will appear further down a river system or at the end or mouth of a river system. Water travelling down a river is subject to *transmission losses*. These losses include *evaporation* (water re-entering the atmosphere in the form of water vapour), *evapotransporation* (water taken up by plants and later emitted to the atmosphere), and soakage into the bed and banks of the river. Hydrologists refer to this last phenomenon as *infiltration.* In more arid climates these transmission losses can be very large. For example in the Murray-Darling Basin around half of the surface runoff is lost to these natural processes. In a more general sense, water getting into the groundwater systems, including typically from irrigation, may be referred to as *accessions to groundwater*.

<u>Hydrograph</u> – Two types of graphical representation of flow may be referred to as hydrographs. Both are simply a graph or chart showing values of flow plotted against time. One kind is a graph of a particular flow event, such as a flood. The time scale here will typically be days or maybe even hours.

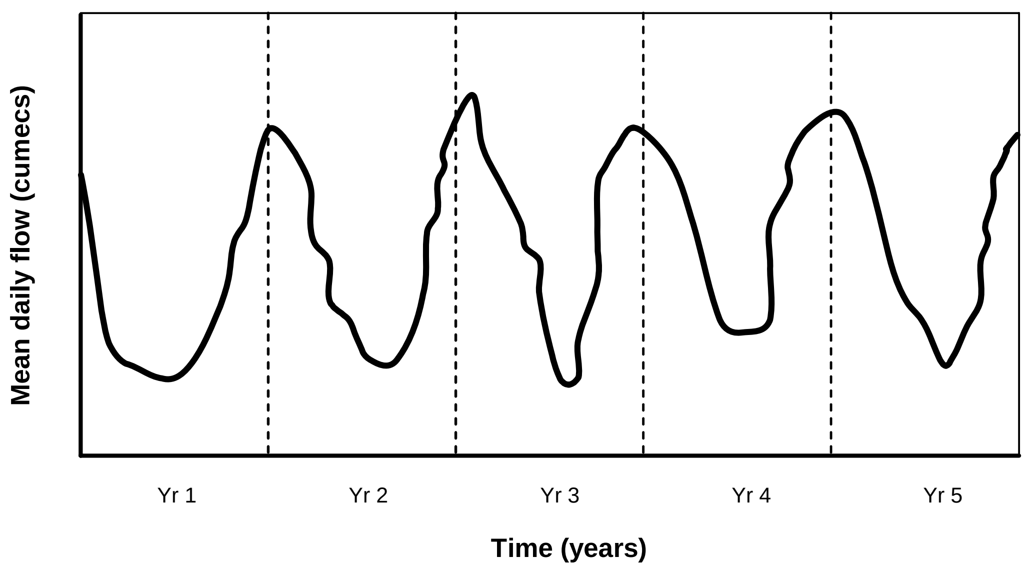
Fig 3.1: Example of flood hydrograph



For flood hydrographs, such as the example in Figure 3.1, the vertical axis might also be plotted as river height or *stage*. The falling limb of a flood hydrograph may also be referred to as a *recession curve*.

The other kind of hydrograph is where flow data may be aggregated into some chosen time period, for example, mean daily flows, then plotted over an extended period of time. Hydrologists will call this a *time-series plot*. Similarly, a database that contains hydrology data that includes the time at which each piece of data was measured is called a *time-series* database. There is quite sophisticated software for storing and manipulating time-series data. The MRC Secretariat uses software known as *HYMOS* for this purpose.

Fig 3.2: Example of time-series plot



Velocity – This is the speed of water flow, expressed typically as *metres per second*.

Students of mathematics will recognise that flow, stage and velocity are all connected through the area of the river cross-section. The measurement of river flows is done by hydrographers who do not measure flow directly, but instead measure velocity and cross-sectional area. The product of the two is flow.

$$\text{velocity (m/sec)} \times \text{cross section area (m}^2\text{)} = \text{flow (m}^3\text{/sec)}$$

The actual channel cross-sectional area at any particular river depth can be graphed against that depth. This in turn enables the hydrographer to construct a graph of river depth versus flow – known as a *stage-discharge curve* or a *rating curve*. In this way, measurement of river flow can be directly related to river depth and this is the principle on which nearly all river gauging stations work. The gauging station equipment measures (and sometimes records, and may even transmit) river level or *stage*. The hydrographer then refers to the *rating curve* for that station to get a reading of flow or *discharge*.

Probability – Probability concepts are fundamental to river flow hydrology. All of the discussion about probability concepts for rainfall also applies to flows. Thus the notion of a return period is commonly also used for flows. For example: "Spillways on major dams should be designed to safely pass floods with a return period of at least 10,000 years." The same caution is needed about understanding that this period is "…on average". It is quite possible to get two 1 in 1000-year floods in succeeding years. In fact, this is exactly what happened during the building of the Kariba Dam on the Zambesi River in Africa.

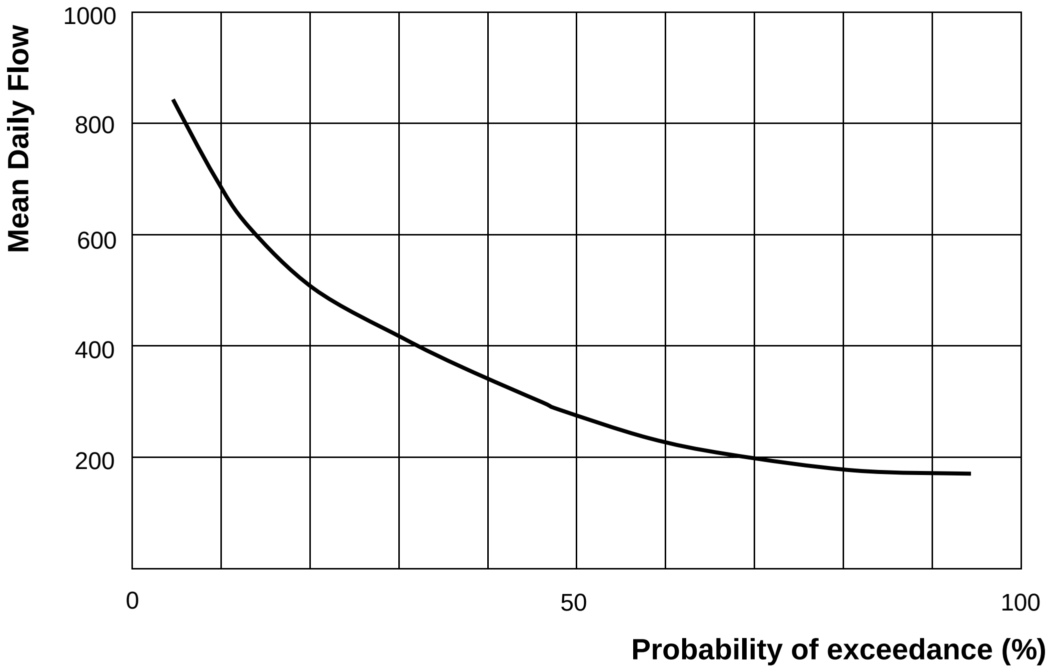
This use of probability (the notion of the probability of a flow event of a particular magnitude occurring within some chosen period of time) is used rather more for engineering design of structures or for flood planning than for basin development planning. This period might be monthly or annually, but is commonly yearly and hydrologists will speak about *annual exceedance probability*, which they shorten to *AEP*. Using the 1 in 10,000 year flood example, this equates to an AEP of 0.01%. The *annual exceedance probability* concept can be applied to other flows such as average daily flow or any other flow that might be useful for planning purposes.

More commonly in environmental assessment (and therefore in basin planning) various kinds of cumulative probabilities are used. These probabilities tell the planner about the proportion of time that certain flows occur or are exceeded.

Hydrologists will use the term *percentile* to describe the range of flows that occur for a particular period of time. For example, the 95th percentile flows are those flows that occur or are exceeded 95 percent of the time. In other words, the 95th percentile is a rather low flow. The 50th percentile flow is the flow that occurs or is exceeded half of the time. The next concept explains this further.

Flow duration curve – This concept is a graphical way of showing the full range of flows recorded at some chosen point in a river together with their associated exceedance probabilities. In the language of statistics it is a *cumulative frequency curve*. The MRC DSF contains software that will automatically construct flow duration curves from time series flow data.

Fig 3.3: Example of flow duration curve



A great deal of information can be got from a flow duration curve. In the example above, the cumulative frequency distribution of the observed mean daily flow at some imaginary gauging station is shown. The graph shows that the maximum flood is around 950 cumecs (never exceeded) and the lowest flow is around 40 cumecs (exceeded 100% of the time). It shows that the mean daily flow is above 200 cumecs for about 45% of the time but above 600 cumecs for only about 8% of the time.

Because natural river ecological processes vary up and down the river banks and with the depth of flow, the flow duration curve is a major tool in assessing variations in the flow regime caused by actions such as water extractions, dams and weirs, and so on. This is further described in the next section on simulation modelling.

3.1.2 Flow models

A flow model (or hydrology model) is an attempt to describe mathematically the behaviour of some part of a watershed and river system. The hydrologists construct equations to represent this behaviour, and then test them by feeding in actual observed data, say at the upstream end of a section of river, then checking to see whether the output from the model at the downstream end of the section (i.e. the results of the equations) looks anything like the observed data at that point.

The hydrologists vary parameters within the equations to get the best match between the computed and the actual data. When this has been achieved, the model is said to have been *calibrated*. It then becomes possible to feed in other data, such as flows modified by increases in irrigation water extractions, and to have some confidence that the results of the equations will fairly accurately predict or *simulate* the results that might be achieved in a real situation.

Hydrologists use three major kinds of models.

Rainfall-runoff models

In a simple sense these models are the collection of equations (or relationships) that describe the physics of rainfall landing in a watershed and partially soaking in to the ground, with the balance remaining as surface runoff. To construct a model, the modeller needs to know primarily the topography of the watershed (shape, size, slopes etc), the nature of the ground (soil types etc), and the nature of the vegetation and other ground cover.

The input to the model will typically be time-series data of historical rainfall records, and the output will typically be time-series data of flow at the outlet or lowest point of the watershed.

The models can be used to predict what might happen if vegetation cover is changed, or if future rainfall is more or less than the historically observed rainfall. Some models include equations for the effects of temperature on evaporation and so forth and so can be used to predict what might happen to runoff in the event of climate change.

River flow routing models

These models are sets of equations that describe the changes in flow as water travels down a river channel. There are a number of ways to set up such models but a common approach is to divide the river up into sections (or *reaches*) and to compute a *water balance* for that section. In a very simple sense the overall relationship is:

Water flow into section **plus** Inflows **less** Outflows **equals** Water flow out of section

Inflows include such things as flows from tributary streams, runoff, artificial flows such as drains and so forth. Outflows include such things as water extractions, losses to groundwater, diversions, evaporation and so forth. Models, naturally, can be quite complex, particularly because of water travel time effects, parameters that vary with water depth (for example losses) and so on. To construct a model, the modeller needs to know primarily river channel geometry (size, shape, surface roughness, slope etc), together with all the inflows and outflows and their relationships.

The input to the model will be time-series data of the historically observed stream flow records, and the output will be time-series data of the flow patterns at selected *nodes* of the model (ends of sections).

The model can be used to predict what might happen if either inflows or outflows are altered. For example, the model can predict changes in the flow regime that would occur if extractions of water for irrigation were to be increased. The models can also simulate what would happen to the flow regime if a dam were to be constructed across the river. In this case the reservoir becomes a section in the model and the modeller will set up equations that describe the relationship between outflows and inflows or, in other words, the operating rules for the dam.

For both rainfall-runoff and flow routing models, the output is time-series data. Such data needs manipulation before it of use to basin planners, river managers and other decision-makers. This manipulation may take the form of simply presenting the data in an understandable fashion – such as time-series plots of flows, either as line plots or as bar charts etc – or, commonly, will take the form of supplementing such plots with statistical analysis of the data. This analysis is typically a frequency analysis and produces tabular and graphical output such as flow duration curves and the like.

The MRC Decision Support Framework (DSF) contains many such analysis tools, including the capability of spatial outputs that allow, for example, the outputs to be viewed in map form along with other mapped data to allow for visual and other interpretation. The amount and types of analysis to be performed are limited only by the needs and imagination of the users.

Hydrodynamic (or hydraulic) models

For basin planning purposes, these are models that describe the flow of water over floodplains. That is, water that is not in a linear river channel.

Hydrodynamic models work in a similar way to river flow routing models in that they are set up to compute water balances for chosen elements of the flow path. The key difference is that for river flow routing the elements, or sections, form a simple, linear chain, linked end to end; whereas for a floodplain model the 'sections' are really a network of 'cells' that are linked side by side as well as end to end. Hydrodynamic models are thus two-dimensional in nature.

To set up a hydrodynamic model, the modeller needs to know essentially similar things to those needed for a river model, particularly the geometry of the floodplain. This geometry, which will include channels within the floodplain, is ideally in the form of a digital elevation model (DEM) which can be assembled from ground surveys or by remote sensing techniques to give a database of heights of the landscape, generally in some kind of grid pattern.

Inputs are time-series data of the flows into the floodplain area and outputs are time-series data of the flow heights within each cell.

Hydrodynamic models are primarily used to study the effects of altering the geometry of the floodplain, say by construction of levees or elevated roads.

Such models will generate vast quantities of data, depending on the size and number of the cells that are chosen. The more cells, the more accurate the outputs, but also the greater volume of data. Because of this volume of data, planners, managers and decision-makers need to be prudent in selecting how much analysis of the data is needed. It is possible to use a lot of time and resources in such analysis. Therefore it is usual to only seek the minimum analysis that is really needed. Typically this will include study of the peak of a flood and the analysis will generate such data as the spatial extent of floodplain inundation. The other common analysis is of the time or duration of this peak inundation, or perhaps durations at selected critical flood heights such as the flood height that cuts off road access to a town for example.

3.1.3 Accuracy and usefulness of flow models

Flow models are expensive to build and maintain. The expertise to run the models is highly specialised and, despite the very mathematical nature of the models, they contain many assumptions as to relationships between variables, they can only be calibrated to historical data, and they are strongly dependent on the quality and extent of that data. Modelling is an art as well as a science. This suggests that hydrology models may be of limited utility.

In fact, the opposite is true. Such models form a vital and indispensable tool for basin planning, and even relatively primitive models will give valid support to planning decisions. This is because what is being studied is the *comparison* of scenarios. It is a scientific fact that whilst the absolute values of the data that is generated may have fairly wide confidence bounds, the computed differences between data from two model runs are significantly more accurate. The validity of simulation models in supporting a decision as to which of a selection of scenarios is 'best' is therefore well accepted in the world of water resource management and basin planning.

3.2 Suggested process for identifying basin planning needs

The Decision-Support Framework (DSF) was developed under the WUP for general use within the MRC programmes. The DSF comprises a suite of numerical models for analysis of flows, water quality and water balances.

The following observations and recommendations were made after a training session on *'Use of the DSF for Basin Planning'* in December 2003, as part of the MDBC training module 3 '*Scenario Based Planning For The Mekong Basin',* conducted at Napakuang, Laos PDR.

Having developed the MRC's Decision Support Framework (DSF), the WUP-A program proposed a context within which it could be used to assist Basin Planning, including serving the need for spatial analysis. The suggested Basin Planning Steps were presented during the training conducted by the MDBC in Lao during December *2003* in "*Basin Planning Module 3 – Scenario Based Planning For The Mekong Basin*". Table 3.1 below summarises those planning steps.

Table 3.1: Use of the DSF within the context of generic basin planning steps

	Planning steps	Remarks
Planning preparatory work		
A	Development goals	*Planners define the development aims and objectives that their plans or assessments are expected to achieve*
B	Assessment framework	*Planners define the high-level development indicators that effectively demonstrate whether the development goals are being achieved*
C	Development opportunities	*Planners define the different development opportunities that may exist to achieve the development goals*
D	Development Scenario	*Planners define the development scenarios that need to be investigated*
Scenario definition and reporting		
E.1	Scenario Objective	*For each planning issue, planners define a scenario objective that states what is to be tested against which potential sectoral interests*
E.2	Scenario Components	*Agreement is reached between the DSF modelling team and planners on the scenario's components, i.e. hydrological conditions, prevailing demands and interventions in place*
E.3	Relevant trans-boundary issues by Sector	*The DSF modelling team agrees with the planners which relevant issues are to be investigated when running the scenario*
E.4	Indicators relevant to trans-boundary issues	*The DSF modelling team agrees with the planners which indicators are to be tested for each selected trans-boundary issue*
E.5	Tools for testing changes in indicators	*The DSF modelling team selects the tools required to test the selected indicators*
E.6	Reporting	*The DSF modelling team agrees with the planners how information on each indicator is to be reported*
End-user scenario post-assessment		
F	Multi-criteria analysis format	*The end-user defines a procedure for multi-criteria assessment of alternative scenarios, linking the high-level development indicators to the indicators used for analysis of trans-boundary issues*
G	Multi-criteria assessment	*Each scenario is assessed using MCA to find out the one that best meets the development goals with the most acceptable mix of development indicators*

3.3 The socio-economic goals of the 1995 Agreement

How do BDP Planners intend to interpret the socio-economic goals of the 1995 Agreement? This question relates to step 'A' in Table 3.1 above and is critical to the determination of the broad types of indicators (Step 'B') that are relevant to those goals. Some possible social and economic indicators are suggested below.

Table 3.2: Possible social indicators:

Health	Employment	Poverty alleviation
Access to clean water supplies	Jobs in agriculture	Household Incomes
Sanitation facilities	Jobs in freshwater fisheries	Household debt levels
Hygiene awareness	Jobs in brackish water fisheries	Household assets
Food & protein security		Level of education
Disease incidence		

Table 3.3: Possible economic indicators:

Production outputs
Hydropower energy production
Fresh and brackish water fisheries production
Agricultural production on flood plains
Irrigated agricultural production
Navigation and related in-stream uses

Analysis using the above indicators would be largely be conducted through the use of spatial analyses. Differences between scenarios, revealed by DSF simulated flood and water quality maps, would be compared to various geo-referenced spatial themes representing the various indicators listed above.

The analysis of economic indicators in the DSF is proposed to be at two levels[1]. Simple, dimensionless, macro-economic analyses would be conducted to determine if a particular scenario is 'sustainable' in the context of the three questions listed in the table below. Of these three, the middle one regarding compliance with the rules and guidelines (of the 1995 Mekong Agreement) requires some spatial analysis.

[1] See Appendix B of: Final Report Volume 19, Document Number WUP-A640, 'Impact Analysis Tools', prepared for the MRC Water Utilisation Project Component A: Development of Basin Modelling Package and Knowledge Base (WUP-A), Halcrow March 2004.

Table 3.4: Indicators for macro-economic analysis:

Indicator	Approach
Dimensionless 'yes'/'no' statements of whether there was *sufficient water to meet the demands?*	No spatial analysis
Dimensionless 'yes'/'no' statements of whether the *rules and guidelines were complied with?*	Spatial analysis to determine area affected by increases in peak flood levels Spatial analysis of Tonle Sap flooded area re Article 6c
Dimensionless 'yes'/'no' statements of whether there are *any factors outside the operation or timeframe of the model that threaten the long-term sustainability of the scenario?*	No spatial analysis

3.4: Potentially Impacted Population (PIP) analysis indicators

The choice of indicators for socio-economic assessment of alternative basin-wide development plans has yet to be made within MRC. It is anticipated that these will stem from an assessment of each country's development priorities as expressed in their own national plans and as reflected in the goals and objectives of the 1995 Agreement[2].

It is probable that the choices between plans will be made on the basis of a multi-criteria assessment of a range of indicators. The IAT Technical Report (Document No. WUP-A DSF640) provides the following non-comprehensive list of indicators as a starting point (Table 3.5).

[2] Ibid, p47

Table 3.5: Preliminary suggested list of PIP indicators

Issue	Circumstance	Indicator	Data from	Remarks
Health	Access to water supply	Water supply demands satisfied	IQQM report	Normally there should be no constraint for this small amount of water
	Food security	Adequate per capita income	Knowledge Base and spatial analysis of land use potential change	Requires a production function from Sector Programmes for land use classes
		Sustained local fish production	IAT applied to flow state indicators	Probably only measurable as favourable/unfavourable to fish
Employ-ment	Jobs in agriculture	Area irrigated	IQQM Report	Requires a production function from Sector Programmes for land use classes
		Employment potential of land	Knowledge Base and spatial analysis of land use potential change	Requires a production function from Sector Programmes for land use classes
	Jobs in freshwater fisheries	Sustained local fish production	IAT applied to flow state indicators	Probably only measurable as favourable/unfavourable to employment
	Jobs in brackish water fisheries	Extent of appropriate level of salinity	Mapping tools and ArcView analysis of salinity model results	Requires a production function from Fisheries Programme of employment characteristics of shrimp industry
Poverty alleviation	As all above	Extent to which impacts are felt on areas of relative poverty	Knowledge Base and spatial analysis of impact areas	Requires an interpretation from BDP of "poverty" in relation to quantifiable statistics available at village level (or similar)

In addition to identifying indicators for each of the above three issue groups, socio-economists commonly identify capacities and vulnerabilities against society's assets. The five types of capital assets which are commonly identified are listed in the left-hand column of Table 3. For each of these some indicators are suggested that require spatial analysis in the DSF.

Table 3.6: Examples of possible indicators for major capital asset types requiring spatial analysis

Asset	Issue	Capacity	Vulnerability	Indicator	Remarks
Human	Flooding	People are adapted to 'normal' flooding & suffer only 'chronic' impacts, i.e. frequent, but manageable on-going impacts	During larger or longer duration floods people suffer 'acute' impacts, i.e. infrequent but significant impacts	Number of people affected by peak annual flood levels Numbers of people subject to 'excessive' flood durations	BDP input needed re a working definition of 'excessive' depths and durations Use Article 6 definition
	Availability of clean & reliable drinking water	Simple sedimentation & boiling of locally acquired ground and surface water by most rural populations	Lack of fuel for boiling during extended floods leading to higher prevalence of water borne disease following extended flooding	Numbers of people subject to 'excessive' flood durations	BDP input needed re a working definition of 'excessive' depths and durations
	Disruption to education	Boats are used by children in areas frequently subject to deep floods	Large floods can stop children getting to school in areas not normally subject to deep flooding	Numbers of children of school age subject to 'excessive' flood depths/durations	BDP input needed re a working definition of 'excessive' depths and durations
Social	Disruption to transport	Boats are used by people in areas frequently subject to deep floods	Large floods can prevent people moving in areas not normally subject to deep flooding	Numbers of people subject to 'excessive' flood depths/durations	BDP input needed re a working definition of 'excessive' depths and durations
	Rapid change in landuse	Some people readily take up new opportunities	Some people are displaced by new activities	Numbers of people in areas subject to new landuses	Enter new landuse layers into DSF KB & compare to previous
Physical	Damage to roads	Maintenance budgets/programs are directed at 'normal' conditions	High velocity or protracted duration of flooding	Flow velocity over road Flood duration	Velocities are not a default output from the DSF but can be requested
	Damage to houses	Most rural houses on stilts	High floods can inundate floors of silt houses	Flood depth during wet years	Need to define 'wet' year or 'high' flood
	Damage to crops	Most floodplain crops can tolerate/need some flooding	Excessive depth, particularly too early in the crop growth cycle	Depth on a calendar day relevant to the mean planting time for each region	Cropping patterns (by month) have been documented by WUP-A & are used in IQQM
Financial	Ability to perform existing agricultural pursuits	Some flexibility in the mix of pursuits that each landholder can undertake relative to water availability & WQ	Inability to perform certain pursuits, such as paddy rice, if there is insufficient water or salinity is too high	Crop area & $ value (by crop type) affected by adverse flooding conditions Crop area & $ value (by crop type) affected by adverse salinity conditions Numbers of people in areas suitable for brackish water aquaculture (shrimp)	Need to know typical yields per hectare and commodity prices by crop type
	etc				

Asset	Issue	Capacity	Vulnerability	Indicator	Remarks
Natural	Reliable annual floods	Provide a predicable free resource for ecosystems and gravity-fed irrigated agriculture	Dam construction can reduce flood size and extent Landuse change can increase flood heights & extent	Flooded area during 'dry', 'average' and 'wet' years Flood duration above critical thresholds during 'dry', 'average' and 'wet' years	Default flood depth thresholds are provided in the DSF, which can be changed if needed
	Reliable dry season flows	Provide a predicable free resource for ecosystems & gravity-fed (tide assisted) irrigated agriculture Limit saline intrusion in the delta	Dam construction &/or upstream irrigation (or inter-basin diversions) can reduce flows, thereby reducing flow heights, gravity diversion potential & increasing saline intrusion	Dry season flows by month Maximum saline intrusion Saline intrusion durations above particular salinity thresholds	Default salinity levels are provided in the DSF. These can be changed as necessary if other thresholds are required

3.5 Key environmental issues and indicators

Table 3.7 lists the transboundary issues and sub-issues in the LMB, identifying those that require spatial analysis.

Table 3.7: Spatial analysis requirements for Lower Mekong Basin transboundary issues

1. Water quality deterioration and sedimentation	DSF Spatial Analysis
Increased incidence of eutrophic conditions in the dry season and early wet season due to increased light and temperatures (from river bank clearing), elevated nutrient levels, organic pollution, reduced dry season flows and/or ponding (through dam construction or levees), leading to problems for consumptive water use, recreation, aquatic biodiversity and wildlife conservation	No
Elevation of suspended sediment levels from accelerated catchment and bank erosion, leading to sedimentation of water storages, deterioration of drinking water supplies and adverse impacts on fisheries productivity and aquatic ecology	No
Elevated levels of microbial pollution from urban waste water discharges (sewage and storm-water runoff) during the dry season and early wet season, when river dilution flows are at a minimum, impacting on consumptive water use, recreation and wildlife conservation	No
Pesticide pollution of surface and ground water by agricultural storm-water runoff and irrigation tail-water, that might lead to concentrations in drinking water and fish tissue that exceed health standards, and deterioration of aquatic ecosystems	No
Elevated salinity levels in streams in the Korat Plateau area, due to saline irrigation tail-water sourced from groundwater, leading to impacts on secondary consumptive use and aquatic ecosystems	No
Adverse water quality changes caused by stratification in large and/or deep dams, reducing downstream temperatures, oxygen levels, organic nutrients (nitrogenous carbon) and suspended sediment, and increasing levels of dissolved metals, toxic compounds and inorganic nutrients (N & P)	No
Acidification of surface waters and wetlands by drainage and inundation of oxidized acid sulfate soils in the delta	Yes – but not possible to model at present
Increased saltwater intrusion in the lower delta caused by reduced dry season flows	Yes – salinity intrusion maps

2. Fisheries productivity and ecosystem functioning	DSF Spatial Analysis
Impact of reduced, elevated or smoothed dry season flow regime changes on fisheries productivity and aquatic bio-diversity	No
Impacts of reduced, delayed or otherwise altered, wet season flood flows and flooded area on fisheries productivity, aquatic bio-diversity and wetland condition	Yes – max flooded area, flood duration above depth thresholds & possibly depths on particular calendar dates
Adequate Tonle Sap flow reversal through maintenance of adequate flood flows and flood season verses dry season flow differences	Yes – lake level and surface area
Impact of increased fishing pressure on fisheries productivity and diversity	No
Reduced fisheries productivity and bio-diversity due to obstruction of fish migration/ dispersal (upstream, laterally and downstream), by construction of dams, roads and levees on streams and floodplains	Yes – alter iSIS model due to floodplain developments, then model changed water levels and flooded area. Enter new fish migration route maps into the KB
Impact of elevated (or reduced) suspended sediment levels on aquatic ecology, through impacts on primary productivity in the wet season in floodplain areas (and consequent impacts on juvenile fish survival), and secondary productivity and biodiversity in upland rivers in the dry season	Yes – but by WUP-JICA 3-d hydrodynamic model of the Tonele Sap area
Impacts of pesticide pollution on fish productivity and aquatic biodiversity, taking account of bio-accumulation	No
Impacts of elevated salinity levels in the Korat Plateau area on fish productivity and aquatic biodiversity	No
Impacts of cold and/or deoxygenated water releases from large and/or deep dams on fish productivity and aquatic biodiversity	No
Impacts of soil acidification and associated increases in surface water acidity levels on estuarine wetlands, estuarine fish productivity and aquatic biodiversity	Yes in principle, but currently inadequate data to assess
Impacts of decreased brackish zone area on estuarine fish productivity and aquatic biodiversity	Yes – salinity levels at maximum annual salinity intrusion &/or other important dates; salinity intrusion durations for key salinity thresholds
3. River bank erosion	**DSF Spatial Analysis**
Modification of territorial boundaries through accelerated, but progressive, river bank erosion	No
Destruction of valuable urban/industrial and agricultural land and infrastructure (bridges, roads, pump stations, etc), through accelerated river bank erosion	No
4. Obstruction to Navigation	DSF Spatial Analysis
Structural obstruction of river navigation by dams, weirs and bridges	Yes – by entering new navigation themes into the DSF KB representing the location of existing and new obstructions
Reduced navigation opportunities due to reduced dry season flows (and therefore depths) or rapidly fluctuating river levels	No
Reduced navigation opportunities due to river channel and estuarine sedimentation reducing river depths	No
5. Inadequate dry season flows	**DSF Spatial Analysis**
Impact of altered catchment runoff on dry season flows caused by changes in catchment landuse and/or land cover, or climate change	No
Impact of dam storage/release operations, or inter-basin transfers, on dry season flows	No
Impact of reduced dry season flows on water availability for irrigation, aquaculture, village and urban/industrial water supply and estuary land reclamation of acid sulfate and saline soils	No
Impact of reduced, elevated or smoothed dry season flow regime changes on critical habitats for fisheries productivity and aquatic biodiversity	No

6. Flooding	DSF Spatial Analysis
Impact of altered catchment runoff on wet season flows and flooding	Yes – maximum annual flood extent and flood durations above important depth thresholds
Impact of dam storage/release operations, or inter-basin transfers, on flood flows and flooding	Yes – maximum annual flood extent and flood durations above important depth thresholds
Impact of flood mitigation works on flood flows and flooding	Yes – maximum annual flood extent and flood durations above important depth thresholds
Potential for loss of life and increased incidence of water-related diseases during flooding	Yes – maps and tabulated areas for particular flood depths and durations
Potential destruction and damage to infrastructure requiring post-flooding repair	Yes – maps and tabulated areas for particular flood depths and durations
Disruption to the use of community infrastructure during flooding, such as roads, power, water supply facilities and communication	Yes – maps and tabulated areas for particular flood depths and durations
Loss of agricultural production due inundation of crops, machinery, supplies or other necessities of production	Yes – maps and tabulated areas for particular flood depths and durations
Reduced flooding in important habitats, including the Great Lake, floodplain forests and freshwater and estuarine wetlands.	Yes – maps and tabulated areas for particular flood depths and durations

3.6 Indicators of relevance to sector programmes

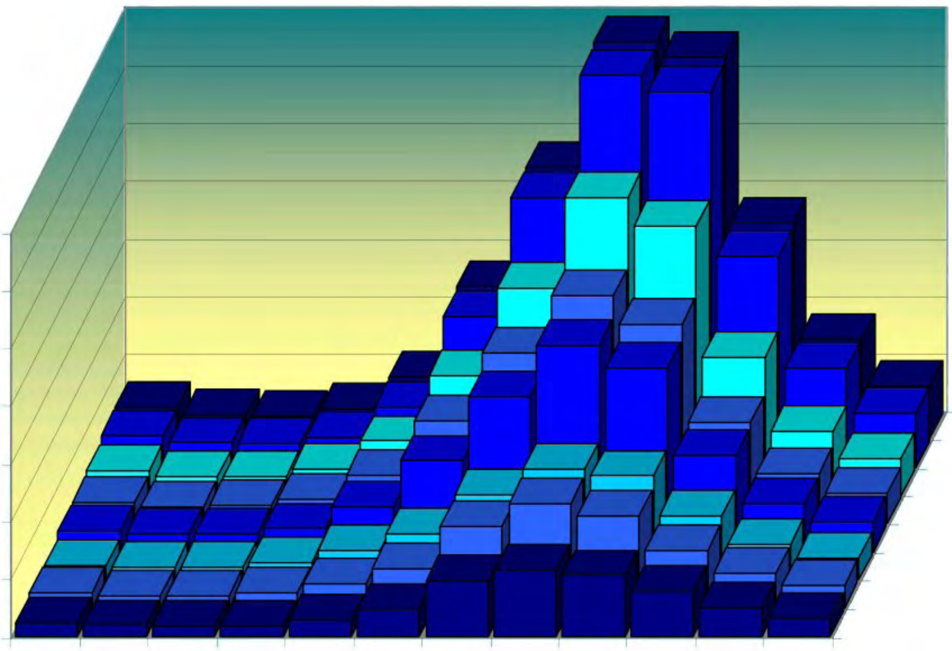
An alternative way of addressing the identification of issues and relevant indicators, is by sector. The key water related sectors of relevance to basin planning include:

- irrigated agriculture
- watershed management
- fisheries and bio-diversity
- hydropower
- navigation
- tourism
- domestic and industrial water supply
- flood management

These sector issues are addressed through a number of programmes within the MRC. The table below lists some of the more critical data for spatial analyses.

Table 3.8: Some indicator data requirements for spatial analysis by sector programme

MRC Programme	Examples of indicator data requirements to support spatial analysis of trans-boundary impacts
BDP	Population data (by province, with preferably greater detail on flood plains) Social impact data (relationships between access to water and socio-economic conditions) Rural, urban and industrial water demands
Fisheries Programme	Status, trends and water conditions required for river and flood plain fisheries Status, trends and water conditions required for brackish water aquaculture Location, extent and relative importance of spawning grounds Location, extent and relative importance of fish migration routes
Environmental Programme	Status and trends in water quality Location, extent and relative importance of ecologically sensitive habitats Water conditions required for ecologically sensitive habitats Daily time series data for climate change scenarios
Navigation Programme	Location, extent and relative importance of navigation routes Water conditions required for navigation
Water Resources Programme	Location, storage, installed generating capacity and expected operating rules for possible future dams within the basin Location and extent of possible future flood control works within the basin
Agriculture Programme	Agricultural data (production values and relationships to water conditions, including tolerance to flooding, salinity and water stress) Future trends in terms of evolving agricultural practices Limits of maximum irrigable land (ie irrespective of water availability)



4 Analysis of baseline conditions

by Richard Beecham, March 2004

4.1 The baseline concept

4.1.1 Need for a baseline

Over the course of developing the BDP and implementing the WUP, the member countries will consider a range of basinwide water resource development scenarios. These scenarios will need to meet national and regional development goals, as well as having transboundary impacts acceptable to all the member countries. There needs to be a means to compare these scenarios, as well as defining a level of impact that is acceptable. A baseline is a device that can meet this need.

4.1.2 What is a baseline

A baseline is a reference state to compare other values against. An example of a baseline in another context is the use of mean sea level (MSL) as a datum for measuring relative heights of land surface elevations or water levels. Users of a height at any point measured against this datum can then know if this is higher or lower that a point measured against this datum at any other location.

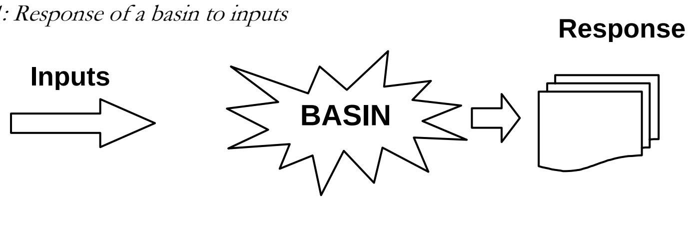
In the context of a basinwide natural resource management agreement, a baseline condition is a reference state of the physical characteristics of the basin, and the way it is managed at a point in time. A baseline scenario also includes a reference climate data set.

4.1.3 Baseline use

By considering the basin as a system, a given set of inputs to this system will result in a response that can be estimated (Figure 4.1). Changing the characteristics of the basin will result in a change to its response.

The inputs to the basin are climatic, ie., precipitation, humidity, temperature, solar radiation, and wind. Physical characteristics of the basin include topography, soil, land cover, land use, population distribution, and infrastructure. Topography influences the dynamics of water movement. Soils and land cover influence the water yield characteristics. Land use, in particular irrigated agriculture, influences water usage, as does the population distribution. Infrastructure such as large dams, can directly affect flows in rivers. Management characteristics include the way dams are operated to release water, as well as how efficiently water is distributed to the consumptive water users.

Figure 4.1: Response of a basin to inputs



For a given set of climatic inputs and basin characteristics, a hydrologic, environmental, and socioeconomic response can be estimated or measured to some degree. A change in these basin characteristics will result in a changes to the hydrologic, environmental and socioeconomic response that can also be estimated or measured to some degree.

Measurements of the response to the current basin development condition and climated are on-going in the Mekong Basin. However, it is only possible to measure a current development condition, it is not possible to measure a proposed scenario as these do not exist. Instead, the hydrologic responses to various basin development conditions, including the baseline, are estimated with the simulation models that are part of the DSF.

By using a reference set of basin characteristics, ie., the baseline condition, changes in responses to different changes in basin characteristics for the same set of inputs can be compared.

The WUP IBFM is considering adopting a Baseline condition to set its "Rules" under Article 6 of the Agreement. The BDP will be adopting a Baseline condition to compare basin development indicators, such as food production, against. The same Baseline will need to be adopted by both programs, so as to prevent confusion in the future.

4.1.4 Examples in use in the Murray Darling Basin

There are two notable examples of the use of baselines in Natural Resource Management in the Murray Darling Basin (MDB).

The MDB Ministerial Council (MDBMC) cap on irrigation diversions (The Cap).

The Cap uses the level of irrigation development, and associated management practices in 1993/4 as a baseline condition. The objective of The Cap is to restrict growth in irrigation diversions in the MDB. The design of regulations under The Cap ackowledge that irrigation diversions will vary year to year depending on the climate. Therefore, it sets out that the irrigation diversion in the current year should not exceed that which would have occurred with 1993/4 levels of irrigation development. Basin scale water resources management models are used to estimate what this should have been, and these estimates are compared with measurements of water usage to ensure that the member states are complying with The Cap.

The MDBMC Basin Salinity Management Strategy (BSMS).

The BSMS uses the MDB physical catchment condition and management practices that existed at 1 January 2000 as a baseline to determine what the in-stream salinity behaviour would be. This baseline condition together with a Benchmark Climatic Period (01/05/1975-30/04/2000) to simulate the salinity response. The aim of the strategy is to slow down, and eventually reverse the predicted increases in instream salinity in the MDB. The impacts of future salinity management scenarios are evaluated against this baseline.

4.2 Components of the DSF Baseline

The Baseline needs two sets of data so that future scenarios can be compared.

1. *A fixed set of inputs, ie., climate data, similar to the BSMS Benchmark Climatic Period.*

The DSF currently has a basinwide set of climate data for the period 01/01/1985 - 31/12/2000.

2 *A refererence set of data describing the physical and management characteristics of the Basin.*

The reference set of data is essentially the level of water resources development that was in place at a point in time. The major physical and management characteristics of the LMB that affect water usage, ie, storages and irrigated crop areas, are reasonably well described for the period 1985-2000. The noted exception here are the gaps in dam information in Thailand, described in the DSF Technical Report Volume 11. Land cover should also be part of the baseline condition. However, only one landcover data set is available at MRCS for the LMB, at 1997.

4.2.1 Alternate baseline conditions considered

Three alternate baseline conditions are considered in this study. These, along with the reasons they are being considered are discussed in the following three subsections.

No development scenario

This scenario considers that the condition where there is no development of water resources in the basin whatsover, but it does not consider land cover changes otherwise. This scenario removes the impact of all consumptive water usage in the LMB, as well as the impact of regulation by large dams.

The purpose of this development condition scenario is not to put forward as a feasilbe baseline for either BDP, or IBFM. Rather, it is an absolute reference point, and it allows the water usage impacts of 1995 and 2000 development scenarios to be compared.

1995 levels of development scenario

This scenario uses the areas of crop that were irrigated in 1995, as well as the the large dams that were operating in Laos, Cambodia and Viet Nam in 1995. In this case it is only Nam Ngum dam, which was commissioned in 1972. No changes in land use were considered as there is no data to estimate this with. Similarly, the iSIS model was not changed as there is not complete information on the topography (roads, dikes, salinity barriers) available at that time.

2000 levels of development scenario

This scenario uses the areas of crop that were irrigated in 2000, as well as the the large dams that were operating in Laos, Cambodia and Viet Nam in 2000. In this case four additional hydropower dams were commissioned in Laos and Viet Nam; Nam Leuk, Nam Theun-Hinboun, Houay Ho, and Ya Li. Nam Song was also commissioned to divert water to Nam Ngum, but not generating hydropower itself. The topography in the iSIS model is representative of this year.

4.3 Method

The simulation models were configured to represent the development conditions for each scenario. No changes needed to be made to the SWAT model as no change in land cover or climate was proposed.

The models were developed and tested outside the DSF. New scenarios were created in the DSF, and the respective network and data files for IQQM and iSIS were imported. These are described in Section 3.2 and Section 3.3 for IQQM and iSIS respectively. The three created scenario names are:

(i) No water resources development.

(ii) Year 1995 Development conditions.

(iii) Year 2000 Development conditions.

The simulation models were run using the DSF, and a set of results were saved, linked to that scenario in the DSF. The set of results saved is described and listed for IQQM and iSIS respectively.

4.2.2 Upstream of Kratie

Changes upstream of Kratie were made for the IQQM simulation model only. The parent model for all these models were the calibrated IQQM model. This model is stored in the DSF as the simulation model "*uskr0400 Calibrated IQQM*" in the Scenario "*Calibrated IQQM u/s Kratie*". This model has:

- calibrated inflows;
- all the dams in Laos and Viet Nam extant in 2000;
- constant domestic and industrial demands based on year 2000 populations; and
- time series of crop areas and types, based on historical records.

The last dot point is a useful characteristic of this system file. The historical areas for any year from 1985-2000 can be loaded into the system file by running the calibration model to the year to be saved, and then saving the system file (with a different name). The references at the irrigation nodes then needs to be removed, either through the dialogues, or as through the text editor.

Year 2000 Development Conditions

A system file was developed based on the calibrated model. The system file wsa given the name *uskr0401.sqq*, and imporated the the *Year 2000 Development conditions* scenario.

Irrigation demand

The crop areas from the time series crop files for the year 2000 were loaded into the system file by the method described above, and all references to time series crops deleted.

Domestic and industrial demands

All domestic demand nodes were unchanged from that described in the DSF Volume 11.

Dams

All six storages and the ordering nodes were left active.

Year 1995 Development Conditions

A system file was developed based on the calibrated model.. The system file wsa given the name *uskr0402.sqq*, and imported the the *Year 1995 Development conditions scenario.*

Irrigation demand

The crop areas from the time series crop files for the year 1995 were loaded into the system file by the method described above, and all references to time series crops deleted. There is no evidence that irrigation management practices have changed from 1995 to 2000. Therefore, the same efficiencies and return flows were used as for 2000.

Domestic and industrial demands

All domestic demand nodes were unchanged from that described in the DSF Volume 11. This would overestimate the domestic and industrial demands by ratio of 1995 population to 2000 population. No data was available to estimate this directly, but would be of the order of 10%. As the volume of domestic and industrial demands is of the order of 2-3 % of the irrigation demands, the overestimate would be approximately 0.2%, and is would not significantly affect the conclusions of this study.

Dams

The following dams and their ordering nodes were made inactive:

- Nam Song
- Nam Leuk
- Nam Theun-Hin Boun
- Houay Ho
- Ya Li

The storage node and its ordering node at Nam Ngum remained active, as this storage was operating in 1995.

No Development Conditions

A system file was developed based on the calibrated model.. The system file was given the name uskr0400.sqq, and imported the No development scenario.

Irrigation demand

All irrigation nodes and associated return nodes were made inactive. No irrigation demand, diversions, or return flow would be modelled.

Domestic and industrial demands

All domestic and industrial demand nodes were made inactive. No demand or diversions would be modelled.

Dams

All dam nodes and their associated demand nodes were made inactive. No storage or releases would be modelled.

4.2.3 Downstream of Kratie

Changes downstream of Kratie were made for the:

a IQQM simulation models used to estimate irrigation and domestic and industrial demands.

b iSIS simulation model of the Mekong River system downstream of Kratie.

IQQM demand models

Separate demand models were developed in the DSF for the demands in the

a Great Lake region, from downstream of Kratie to the border between Cambodia and Viet Nam

b Mekong Delta region, from the the border between Cambodia nad Viet Nam to the sea.

The same as for the simulation model upstream of Kratie, the demand models for the calibration had time series of crop areas and types derived from official statistics for the period 1985-2000. These can be used to derive demands for any irrigation development condition over this period.

iSIS simulation model

The calibrated iSIS model was the parent model for the Baseline scenarios. Prior to use for the Baseline scenarios, the following data upgrades were made:

a Upgrading the downstream tidal boundary conditions.

b Upgrading the upstream boundary condition. The simulated flows at Kratie for the respective simulations were input.

c The demands were updated. The calibrated model used demands estimated from IQQM, and averaged over a 90 days period. The 90 day averaging was thought to be long a period to average over, and the data was recalculated over time periods and substituted in the data files. However, the simulation model could not run continuously with the shorter time period, and the 90 day average was agreed on.

Year 2000 Development Condition

System file was developed based on the calibrated model. The system file were given the name *delt0201.sqq* and *lake0301.sqq*, and imported to the *Year 2000 Development conditions* scenario.

Irrigation demand

The crop areas from the time series crop files for the year 2000 were loaded into the system file by the method described above, and all references to time series crops deleted.

Domestic and industrial demands

All domestic demand nodes were unchanged from that described in the DSF Volume 11.

iSIS simulation model

The upstream boundary condition for Kratie was changed to the simulated flow result from the Section 0. The irrigation demands were changed to the results from the IQQM demand models described previously in this section. No changes were made to the topography.

Year 1995 Development Conditions

System file was developed based on the calibrated model. The system file were given the name *delt0205.sqq* and *lake0302.sqq*, and imported to the *Year 1995 Development conditions* scenario.

Irrigation demand

The crop areas from the time series crop files for the year 1995 were loaded into the system file by the method described above, and all references to time series crops deleted.

Domestic and industrial demands

All domestic demand nodes were unchanged from that described in the DSF Volume 11. As for the simulated upstream, this would overestimate the domestic and industrial demands by ratio of 1995 population to 2000 population. It is assumed that this would not significantly affect the conclusions of this study.

iSIS simulation model

The upstream boundary condition for Kratie was changed to the simulated flow result from the Section 0. The irrigation demands were changed to the results from the IQQM demand models described previously in this section.

No changes were made to the topography, or management for this simulation. It is probable that there have been changes in road embankments, dikes, and salinity intrusion barriers over this time, and that these changes would affect the results of the flood patterns and salinity intrusion extent. Further, making these changes would take some time to test and implement.

Therefore the results reported here can only be said to represent the impact of water resource development, and not on structural changes in the Mekong Basin downstream of Kratie.

No Development Conditions

iSIS simulation model

No system file changes were necessary for the IQQM demand models. Instead, all the demands were set to zero in the iSIS simulation model.

The upstream boundary condition for Kratie was changed to the simulated flow result from the Section 0.

No changes were made to the topography, or management for this simulation. It is probable that there have been changes in road embankments, dikes, and salinity intrusion barriers over this time, and that these changes would affect the results of the flood patterns and salinity intrusion extent. Further, making these changes would take some time to test and implement.

Therefore the results reported here can only be said to represent the impact of water resource development, and not on structural changes in the Mekong Basin downstream of Kratie.

4.3 Results reported

Results were saved within the DSF for a number of parameters, then exported and analysed in spreadsheets. For simulated flows, these results were saved at at monitoring points. The other parameters are saved on a BDP subarea basis. The results were saved using the DSF Simulation Model result saving tool.

DSF changes made

Changes were made to the DSF database to enable this. Previously, the diversions were saved as a subparameter *"Demand"* of the parameter *"Flow"*, and assigned a negative value. This label does not clearly describe the parameters[3], nor does it allow the saving of the different classes of diversions, ie., irrigation and domestic and industrial. A new parameter was introduced to the DSF *"Diversion"* with subparameters: (i) *"Irrigation"*; (ii) *"Dom and Ind"*; and (iii) *"Net"*.

The parameter describing the energy produced by hydropower demands was also corrected. Previously it had been described as *"Power"*, whereas the correct term is *"Energy"*, with the units MWh.

Default node changes made

The default results saved to the DSF are defined in a data file "defaultnodes.csv". The one supplied with the delivery of the DSF was incomplete in its node coverage, and also did not have all the parameters saved as required. A new *defaultnodes.csv* file was derived. The first stage of this was mapping the IQQM nodes into ArcView, and then overlaying it on the ArcView shapefile used to produce the map shown in Map . Some manual adjustment had to be made to ensure the nodes were located in the right BDP subareas. These were then reported using the Geoprocessing tool in ArcView, and imported to a spreadsheet.

The following results were saved on a BDP sub-area basis:

- Irrigation demands
- Domestic and Industrial diversions
- Net diversions

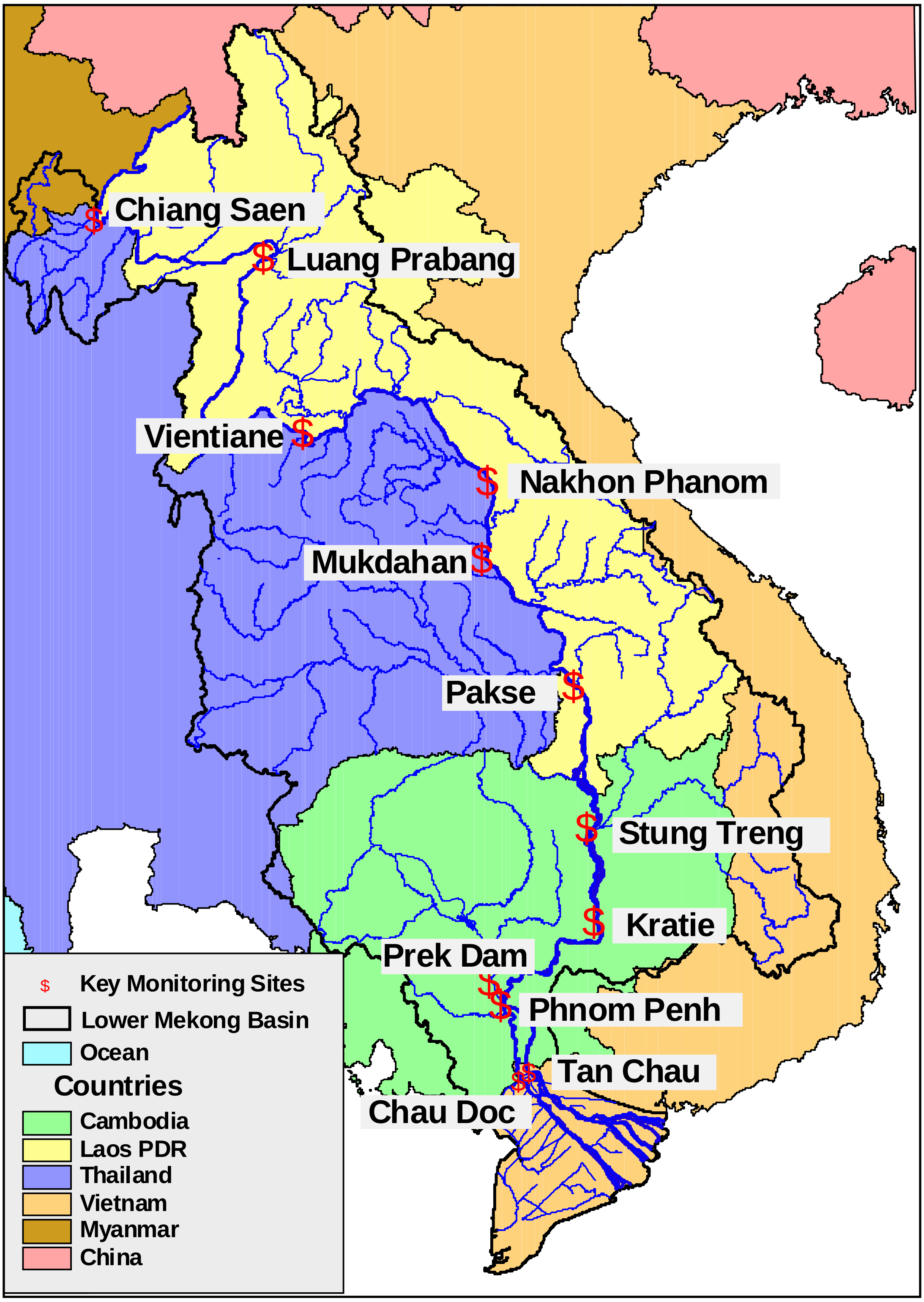
[3] Demand is the water needed, whereas diversion is the water extracted from the river system

- Total crop area
- Sustainable area

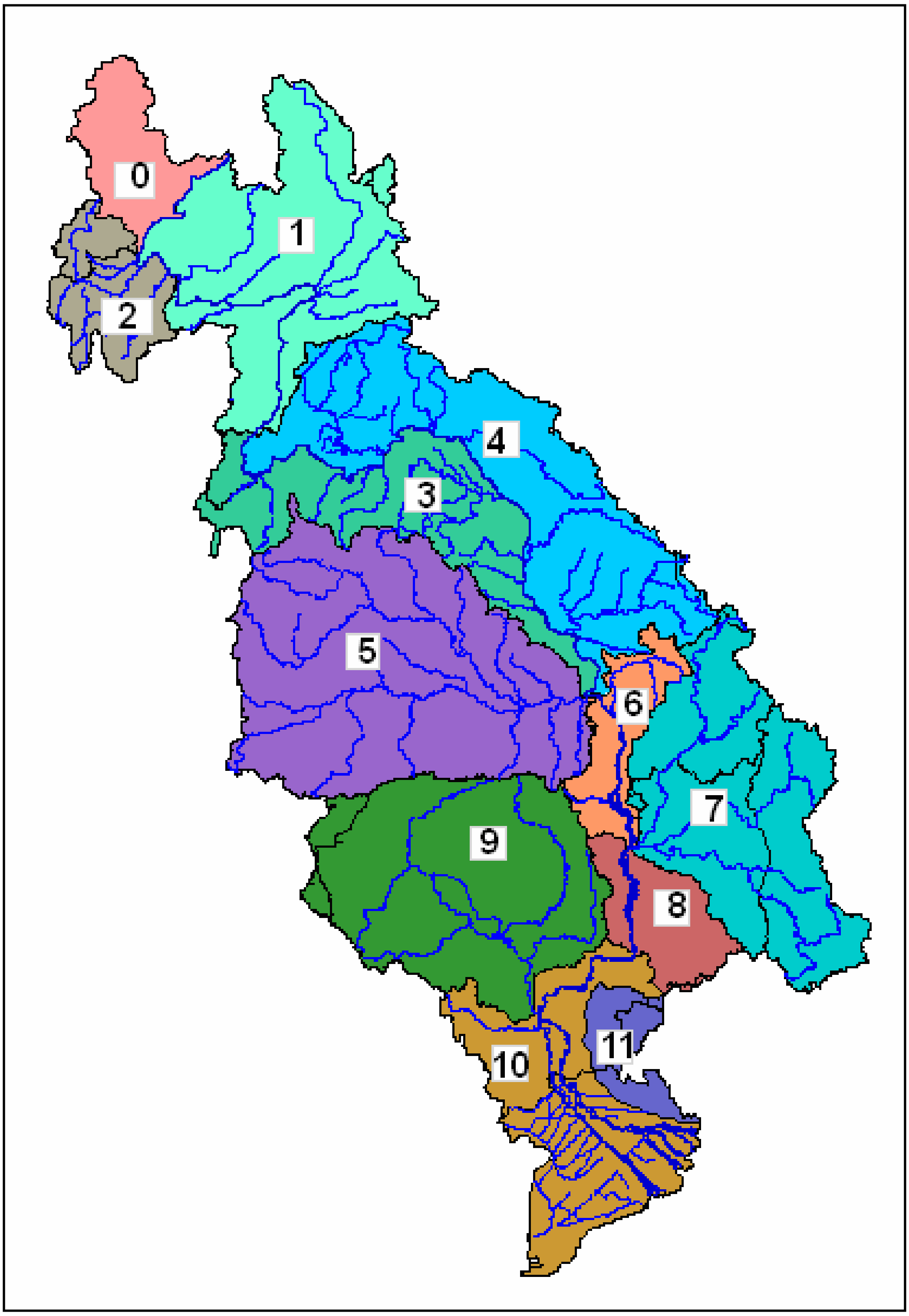
The following results were saved to the DSF at specific points:

- Simulated flows
- Inflows from tributaries and from the Mekong junst upstream of where the tributary enters.
- Energy produced at hydropower dams.

Map 4.1: Location of monitoring points for reporting simulated flow results



Map 4.2: Location of BDP subareas for reporting



4.3.1 Simulated flow

Simulated flow was reported using results from the IQQM simulation models and the iSIS simulation model. The results reported are:

a Mean monthly volumes for the simulation period

b Standard deviation of monthly volumes for the simulation period

c Maximum and minimum volume for the simulation period.

d Changes in the 5th, 50th, and 95th percentile exceedance of daily flows.

The results were reported at the following locations:

- Chiang Saen
- Luang Prabang
- Vientiane
- Nakhon Phanom
- Mukhdahan
- Pakse
- Stung Treng
- Phnom Penh
- Prek Dam
- Chao Doc
- Tan Chau

These results will directly provide the BDP planners with indicators of the flow changes. They can then be used in further impact analysis, such as estimates of flood extent and salinity intrusion in the iSIS simulation model, and throught this impacts in environmental indicators, fish production, navigability etc.

Further, it is likely that Rules for Water Utilisation will be based in part on changes in flow from a Baseline Scenario, Therefore directly reporting these results will inform the BDP planners on whether a scenario complies with the “Rules”.

4.3.2 Net diversions

Net diversions (Div_{net}) are the net amount of water taken from the river system, and represents the total consumptive water usage, and is calculated by **Error! Reference source not found.**

$$Div_{net} = Div_{Irrig} + Div_{D\&I} - Q_{ret} \qquad \textit{Equation 1}$$

Where: Div_{irrig}= water diverted by irrigation demand

$Div_{D\&I}$= water diverted by domestic and industrial demand

Q_{ret}= return flow from irrigation

The water diverted may be less than demands at any of the the irrigation and domestic and industrial if there is insufficient water in the river to satisfy these demands. The net diversions are aggregated and reported as:

a Monthly and annual averages; and

b Monthly and annual maximums, for each BDP subarea.

These results will provide the BDP planners a direct measure of consumptive water usage in the LMB, and also how much additional water availability may be in catchments.

4.3.3 Total crop area and Sustainable Area Index

The alternative baseline scenarios all have a fixed crop for each month of each year, however the irrigation demands and diversions change from year to year depending on climate and water availability. The parameter Total Crop Area is thus reported graphically as the total area for each month for each BDP subarea.

IQQM was enhanced for the DSF to calculate a "Sustainable Area" at each irrigation demand node, as a reality check on maximum area at that node. The irrigation demand is estimated in IQQM from crop areas, types, management, and climate. The IQQM configuration for the LMB will plant whatever area is specified at the irrigation demand nodes, regardless of water availability.

The Sustainable Area reported by IQQM is the area that could have been grown at that location, based on irrigation demand and water availability. For example, if a irrigation demand node estimates that 1000 ML is required to irrigate 10,000 ha that day, but there is only 800 ML available in the river, then the Sustainable Area estimate on that day is 8,000 ha. A ten-day moving average, and no increase over the growing season rule constrains the calculation. It is <u>not</u> the area that can be sustainably grown in the LMB under a general condition.

The Sustainable Area is <u>scenario specific</u>. It will change from scenario to scenario, depending on changes in flow resulting from water resource development upstream. It will change in certain subareas as a result of regulation of flow by storages upstream in the LMB. It will change depending on *in situ* crop areas, types, and management, as well as domestic and industrial demands.

Therefore, rather than report a Sustainable Area, which may create the impression that it is a universal measure of how much area can be grown. It will be referred to as a Sustainable Area Index (SAI), and reported as a percentage of the planted crop area on an annual basis for that sub-area. It is scenario specific, and has to be considered in the context of that scenario.

The SAI will be reported for the month at the end of the growing season for each crop. A SAI will be quoted at least for the dry season and wet season, typically in April / May, and October / November respectively. A third month may be reported if there is a third significant crop type ends it growing season during another month.

4.3.4 Diversions

Diversions are reported for domestic and industrial demand nodes, and also the net diversions on a sub-area basis.

4.3.5 Hydroenergy generated

The power generated at each hydropower dam is calculate using **Error! Reference source not found.**, and the energy is calculated using **Error! Reference source not found.**.

$P = Q_{turbine} * H * \eta * \gamma * g * 0.001$ *Equation 2*

Where: P= Power generated (MW)

$Q_{turbine}$= water released through turbine (m^3/s)

H = Net head (m)[4]

η= efficiency of trubines (estimated as 0.9)

g= gravitational acceleration constant ($9.81 m/s^2$)

γ= weight of water ($1000\ kg/m^3$)

The Energy generated is this power integrated over time, and is calculated as

$E = P * t$ *Equation 3*

Where: E= Energy (MWh)

t= time (hours)

[4] Estimated as difference between water level in dam and level of outlet.

4.4 Results

Results are shown in the following figure and in Tables 4.1 through 4.5.

Figure 4.2: Monthly flow volumes at monitoring points

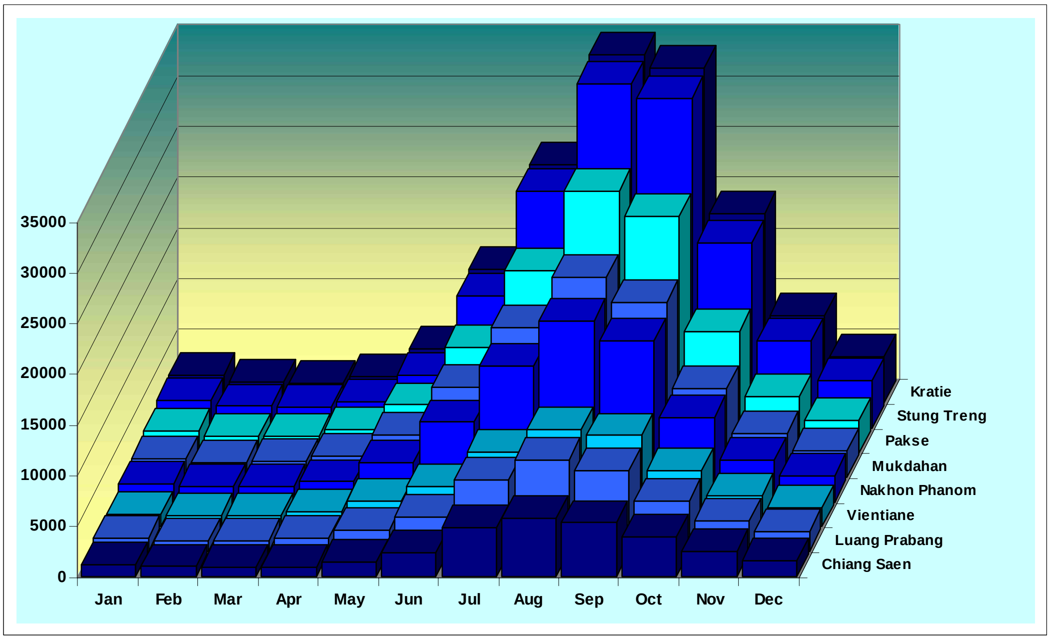


Table 4.1. Average monthly simulated flows (m³/s) for no development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	3,108	2,390	2,377	2,439	3,791	6,146	12,851	15,490	14,049	10,369	6,364	4,241	83,727
Luang Prabang	3,757	2,868	2,879	3,396	5,566	8,843	18,815	24,558	21,149	13,493	8,171	5,290	118,610
Chiang Khan	3,539	2,740	2,930	3,692	6,639	10,229	20,509	27,218	24,215	14,828	8,354	5,135	129,855
Nong Khai	3,599	2,775	2,989	3,861	7,586	11,623	20,969	27,586	25,405	15,753	8,533	5,165	135,593
Vientiane	3,563	2,768	2,978	3,796	6,913	10,412	19,887	26,097	23,888	15,027	8,294	5,082	128,530
Nakhon Phanom	4,852	3,631	3,807	4,876	10,084	20,607	36,358	49,000	42,359	22,708	11,199	6,893	216,060
Mukhdahan	4,976	3,717	3,919	5,028	10,851	23,180	39,723	53,849	45,750	24,162	11,585	7,090	233,468
Pakse	6,157	4,556	4,618	5,773	12,728	27,814	49,405	71,170	61,885	33,113	15,292	9,038	301,089
Stung Treng	8,075	5,753	5,481	6,479	14,356	35,314	64,492	93,477	85,214	49,537	22,701	12,840	402,971
Kratie	7,997	5,722	5,501	6,619	14,816	35,747	65,061	94,453	86,858	50,466	22,863	12,793	408,134

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 4.2. Average monthly simulated flows (m^3/s) for Year 1995 development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	3,105	2,387	2,375	2,438	3,790	6,130	12,839	15,483	14,038	10,360	6,361	4,238	83,659
Luang Prabang	3,725	2,838	2,857	3,387	5,558	8,738	18,728	24,495	21,053	13,398	8,145	5,257	118,009
Chiang Khan	3,506	2,713	2,909	3,682	6,629	10,119	20,383	27,136	24,105	14,695	8,311	5,097	129,119
Nong Khai	3,553	2,736	2,960	3,847	7,574	11,499	20,820	27,498	25,294	15,586	8,465	5,116	134,700
Vientiane	3,521	2,733	2,952	3,783	6,903	10,299	19,754	26,021	23,787	14,875	8,230	5,038	127,724
Nakhon Phanom	4,948	3,730	3,944	5,011	10,239	20,564	35,620	48,134	41,854	22,489	11,194	6,971	214,494
Mukhdahan	5,064	3,809	4,050	5,162	11,003	23,119	38,949	52,958	45,188	23,876	11,567	7,157	231,650
Pakse	6,072	4,482	4,616	5,827	12,570	27,323	47,672	69,307	60,604	31,998	14,834	8,959	293,934
Stung Treng	7,885	5,590	5,411	6,475	14,183	34,828	62,776	91,575	83,904	48,400	22,110	12,622	395,157
Kratie	7,802	5,558	5,421	6,586	14,638	35,264	63,349	92,548	85,546	49,324	22,260	12,563	400,243

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 4.3. Average monthly simulated flows (m^3/s) for Year 2000 development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	83,625
Luang Prabang	3,698	2,814	2,839	3,384	5,559	8,713	18,713	24,485	21,033	13,369	8,117	5,226	117,781
Chiang Khan	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	128,816
Nong Khai	3,498	2,689	2,925	3,837	7,573	11,462	20,787	27,480	25,271	15,531	8,394	5,042	134,239
Vientiane	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	127,305
Nakhon Phanom	4,817	3,674	3,973	5,128	10,364	20,465	35,557	48,063	41,750	22,131	10,904	6,789	213,408
Mukhdahan	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	230,351
Pakse	5,608	4,144	4,444	5,848	12,542	26,942	47,335	69,047	60,541	31,592	14,348	8,412	290,512
Stung Treng	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	7,885	391,255
Kratie	7,166	5,250	5,425	6,789	14,629	34,796	62,910	91,917	85,468	48,875	21,650	12,030	396,340

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 4.4. Percent difference in average monthly flows for 1995 Development conditions compared with no development scenario.

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	-0.1	-0.1	-0.1	0.0	0.0	-0.3	-0.1	-0.1	-0.1	-0.1	0.0	-0.1	***-0.1***
Luang Prabang	-0.9	-1.1	-0.8	-0.3	-0.1	-1.2	-0.5	-0.3	-0.5	-0.7	-0.3	-0.6	***-0.5***
Chiang Khan	-0.9	-1.0	-0.7	-0.3	-0.1	-1.1	-0.6	-0.3	-0.5	-0.9	-0.5	-0.7	***-0.6***
Nong Khai	-1.3	-1.4	-1.0	-0.4	-0.2	-1.1	-0.7	-0.3	-0.4	-1.1	-0.8	-1.0	***-0.7***
Vientiane	-1.2	-1.3	-0.9	-0.3	-0.2	-1.1	-0.7	-0.3	-0.4	-1.0	-0.8	-0.9	***-0.6***
Nakhon Phanom	**2.0**	**2.7**	**3.6**	**2.8**	**1.5**	-0.2	-2.0	-1.8	-1.2	-1.0	0.0	**1.1**	***-0.7***
Mukhdahan	**1.8**	**2.5**	**3.3**	**2.6**	**1.4**	-0.3	-1.9	-1.7	-1.2	-1.2	-0.2	**0.9**	***-0.8***
Pakse	-1.4	-1.6	-0.1	**0.9**	-1.2	-1.8	-3.5	-2.6	-2.1	-3.4	-3.0	-0.9	***-2.4***
Stung Treng	-2.4	-2.8	-1.3	-0.1	-1.2	-1.4	-2.7	-2.0	-1.5	-2.3	-2.6	-1.7	***-1.9***
Kratie	-2.4	-2.9	-1.4	-0.5	-1.2	-1.4	-2.6	-2.0	-1.5	-2.3	-2.6	-1.8	***-1.9***

Table 4.5. Percent difference in average monthly flows for Year 2000 Development conditions compared with no development scenario.

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	-0.2	-0.3	-0.2	0.0	0.0	-0.4	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	*-0.1*
Luang Prabang	-1.6	-1.9	-1.4	-0.3	-0.1	-1.5	-0.5	-0.3	-0.5	-0.9	-0.7	-1.2	*-0.7*
Chiang Khan	-1.8	-1.9	-1.4	-0.4	-0.2	-1.4	-0.7	-0.4	-0.6	-1.2	-1.0	-1.6	*-0.8*
Nong Khai	-2.8	-3.1	-2.1	-0.6	-0.2	-1.4	-0.9	-0.4	-0.5	-1.4	-1.6	-2.4	*-1.0*
Vientiane	-2.5	-2.8	-1.9	-0.6	-0.2	-1.4	-0.8	-0.4	-0.5	-1.3	-1.6	-2.2	*-1.0*
Nakhon Phanom	-0.7	1.2	4.3	5.2	2.8	-0.7	-2.2	-1.9	-1.4	-2.5	-2.6	-1.5	*-1.2*
Mukhdahan	-1.5	0.2	3.6	4.9	2.6	-0.8	-2.1	-1.8	-1.5	-2.8	-3.0	-2.2	*-1.3*
Pakse	-8.9	-9.0	-3.8	1.3	-1.5	-3.1	-4.2	-3.0	-2.2	-4.6	-6.2	-6.9	*-3.5*
Stung Treng	-10.5	-8.4	-1.1	3.1	-1.3	-2.7	-3.3	-2.7	-1.6	-3.2	-5.3	-5.7	*-2.9*
Kratie	-10.4	-8.2	-1.4	2.6	-1.3	-2.7	-3.3	-2.7	-1.6	-3.2	-5.3	-6.0	*-2.9*

5 Analysis of increased storage capacity

by Richard Beecham, May 2004

5.1 Introduction

The present chapter presents results of DSF simulations carried out in early 2004 in connection with the initial scenario analysis.

5.2 Basic assumptions

Table 5.1: Hydrologic and physical characteristics of proposed Chinese dams in Upper Mekong Basin

Dam name	Completion data	Catchment area (km^2)	Average inflow		Dam height (m)	Storage level (m ASL)		Storage volume (mcm)		Area inundated (ha)
			(m^3/s)	(mcm)		Normal	Minimum	Total	Active	
Gonguoqiao	-	97,200	985	31,060	130	1319	1311	510	120	343
Xiaowan	2013	113,300	1,220	38,470	300	1236	1162	14,560	9,900	3,714
Manwan	1993	114,500	1,230	38,790	126	994	982	920	257	415
Dachaoshan	2003	121,000	1,340	42,260	110	895	887	933	367	826
Nuoshadu	2017	144,700	1,750	55,190	254	807	756	22,400	12,300	4,510
Jinhong	2010	149,100	1,840	58,030	118	602	595	1,233	249	511
Ganlanba	-	151,800	1,880	59,290	-	533	-	-	-	12
Mengsong	-	160,000	2,020	63,700	-	519	-	-	-	58

(adapted from Plinston and Daming, 1999)

Table 5.2: Hydropower characteristic of proposed Chinese dams in Upper Mekong Basin

Dam name	Head (m)	Installed capacity (MW)		Firm Power (MW)		Utilisation (hours)	Total Energy (GWh)	
		Single	Cascade	Single	Cascade		Total	Active
Gonguoqiao	130	750	750	170	170	5,420	4,063	4,063
Xiaowan	300	3,600	4,200	1,740	1,765	4,850	18,207	17,548
Manwan	126	1,250	1,500	314	796	5,260	6,710	7,884
Dachaoshan	110	1,000	1,350	276	680	5,200	5,500	6,500
Nuoshadu	254	4,500	5,500	2,100	2,322	5,130	22,396	23,107
Jinhong	118	900	1,500	300	765	5,690	5,570	7,686
Ganlanba	10	100	750	27	75	5,180	587	777
Mengsong	28	400	400	112	337	5,640	2,417	3383

(adapted from Plinston and Daming, 1999)

5.3 Method

5.3.1 Hydrology

The hydrology for the simulation is based on analyses reported in Plinston and Daming. Statistics for five gauging stations along the Lancang were reported in China, at Changdu (catchment area 53,800 km^2); Liutongjiang (76,690km^2); Jiuzhou (87,205 km^2); Gajiu (107,681 km^2), and Jinghong (140,933 km^2). These results were used to estimate the inflows to the storages reported in Table 5.1.

No time series flow data is available at the MRC for any of these stations. It is understood that in recent years, stage data during the wet season has been supplied to the MRCS by the Chinese authorities at Jinghong and a tributary stations for the purpose of flood forecasting. This data falls far short of what is needed for simulating inflows to the storages.

The best available data for this purpose is the flow data at Chiang Saen. This gauging station location has 88% of its catchment area in China. This time series was used as the basis for all the inflows to the storages along the Lancang.

Table 5.3: Inflow estimates to the Chinese Dams

River Reach	Percent of Chiang Saen flow		Annual average flow (mcm)
	Incremental	*Cumulative*	
Headwater *to* Gonguoqiao	36.5	36.5	31,060
Gonguoqiao *to* Xiaowan	8.7	45.2	38,470
Xiaowan *to* Manwan	0.3	45.6	38,790
Manwan *to* Dachaoshan	4.1	49.7	42,260
Dachaoshan *to* Nuozhadu	15.2	64.9	55,190
Nuozhadu *to* Jinghong	3.3	68.2	58,030
Joinghong *to* Ganlanba	1.5	69.7	59,290
Ganlanba *to* Mengsong	5.2	74.9	63,700
Mengsong *to* Chiang Saen	25.1	100.0	85,100

5.3.2 Dam physical characteristics

The detailed required to model a storage in IQQM vary based on the purpose of the modelling. During the calibration of IQQM for the DSF development, detailed information of storage characteristics and operation rules were needed to accurately model storage inflows, releases, and associated storage behaviour. For scenario purposes, it is possible to simulate storage effects with less detailed information.

The most important storage characteristic needed to reasonably estimate the impacts on hydrologic regime is the active storage, that is the volume in the dam that is available to store and release water. In absence of additional data, feasible assumptions can be made of the other physical and operational characteristics.

The data presented below, in combination with some reasonable assumptions, are sufficient to provide an adequate set of physical characteristics, and a feasible set of operational release rules for the storage. The main information gap is the flood operation characteristics.

Storage curve

Three points on the storage curve could be estimated from the data, as described in Table . The assumptions made here are that the relationship between volume, area and height vary linearly. Alternate simple relationships can also be explored, such as using the equations describing the volume of shapes such as half conic prism, or half-rectangular pyramdical prism. More accurate information may be derived from detailed topographic maps, or from the dam survey, if these were available. For a first estimate, the

Table 5.4: Estimating basic storage characteristics from data presented in Table 5.1

Storage curve level	Volume (ML)	Area (ha)	Height (m)
Highest	Total volume	Maximum area inundated	Normal storage level
Inactive	Total volume – active volume	Maximum area inundated * Total volume /Inactive volume	Minimum storage level
Lowest	0	0	Normal storage level – height of dam

Valve characteristics

The rate at which water can be released through the turbine from a storage is typically higher at the maximum storage level, and decreases towards the inactive storage level, and can be described by relationships such as those in Equations 1 and 2.

$Q_{turbine} = a*V^b$ (Equation 1)

$Q_{turbine} = a + b*V$ (Equation 2)

No data is available to desrcribe this relationship. The only part of the relationship that can be estimated with any certainty is the maximum release rate (Q_{max}). This can be calculated by Equation 3, using Head and Installed Capacity data in Table 5.2:

$P_{max} = H * Q_{max} * \eta * \gamma$ (Equation 3)

Where: P_{max} = Installed capacity (MW)

H = Net Head (m)

η= Turbine efficiency (~ 0.9)

γ= Density of water (9,800 kg/m^3).

Spillway characteristics

No information is available to estimate these. Plinston and Daming do not indicate whether these storages have flood gates, or use an uncontrolled spillway. No information is available on the top level of the storage, or geometry (length) of spillway, or gate opening widths, heights, or number. For the purposes of this preliminary analysis, a large discharge capacity spillway was specified, greater than or equal to the maximum daily flow for the simulation period. This assumption may affect estimates of flows during the wet season.

5.3.3 Dam operational rules

Dam operational rules refers directly to decisions on when, and how much water to release from the dam. For the storages modelled in the calibrated model in the LMB, these rules were derived by analysing daily storage level and release data from the dams in Laos, and in the case of Ya Li Dam, from Rule Curves supplied. The results from Ya Li and the Laos dams are some guide as to what the release patterns may look like. The general pattern is that releases are higher in the wet season, as may be expected, and that releases are decreased as storage level decreases.

Neither data nor information is available for the Chinese dams. These had to be derived based on (i) assumptions of how it would be operated, and (ii) data available. Plinston and Daming's analysis operated under similar constraints.

The rule curve derived should be feasible, and would give indicative results for storage releases, and therefore downstream flow impacts. However, other feasible rules curves based on additional data, or from a greater understanding on the driving forces for dam releases, would represent downstream impacts more accurately.

The releases would have the objective of maximising the economic benefit from hydroenergy. Other factors that may be considered include other consumptive needs, flood operations, or maintaining a pattern of instream flows for purposes such as ecosystem maintenance or navigability.

Maximising benefit from hydroenergy

Maximising benefit from hydropower would depend on energy pricing, which would be based on the seasonal supply of energy compared with the seasonal demand for energy. For example, energy demand for heating would be greater in winter. Within any one season, there may also be different prices depending on how much power is generated[i]. For example, *"Firm Power"* which can be generated with 100% reliability, might attract a higher price than *"Secondary Power"* which can only be generated during times of high inflows.

No information is currently available on pricing of power to enable release rates to be formulated based on specific economic returns, although further work could develop this approach. Instead, this was simplified to that the operators would want:

(a) To generate the maximum amount of power possible; and

(b) To be able to generate firm power 100% of the time.

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[i] Note: power is an instaneous value, with units for these dams usually expressed as MW. Energy is product of power and time, and

Power generated is proportional to the product of flow through the turbines, and the net head (Equation 3). As the storage level decreases, the net head decreases, and more water must be released through the turbines to generate the same amount of power compared to that at a higher level. The calculations for net head are straightforward. Optimisations were attempted using the What's Best software to formulate this relationship. However, the version available at MRCS could only handle 3-4 year of time series data at a time, and this created difficulties generalising over the sixteen year simulation period to include in IQQM. So, these assumptions were further generalised to the following objectives.

(a) To release the maximum amount of water through the turbines possible; and

(b) To be able to release a minimum flow 100% of the time.

The first objective ensures that, by releasing the maximum amount of water, the storage will not spill as frequently. Water that is spilled cannot be used to generate hydropower. This rule would operate mostly during the wet season, and in the early part of the dry season when the storage is still full. The second objective ensures that Firm Power can be generated at all times. The maximum rate is that which matches the installed capacity (Section 0). The minimum, or firm flow is calculated from Equation 4, using firm power from Table 5.2.

P_{firm}= (1/Utilisation Fraction) * H_{min} * Q_{firm} * η * γ (Equation 4)

The Utilisation Fraction is an estimate of the amount of time during the year the hydropower dam will release water, and takes account of the fact that energy demand is lower during night hours and weekends. While the storage is releasing water, it will be releasing at a higher rate than that calculated above, which averages the release over the day. The Head term in Equation 4 is calculated at the minimum storage level assuming that the Head term in Table 5.1 applies to the Normal Storage Level.

The use of this method neglects head as a variable for maximising power. However, looking at the sensitivity of power esimates to these variables, flow is the more important to maximise.

A computer program was written to meet these objectives, by carrying out a storage balance with the following inputs:

- maximum storage;
- minimum storage;
- maximum release;
- minimum release; and
- starting level.

as well as the time series of inflows at the dam site (Table 5.3).

The program firstly applies maximum releases to the storage, and identifies periods when the actual release is less than the firm release. The program then calculates backwards from the end of these periods a target volume for each month, below which only minimum releases can be maintained. All periods are treated, and the maximum target volume for each month is applied across the whole simulation period. These monthly target volumes form the basis for an IDT at the ordering node below each dam in the simulation model.

Simulation model

The calibrated model to Kratie was amended to include the Chinese Dams. This was a significant augmentation of the calibrated model requiring additional GIS layers, disaggregating the upper two inflow nodes to appear above the dams, and including the two new dams with their ordering nodes.

It was noted in producing these results that the method to calibrate flow at the mainstream is affecting the results of these and other scenarios. The calibration nodes work by extracting a portion of the flow as defined by a look-up table, thereby removing errors in the inflow estimates. As the flow changes with scenarios, a different amount of flow is removed. This has the effect of distorting the impacts of scenarios. The effect in the context of these scenarios will be demonstrated in Section xxx.

This effect can be remedied by fixing the volumes of water removed at these nodes. The method to do this will be described in the recommendations.

Table 5.5: Output for generating rule curves.

Monitoring site	J	F	M	A	M	J	J	A	S	A	N	D
Release above threshold						Q_{max}						
Storage threshold	100	95	90	87	84	81	92	96	100	100	100	100
Release below threshold						Q_{min}						

Other issues for deriving operational rules curves

Other factors may influence the derivation of rule curves, but were not considered at this time.

(a) Consumptive uses would almost certainly be met by hydropower releases, as there is only limited scope for irrigated agricultural production in the UMB.

(b) Flood operations would try to reserve some storage capacity in the dam and discharge water through flood gates at a controlled rate, but still with the objective of ending with the dam full at the end of the wet season. However, this needs some flood risk analysis, as well as information on flood gate levels and configuration.

No information is evident that there will be any releases for instream needs, although this is something that may be considered in deriving flow rules for the Mekong.

5.4 Results

The main changes reported are flow changes[i]. These are reported at selected monitoring points as:

- hydrographs
- flow duration curves,
- changes in exceedance percentiles;
- changes in average monthly volumes.

5.4.1 Manwan and Dachaoshan

Manwan Dam was completed in 1993, and has a total storage of 920 million cubic meters (mcm), and an active storage of 240 mcm. It has an installed capacity of 1,250 MW, which at a head of 99 m corresponds to a release rate of 1,432m3/s (124 mcm/d). Manwan Dam is required to produce a firm power of 314 MW, which at a head of 87 m, and a utilisation fraction of 0.6, corresponds to a release rate of 245 m3/s (21 mcm/d).

Dachaoshan Dam was reported to be completed in 2003, and has similar characteristics to Manwan Dam, with a total storage of 933 mcm, and an active storage of 367 mcm. Maximum and firm release rates are calculated as 1417 m3/s (122 mcm/d) and 261 m3/s (23 mcm/d) respectively.

Analysis of the inflow data to Manwan dam show that average annual inflow is 1200 m3/s. The maximum release is exceeded 32% of the time. The lowest inflow rate to Manwan Dam is 154 m3/s, which is less than the firm release rate. However, for the period of record, inflow rates less than the release rate only occur about 0.2% of the time. This is only during the month of April, during which inflow rate less than the firm rate occurs approximately 2.3% of the time.

The conclusion from this is that Manwan Dam has a very low regulation capacity, and, even when emptied to the inactive volume, can store little more than 1-2 weeks of the flow for the dryest months. Manwan Dam could be expected to spill over 99% of the time, such that combined turbine and spillway/flood gate discharges are very similar to inflows. The geometry and hydrology of Dachaoshan is similar to that of Manwan Dam, and similar conclusions could be drawn.

Operation rules

The method to generate the rules curves described in Section 0 was not used for Manwan and Dachaoshan Dam, for the reasons described in the previous section. A simple monthly demand pattern was applied to each storage, and manually adjusted to minimise periods when releases were below the firm release rate. These resulted in slightly different release rates to those originally calculated, but would not affect flow patterns downstream as this

[i] The flow units used in the reporting flow are either m^3/s or million cubic metres/d (mcm/d). To convert from m^3/s to mcm/d, a conversion factor of 0.0864 is applied.

would be combined with the spilled water. The adopted patterns for Manwan Dam and Dachaoshan Dam are reproduced in Table .

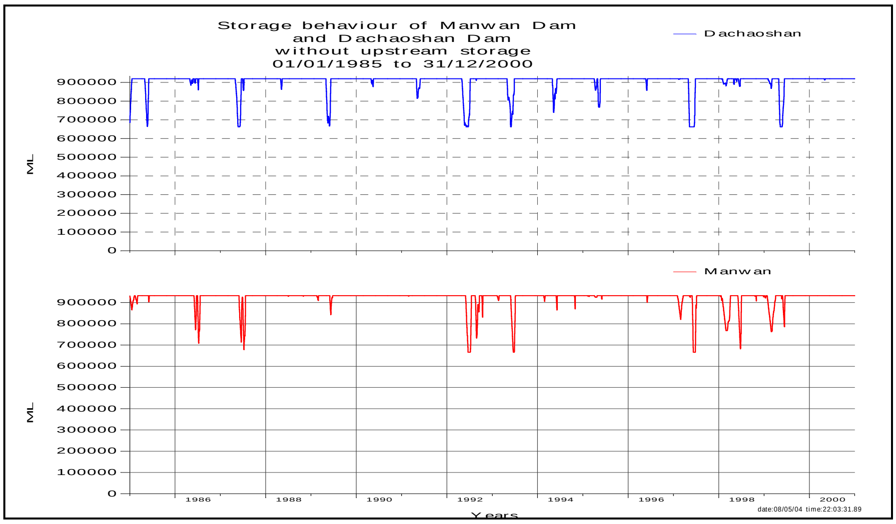
Table 5.6: Adopted release rates for Manwan and Dachaoshan Dam without upstream storage.

Month	Release rate (m3/s)	
	Manwan	Dachaoshan
January	350	440
February	350	440
March	250	275
April	250	275
May	625	440
June	625	825
July	875	1238
August	875	1238
September	875	1238
October	500	1238
November	375	550
December	350	440

Storage behaviour

The changes in the volume of water stored in these two dams for the operating rules described in Section 0 is shown in Figure 5.1. The storages are completely full and releasing all inflows approximately 90% of the time, and are at or close to their inactive volumes approximately 1% of the time. The periods of peak drawdown are usually May-July, during relatively low flows for these months. One of the drawbacks of using monthly patterns is that they release the same volumes no matter the hydrologic or physical conditions. This can be addressed for this scenario, but would ultimately produce results which are qualititatively similar.

Figure 5.1: Storage behaviour of Manwan Dam and Dachaoshan Dam with no upstream storages 1985-2000



Flow changes (1): Hydrographs

The net effect directly downstream of Dachaoshan Dam is shown for the full simulation period at Figure . Inspection of these graphs shows some times there are flow changes at the start of the wet season when the storages are filling. These correspond to the periods of drawdown referred to in Figure 5.2. A notable exception is the dry year 1992, where the storage levels were lower more often, and there were periods throughout the wet season that had lower downstream flows.

Detail for a typical year (1987) is shown in Figure 5.3 to better illustrate the flow changes resulting from releases exceeding inflows. This shows a significant local flow impact, decrease and increases, of these dams during the May-July. The absolute magnitude of these changes are more or less down through the river system, but the relative magnitude of these changes. The significant changes shown in Figure are moderated by downstream inflows. The changes to flow are still quite significant in relative terms for the same period at Chiang Saen, but has more natural characteristics (Figure 5.4). The absolute flow changes at Kratie are simlar, but the relative magnitude is very small, and are difficult to detect at the scale graphed (Figure 5.5).

Figure 5.2: Local impacts of Manwan Dam and Dachaoshan Dam 1985-2000

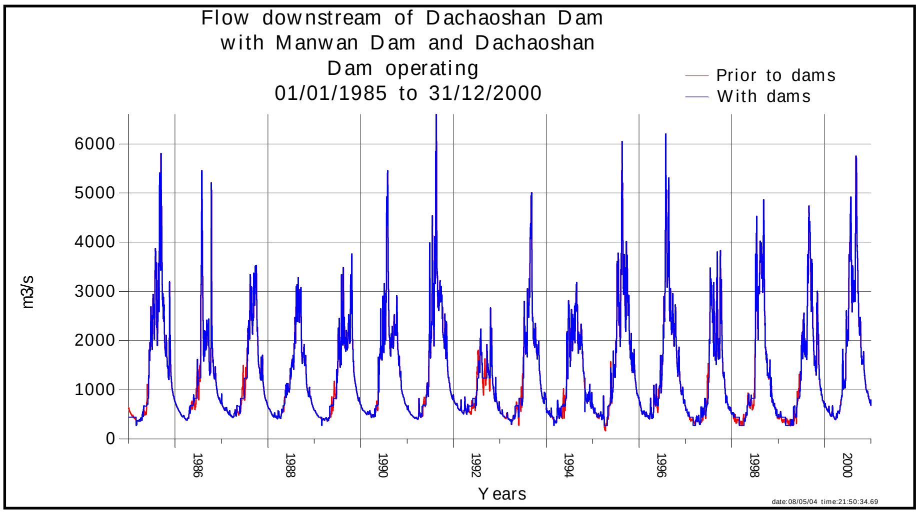


Figure 5.3: Local impacts of Manwan Dam and Dachaoshan Dam 1987

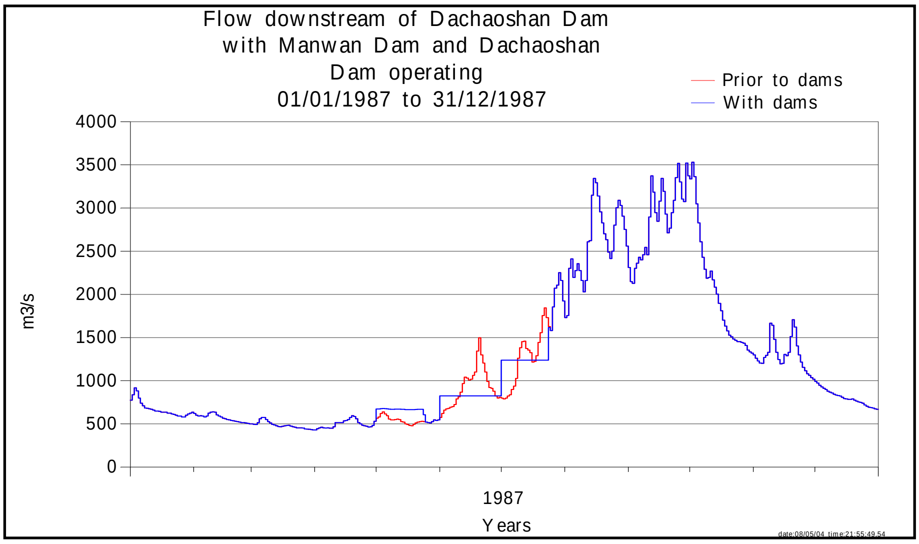


Figure 5.4: Flow impacts of Manwan Dam and Dachaoshan Dam at Chiang Saen 1987.

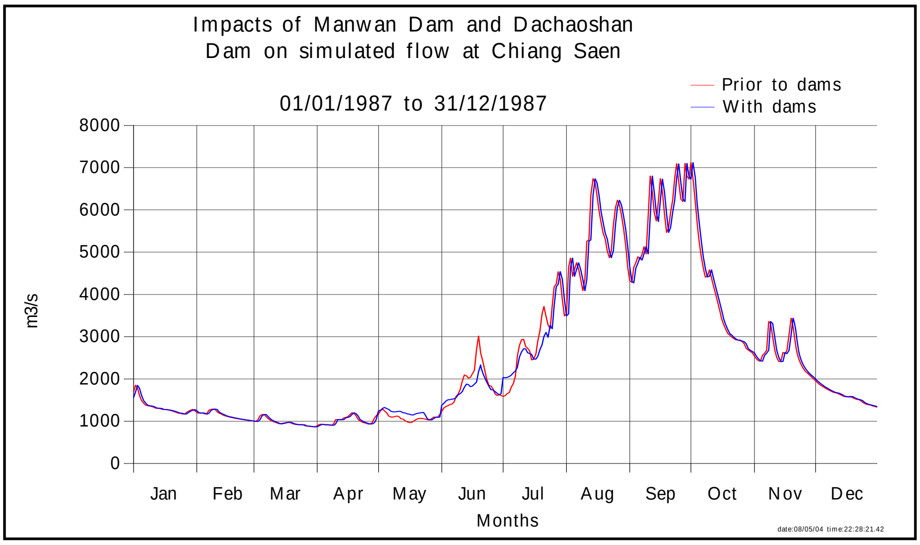
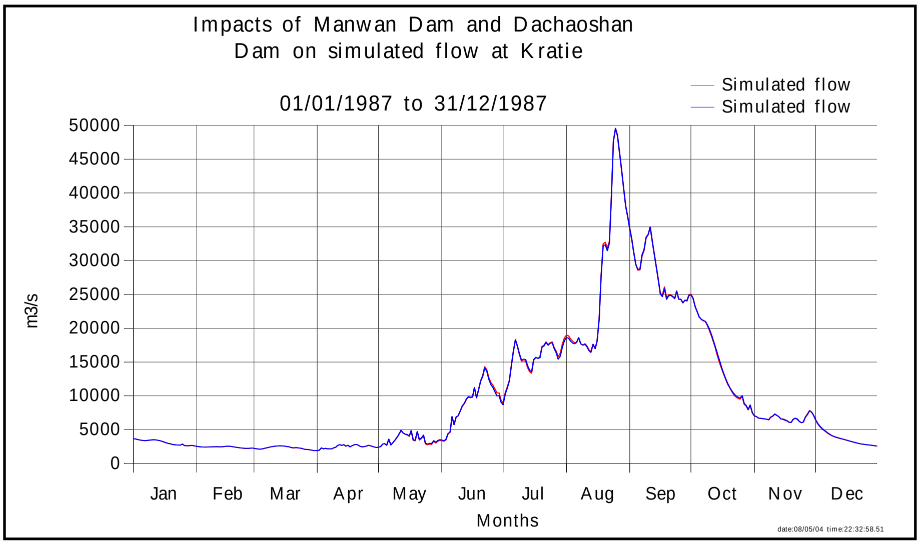


Figure 5.5: Flow impacts of Manwan Dam and Dachaoshan Dam at Kratie: 1987.



Flow changes (2): Monthly flow volumes

Average monthly flow volumes for the simulation period were calculated at all monitoring stations along the mainstream for the scenario based on Year 2000 development conditions, (considered here as a baseline for comparison), and for the scenario with Manwan Dam and Dachaoshan Dam. These results are tabulated in Table 5.7 and Table 5.8 respectively.

Table 5.7: Average monthly simulated flows (mcm) for Year 2000 Development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	3,129	2,424	2,335	2,425	3,844	5,927	12,461	15,314	13,974	10,486	6,448	4,282	83,137
Luang Prabang	3,725	2,849	2,810	3,367	5,617	8,528	18,330	24,323	20,961	13,481	8,220	5,275	117,781
Chiang Khan	3,499	2,713	2,866	3,659	6,681	9,922	19,963	26,954	24,010	14,763	8,371	5,102	128,311
Nong Khai	3,523	2,714	2,906	3,819	7,619	11,312	20,426	27,334	25,216	15,634	8,498	5,089	133,814
Vientiane	3,496	2,716	2,900	3,756	6,949	10,110	19,363	25,864	23,711	14,929	8,267	5,017	126,879
Nakhon Phanom	4,843	3,698	3,964	5,110	10,400	20,358	35,202	47,867	41,686	22,236	10,999	6,840	212,966
Mukhdahan	4,929	3,751	4,052	5,256	11,166	22,902	38,523	52,688	45,015	23,597	11,327	6,989	229,909
Pakse	5,642	4,174	4,437	5,828	12,591	26,891	47,014	68,922	60,552	31,758	14,427	8,469	290,377
Stung Treng	7,263	5,298	5,414	6,660	14,214	34,329	62,011	90,799	83,842	48,125	21,585	12,163	391,120
Kratie	7,197	5,279	5,421	6,770	14,673	34,766	62,582	91,770	85,482	49,045	21,728	12,089	396,202

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 5.8: Average monthly simulated flows (mcm) for Manwan and Dachaoshan dam development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	3,129	2,424	2,335	2,425	3,844	5,927	12,461	15,314	13,974	10,486	6,448	4,282	83,137
Luang Prabang	3,725	2,849	2,810	3,367	5,617	8,528	18,330	24,323	20,961	13,481	8,220	5,275	117,291
Chiang Khan	3,499	2,713	2,866	3,659	6,681	9,922	19,963	26,954	24,010	14,763	8,371	5,102	128,311
Nong Khai	3,523	2,714	2,906	3,819	7,619	11,312	20,426	27,334	25,216	15,634	8,498	5,089	133,814
Vientiane	3,496	2,716	2,900	3,756	6,949	10,110	19,363	25,864	23,711	14,929	8,267	5,017	126,879
Nakhon Phanom	4,843	3,698	3,964	5,110	10,400	20,358	35,202	47,867	41,686	22,236	10,999	6,840	212,966
Mukhdahan	4,929	3,751	4,052	5,256	11,166	22,902	38,523	52,688	45,015	23,597	11,327	6,989	229,909
Pakse	5,642	4,174	4,437	5,828	12,591	26,891	47,014	68,922	60,552	31,758	14,427	8,469	290,377
Stung Treng	7,263	5,298	5,414	6,660	14,214	34,329	62,011	90,799	83,842	48,125	21,585	12,163	391,120
Kratie	7,197	5,279	5,421	6,770	14,673	34,766	62,582	91,770	85,482	49,045	21,728	12,089	396,202

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

These results were compared to see by how much the average flows changed at the stations. These results are tabulated at Table 5.9, and shown graphically at Figure 5.6:. The scaling in the figure is deliberate, to allow comparison for the scenarios with the larger dams.

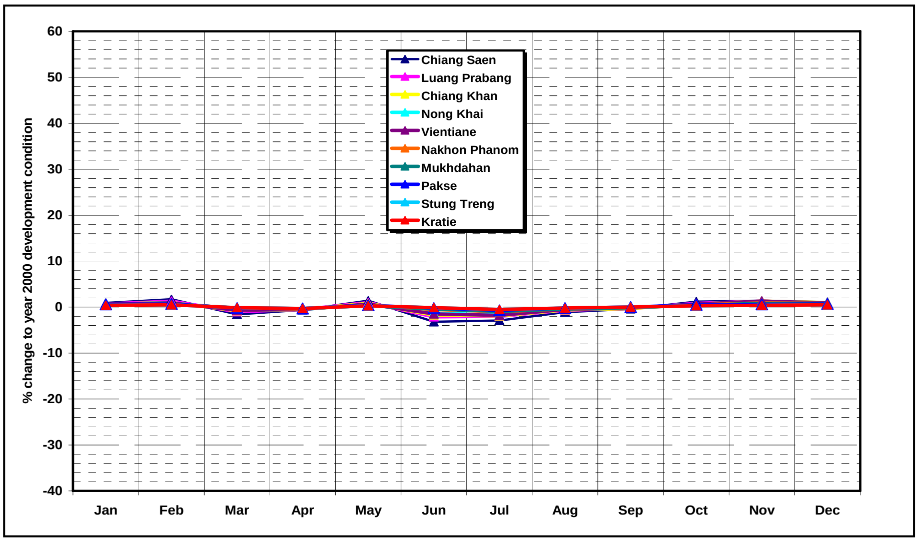
The general pattern of the differences is slightly more flow during the dry season months, and less during the wet season months. The relative difference decreases along the Mekong River, from 1-1.5% higher in the dry season at Kratie, to 0.3-0.4% change. The wet season differences decrease by a higher proportion, from 3% lower during the beginning of the dry season at Chiang Saen, to 0.5% lower at Kratie.

This result is for the release pattern specified above. Variations on these results could be produced from different release patterns. But they would be qualitiatively similar.

Table 5.9: Percent difference in average monthly flows for Manwan and Dachaoshan dam scenario compared with year 2000 development scenario.

Monitoring site	J	F	M	A	M	J	J	A	S	A	N	D
Chiang Saen	0.9	1.7	-1.6	-0.6	1.4	-3.2	-2.9	-1.1	-0.4	1.2	1.4	1.1
Luang Prabang	0.7	1.3	-1.0	-0.5	1.0	-2.1	-2.0	-0.7	-0.3	0.8	1.3	0.9
Chiang Khan	0.7	1.0	-0.8	-0.5	0.8	-1.7	-1.9	-0.6	-0.3	0.7	1.3	1.0
Nong Khai	0.7	0.9	-0.6	-0.5	0.6	-1.3	-1.7	-0.5	-0.2	0.7	1.2	0.9
Vientiane	0.7	0.9	-0.7	-0.5	0.7	-1.5	-1.8	-0.5	-0.2	0.7	1.3	0.9
Nakhon Phanom	0.5	0.7	-0.2	-0.4	0.4	-0.5	-1.0	-0.4	-0.2	0.5	0.9	0.8
Mukhdahan	0.5	0.7	-0.2	-0.3	0.3	-0.4	-0.9	-0.4	-0.1	0.4	0.8	0.8
Pakse	0.6	0.7	-0.2	-0.3	0.4	-0.2	-0.7	-0.2	0.0	0.5	0.6	0.7
Stung Treng	0.5	0.6	-0.1	-0.3	0.3	-0.1	-0.5	-0.2	0.0	0.4	0.4	0.5
Kratie	0.4	0.5	-0.1	-0.3	0.3	-0.1	-0.5	-0.2	0.0	0.3	0.4	0.5

Figure 5.6: Percent difference in average monthly flows for Manwan and Dachaoshan dam scenario compared with year 2000 development scenario



5.4.2 Xiaowan, Manwan and Dachaoshan

Xiaowan Dam construction is underway, and scheduled to be completed in 2010. The dam has a total storage of 14,560 mcm, and an active storage of 9,900 mcm. It will have an installed capacity of 4,200 MW, which at a head of 248 m corresponds to a release rate of 1,920 m^3/s (165 mcm/d). Xiaowan Dam is required to produce a firm power of 1,760 MW, which at a head of 174 m, and a utilisation fraction of 0.55, corresponds to a release rate of 632 m3/s (55 mcm/d).

Xiaowan Dam's active storage is about forty times greater than that for Manwan Dam and Dachaoshan Dam, and enables significant storage and regulation of flow. Xiaowan Dam's active storage can store about three months average inflow, or between six to nine months of dry season flow – without releases.

Xiaowan Dam will significantly affect the operational characteristics of Manwan Dam and Dachaoshan Dam. Instead of receiving a natural pattern of inflows, these dams will receive a highly regulated pattern of inflows. The release pattern will therefore reflect the new patterns of inflows. Maximum and firm release rates for Manwan Dam are 145 mcm and 53 mcm. The corresponding vlaues for Dachaoshan Dam are 165 mcm and 55 mcm.

Operation rules

The method to generate the rules curves described in Section 0 was used to estimate the rules curves sequentially for Xiaowan Dam, Manwan Dam, and Dachaoshan Dam respectively. The target storage levels (TSL) based on Q_{max} and Q_{firm} for Xiaowan Dam were derived intially. The simulation model was then configured with these results, and the inflows to Manwan Dam were extracted from the simulation model results. This regulated set of inflows were then used to generate the TSLs for Manwan Dam. The process was repeated for Dachaoshan Dam. The results from this are reported in Table 5.10.

The TSLs for Xiaowan Dam are logical, suggesting that the most significant failure under maximum release rates would have occurred in July, and that TSLs prior to this increased to maintain a reserve to release firm flows. The TSL is typically 25-40% of the active storage. The TSLs for Manwan Dam and Dachaoshan Dam are very close to the inactive storage volume, and suggest that the regulated inflows reduce the risk of these storages emptying.

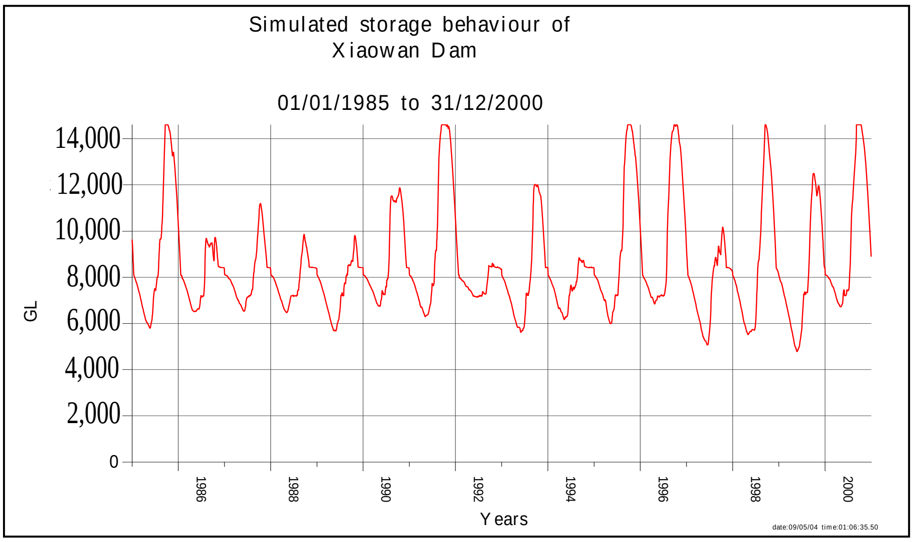
Table 5.10: Target storage levels (TSL (mcm)) for firm power releases for Xiaowan, Manwan and Dachaoshan Dam in series.

Month	Xiaowan		Manwan		Dachaoshan	
	TSL (mcm)	Q_{firm} (mcm)	TSL (mcm)	Q_{firm} (mcm)	TSL (mcm)	Q_{firm} (mcm)
January	8,095	53	702	53	666	55
February	7,978	53	702	53	668	55
March	7,835	53	703	53	669	55
April	7,590	53	703	53	671	55
May	7,412	53	703	53	666	55
Jun	7,171	53	662	53	666	56
Jul	7,129	53	662	53	666	59
August	7,251	53	662	54	666	81
September	8,411	53	662	54	666	62
October	8,411	53	662	78	666	91
November	8,411	53	662	55	666	63
December	8,411	53	684	53	666	56

Storage behaviour

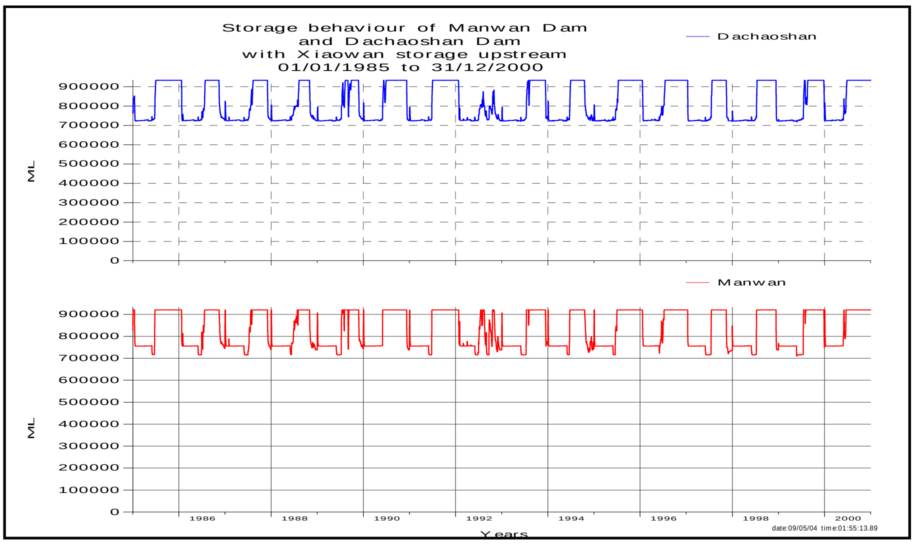
The changes in the volume of water stored in Xiaowan Dam, resulting from the operational rules described above is shown in Figure 5.7. This behaviour appears feasible in that it releases the maximum amount of water, and is not drawn down the the inactive storage volume. The lowest stoage level, just above inactive storage volume, occurs in 1999. The first part of the simulation period, the storage levels are in the range of 25-50% of active storage levels, and in the later part of the period, Xiaowan Dam fills and spills regularly. The impact of this lower head value on power generation would warrant review.

Figure 5.7: Simulated storage behaviour for Xiaowan dam.



The storage behaviours for Manwan Dam and Dachaoshan Dam with Xiaowan Dam regulating releases from upstream are shown in Figure 5.8. These are very different to that from shown in Figure . These dams can be run at higher release rates at a lower level without risk of emptying.

Figure 5.8. Simulated storage behaviour for Manwan Dam and Dachaoshan Dam with regulated inflows from Xiaowan Dam releases.



Flow changes (1): Hydrographs

The net effect directly downstream of Xiaowan Dam is shown for the full simulation period at Figure , and in some detail for a single year. Xiaowan Dam will often, but not always, store a significant part of the early wet season flow. After the storage volume exceeds the target storage level, it will release all the inflows up to the maximum release rate. Thereafter, it stores water while releasing at maximum rate.

For a few weeks after it peaks, it will continue to release water at maximum rate until it reaches a target storage level, after which releases progressively decrease to the firm rate. This results in relatively abrupt changes in flow, sometime between early November and late January. It will then release water at the firm rate until the beginning of the next dry season. The abruptness of the release changes would likely carry through the whole river system.

Compared with the local impacts of Manwan and Dachaoshan Dam alone, which only significantly impact a short period within each year. Xiaowan impacts flow significantly across the year. Dry season flows are typically much higher, and Xiaowan Dam decreases flow over the whole wet season. There will be exceptions to this when the storage spills.

Figure 5.9: Simulated flow impacts downstream of Xiawan Dam- 1985-2000.

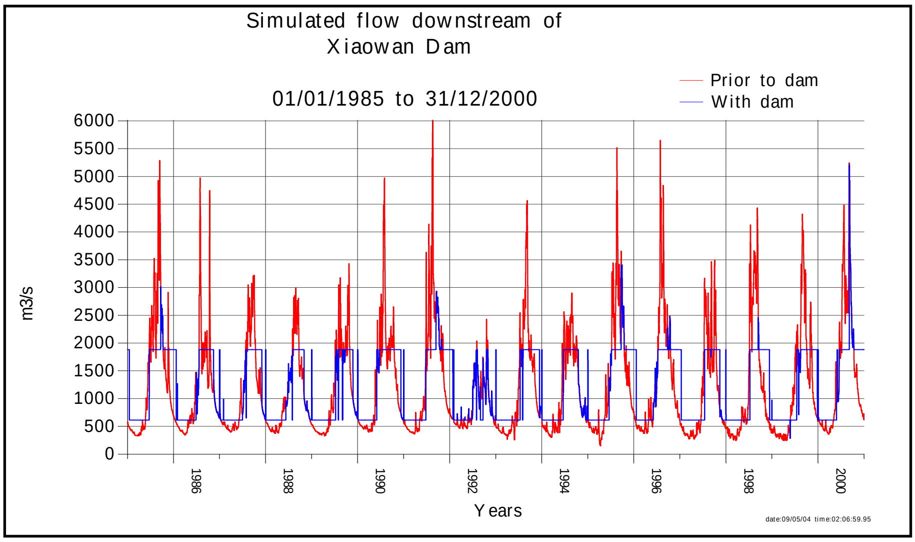
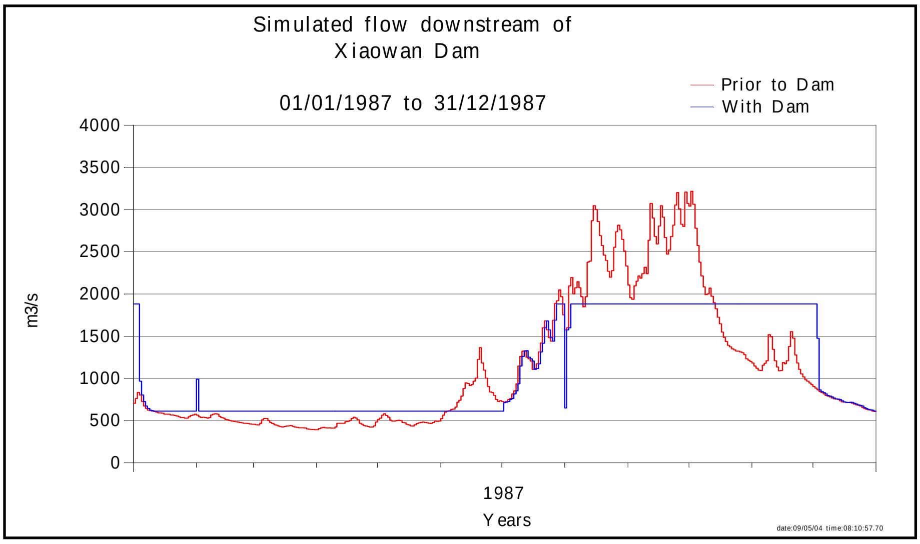
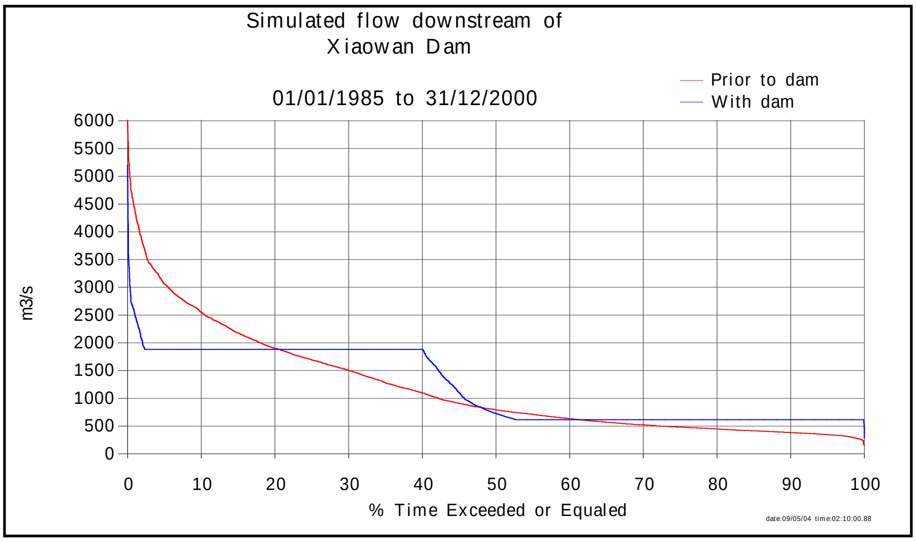


Figure 5.10: Simulated flow impacts downstream of Xiaowan Dam- 1987



The changes in distributions of flows are quite significant, as can be seen from the time series, but also for the flow duration curve of before and after. Flows are increased about 38% of the time, and over 97% of the time in the months of February through April. These flow increases can at times increase by up to 150 %, or 350 m^3/s.

Figure 5.11: Flow duration curve of local effects of Xiaowan Dam.



The flow changes are again dampened along the Mekong, although still significant, especially at the upper gauging stations. The hydrograph for 1987 shows the same general changes in the dry and wet season as shown immediately below Xiaowan Dam. However, as these three dams only regulate just under half the flow at Chiang Saen, then the additional natural flow downstream progressively restores flow variability. The patterns before and after flow regulation have the same shape, however, the absolute changes are still apparent in the higher dry season flows and the lower wet season flows. The abrupt changes at the end of the wet season carry through.

Figure 5.12: Simulated flow impacts at Chiang Saen with Xiawan, Manwan and Dachaoshan Dam- 1987

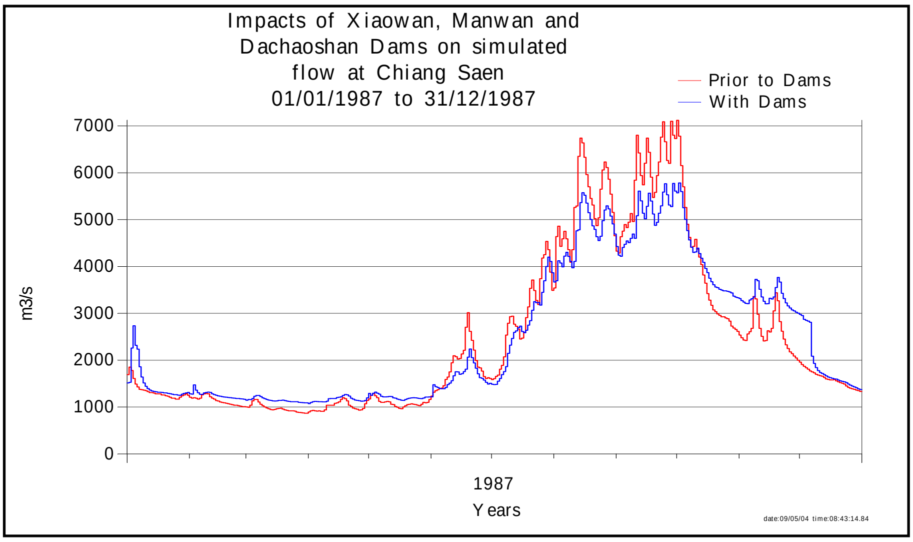


Figure 5.13: Flow duration curve of simulated flows prior to and after Xiaowan, Manwan, and Dachaoshan Dams at Chiang Saen: 1985-2000.

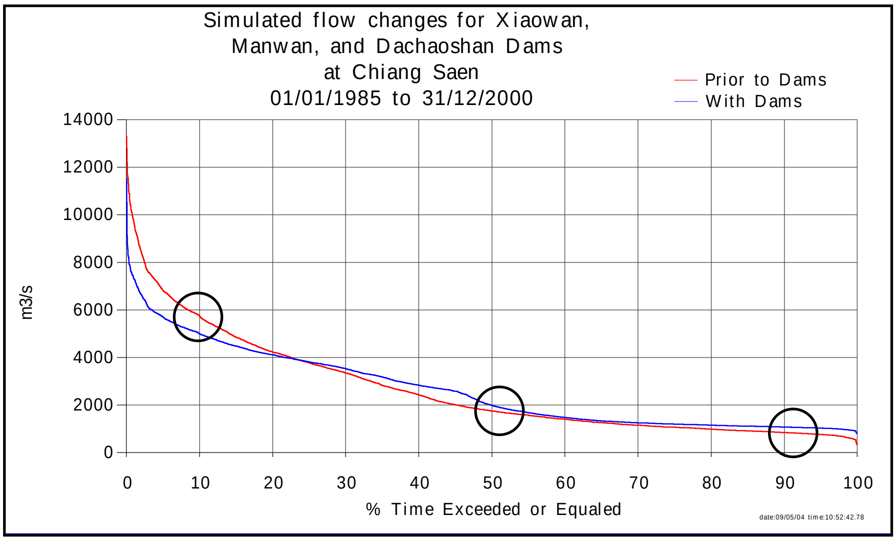
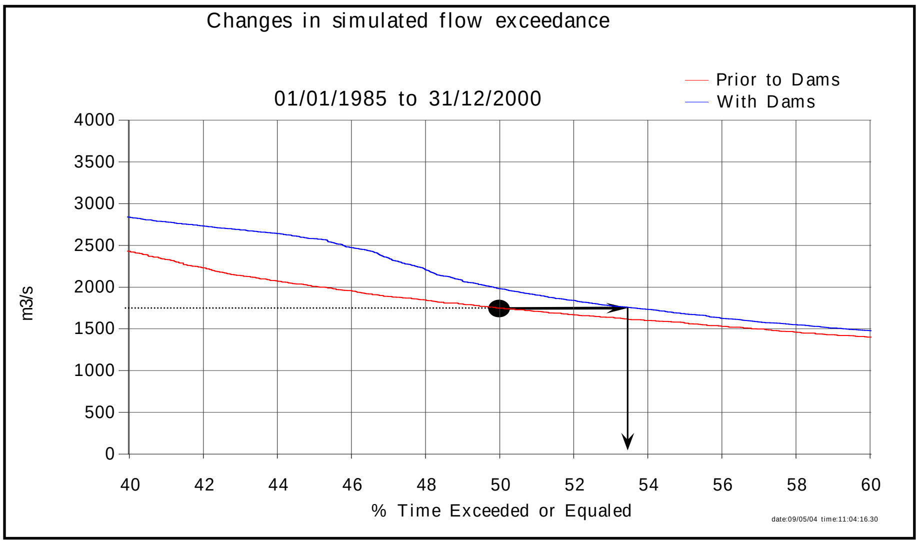


Figure 5.14: Reporting changes in flow exceedance for scenario.



Reporting the changes in exceedance is demonstrated in the example at Figure 5.14. The 50th percentile exceedance of simulated flow at Chiang Saen was 1750 m^3/s prior to these dams. This same flow now occurs 53.5%, ie, 3.5% more frequently. Similar analysis has the 10th percentile flow (5740 m^3/s) occurring 5% less frequently, ie (5% of the time), whereas the 90th percentile flow occurs (846 m^3/s) occurs 9.5% more frequently, (99.5% of the time).

The result at Kratie is a lot less significant, as would be expected. The hydrograph for 1987 is shown for detail at Figure 5.15, and the flow duration curve at Figure 5.16. Inspection of these graphs shows that there is some flow changes at the start of the wet season when the storages are filling. In absolute terms the flow changes are similar, although moderated by the calibration nodes. The abrupt change apparent at the upper sites are not apparent for this year. In relative terms, the changes do not appear as significant, as 90% of the flow at Kratie enters downstream of these dams.

The changes in frequency are also less significant than at Chiang Saen, with the:

(a) 10th percentile exceedance flow of 32,600m^3/s now occuring 9.7% of the time, or 0.3% different;

(b) 50th percentile exceedance flow of 6,430 m^3/s now occuring 48.5% of the time, a change of 1.5%; and

(c) 90th percentile exceedance flow of 1950m^3/s prior to Xiaowan occuring 94% of the time after Xiaowan.

The greatest effect of the dams occurs during lower flow ranges, particularly those occuring during the dry season. These changes would be larger if (a) was calculated only for the wet season, and (c) calculated only for the dry season.

Figure 5.15: Simulated flow impacts at Kratie with Xiawan, Manwan and Dachaoshan Dam- 1987

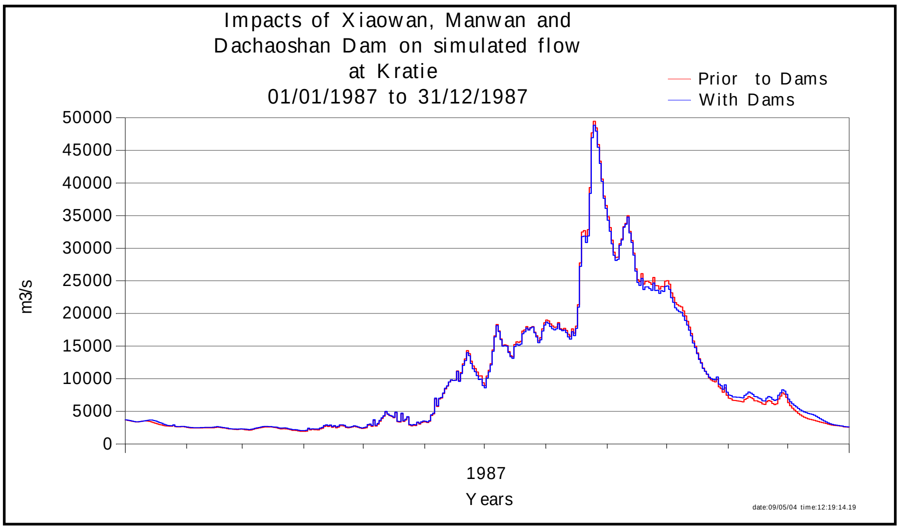
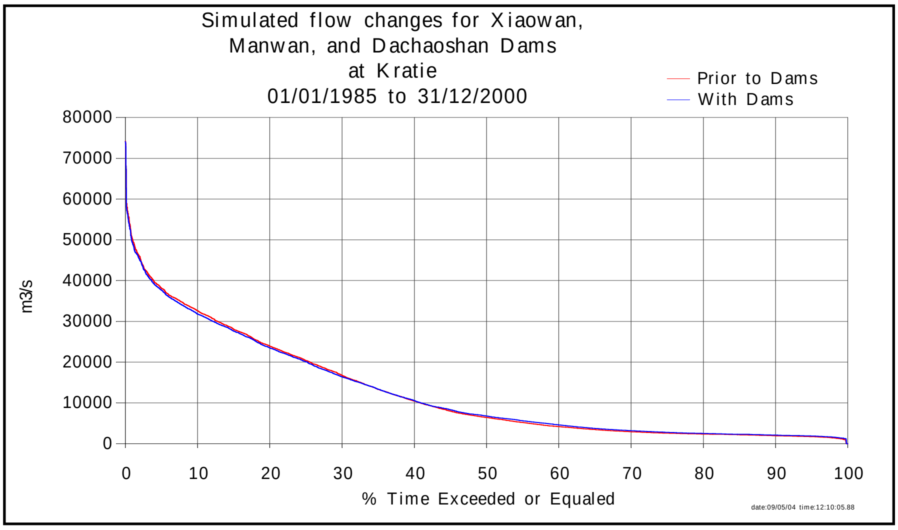


Figure 5.16: Flow duration curve of simulated flows prior to and after Xiaowan, Manwan, and Dachaoshan Dams at Chiang Saen: 1985-2000.



Flow changes (2): Monthly flow volumes

Average monthly flow volumes for the simulation period were calculated at all monitoring stations along the mainstream for the scenario with Xiaowan Dam, Manwan Dam and Dachaoshan Dam.

The percentage changes are about one order of magnitude greater than those for the much smaller Manwan and Dachaoshan Dams. Maximum dry season flows increases are of the order of 40% at Chiang Saen, decreasing to 30% at Vientiane , 20% at Nakhon Phanom, and 10% at Kratie. Maximum wet season flow decreases are of the order of 15% at Chiang Saen, and reduce in Magnitude in a similar manner to 8% at Vientiane, 4% at Nakhon Phanom, and 2% at Kratie. Changes in individual months would be higher.

These results should be treated as indicative at this stage. Two issues have been identified with these changes.

(i) The impact of not fixing the flows removed by calibration, thereby underestimating the impact.

(ii) The greatest simulated increases are in the early part of the dry season, because the derived rules curves release at the maximum rate. An alternate feasible set of rule curves may taper these releases to release more later in the dry season. Largest increases would then appear in March and April.

Table 5.11: Average monthly simulated flows (million cubic metres) for Xiaowan, Manwan and Dachaoshan dam development scenario

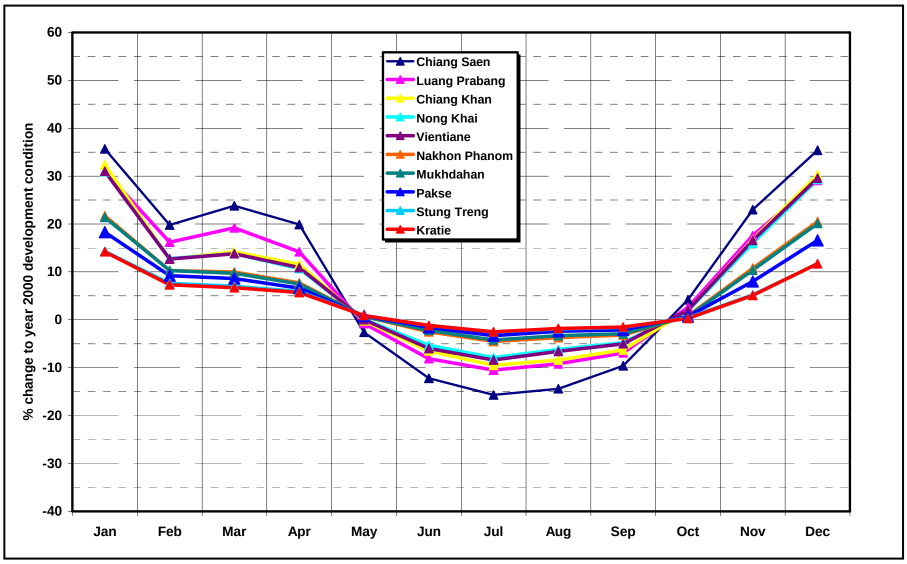
Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	4,210	2,855	2,938	2,923	3,693	5,376	10,818	13,245	12,690	10,787	7,822	5,735	83,202
Luang Prabang	4,846	3,268	3,384	3,866	5,514	8,011	16,751	22,237	19,585	13,719	9,547	6,749	117,293
Chiang Khan	4,601	3,028	3,297	4,103	6,617	9,432	18,426	24,856	22,564	14,953	9,658	6,586	127,921
Nong Khai	4,578	3,033	3,329	4,247	7,580	10,860	19,136	25,763	24,068	15,822	9,740	6,519	134,390
Vientiane	4,547	3,032	3,324	4,183	6,902	9,652	18,070	24,294	22,574	15,126	9,518	6,444	127,458
Nakhon Phanom	5,862	4,052	4,369	5,525	10,434	19,961	33,942	46,303	40,433	22,315	12,084	8,183	213,228
Mukhdahan	5,951	4,110	4,455	5,672	11,209	22,509	37,265	51,126	43,754	23,663	12,403	8,334	230,168
Pakse	6,632	4,525	4,826	6,235	12,638	26,502	45,759	67,362	59,281	31,812	15,495	9,812	290,558
Stung Treng	8,264	5,669	5,796	7,071	14,294	33,955	60,772	89,252	82,529	48,128	22,619	13,515	391,293
Kratie	8,180	5,631	5,789	7,173	14,757	34,394	61,345	90,224	84,164	49,042	22,757	13,442	396,314

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 5.12: Percent difference in average monthly flows for Xiaowan, Manwan and Dachaoshan dam scenario compared with year 2000 development scenario.

Monitoring site	J	F	M	A	M	J	J	A	S	A	N	D
Chiang Saen	35.7	19.8	23.8	19.9	-2.6	-12.2	-15.7	-14.4	-9.6	4.2	23.0	35.4
Luang Prabang	31.0	16.2	19.2	14.2	-0.8	-8.1	-10.5	-9.2	-6.9	2.6	17.6	29.1
Chiang Khan	32.4	12.7	14.2	11.6	-0.2	-6.5	-9.5	-8.4	-6.3	2.0	16.8	30.3
Nong Khai	30.9	12.8	13.8	10.7	0.1	-5.3	-7.9	-6.2	-4.8	1.9	16.0	29.3
Vientiane	31.0	12.7	13.8	10.9	0.0	-6.0	-8.4	-6.6	-5.0	2.0	16.6	29.6
Nakhon Phanom	21.7	10.3	10.0	7.7	0.7	-2.5	-4.5	-3.7	-3.2	0.8	10.8	20.5
Mukhdahan	21.4	10.3	9.7	7.5	0.7	-2.2	-4.2	-3.3	-2.9	0.7	10.4	20.1
Pakse	18.3	9.2	8.6	6.6	0.8	-1.6	-3.3	-2.4	-2.1	0.7	8.0	16.6
Stung Treng	14.3	7.6	7.0	5.9	0.9	-1.2	-2.5	-1.9	-1.6	0.4	5.2	11.7
Kratie	14.2	7.3	6.7	5.7	0.9	-1.2	-2.5	-1.8	-1.5	0.3	5.1	11.7

Figure 5.17: Percent difference in average monthly flows for Xiaowan, Manwan, and Dachaoshan dam scenario compared with year 2000 development scenario



5.4.3 Nuozhadu, Xiaowan, Manwan and Dachaoshan

Nuozhadu Dam is the largest of the dams designed in the Upper Mekong Basin, with an active storage of 12,400 mcm, or about 25% greater than Xiaowan Dam. It has the potential to regulate a further 15% of the water above Chiang Saen, and also to reregulate releases from the upper storages. It will have an installed capacity of 5,500 MW, which at a head of 205 m corresponds to a release rate of 3,042 m^3/s (263 mcm/d). Nuozhadu is designed to produce a firm power of 2,322 MW, which at a head of 154 m, and a utilisation fraction of 0.60, corresponds to a release rate of 1,000 m^3/s (86 mcm/d).

Operation rules

The method to generate the rules curves described in Section 0 was used to estimate the rules curves for Nuozhadu Dam. The simulation model developed for the scenario with Xiaowan, Manwan and Dachaoshan Dams (Section 0) was run, and simulated flows at the Nuozhadu Dam site extracted as input to the program for estimating target storage levels.

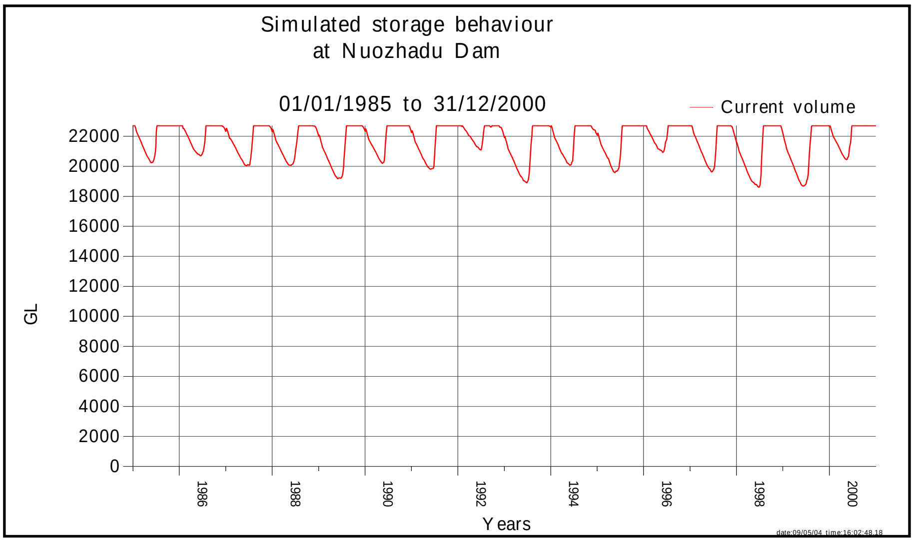
Table 5.13: Target storage levels (TSL (mcm)) for firm power releases for Xiaowan, Manwan and Dachaoshan Dam in series.

Month	TSL (mcm)	Q_{firm} (mcm)
January	20,953	86
February	22,700	86
March	22,481	86
April	22,123	86
May	21,777	86
Jun	21,401	86
Jul	21,158	86
August	21,155	86
September	21,155	86
October	21,155	86
November	21,155	86
December	21,155	86

Storage behaviour

The storage behaviour of the dams above were not changed. The changes in the volume of water stored in Nuozhadu Dam, resulting from the operational rules described above is shown in Figure . The storage does not appear to be drawing down sufficiently to the inactive volume of 10,300 mcm, and these target storage levels could be decreased without it impacting firm power releases. The subsequent analysis is based on these results.

Figure 5.18: Simulated storage behaviour at Nuozhadu Dam



Flow changes (1): Hydrographs

The net effect directly downstream of Nuozhadu Dam is shown for the full simulation period at Figure . This shows basically period of firm release and maximum release, with periods of spill. As discussed in the previous section, the rule curves are underestimating the release rate, with the effect of underestimating increases in dry season flow, and decreases in wet season flow. These rule curves need to be revised. Neverthless, changes for 1987 are shown downstream of Nuozhadu, at Chiang Saen, and at Kratie, at Figure 5.20:, Figure 5.21 and Figure 5.22 respectively to demonstrate the attenuation of flow impacts.

The simulated flow is substantially more in the dry season, as a result of releasing 1000 m^3/s, 3-400 m^3/s greater than the natural flow. The flow is substantially less though the wet season when Nuozhadu is storing water, and greater in the early part of the dry season. As the storage starts to draw down, the release rate is cut back to the firm release rate, still greater than the dry season flows for November and December.

Figure 5.19: Simulated flow impacts downstream of Nuozhadu Dam: 1985-2000

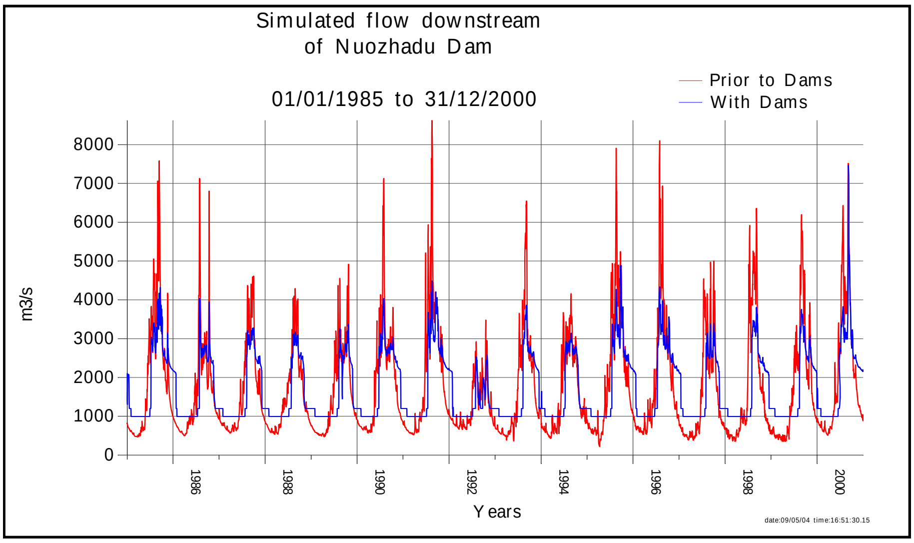
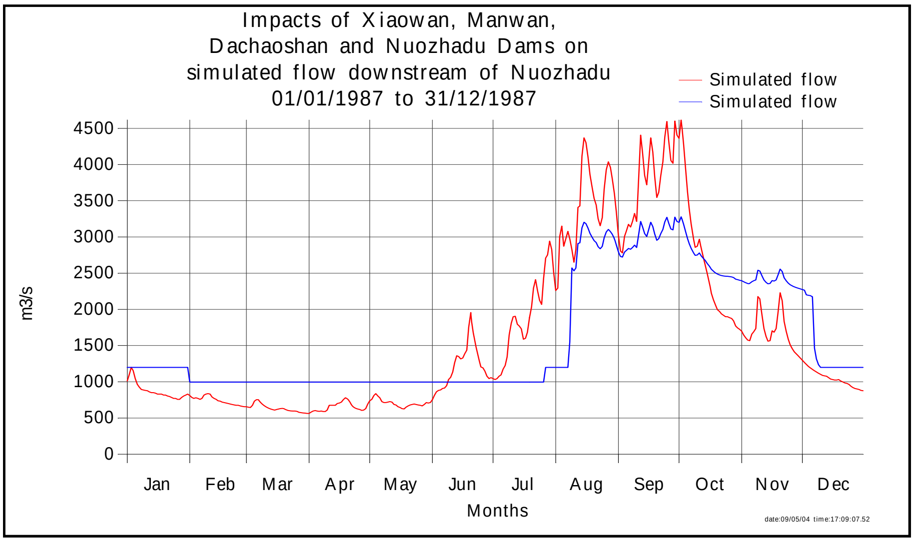


Figure 5.20: Simulated flow impacts downstream of Nuozhadu Dam: 1987



This result is still very significant at Chiang Saen, with the restoration of some flow variability. The decreased wet season flow still appears significant at Kratie for July and September, and the increased dry season flows can still be detected, even at this scale.

Figure 5.21: Downstream flow impacts of Xiaowan, Manwan, Dachaoshan and Nuozhadu Dams at Chiang Saen: 1987

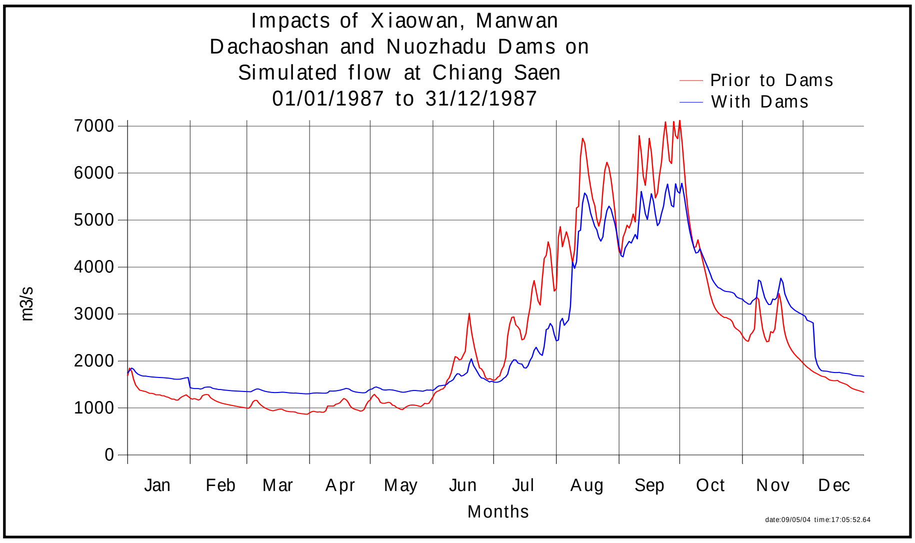


Figure 5.22: Downstream flow impacts of Xiaowan, Manwan, Dachaoshan and Nuozhadu Dams at Chiang Saen: 1987.

Flow changes (2): Monthly flow volumes

Average monthly flow volumes for the simulation period were calculated at all monitoring stations along the mainstream for the scenario with Nouzhadu, Xiaowan Dam, Manwan

Dam and Dachaoshan Dam, and the results reported in Table . The percent changes are reported in Table 5.15:, and shown graphically at Figure 5.23.

These results are similar in pattern to those reported for Xiaowan Manwan, Dachaoshan Dam scenario, but with significantly higher differences. Maximum increases in dry season flows range from 55 % for January at Chiang Saen, decreasing to 44 % at Vientiane, 30 % at Nakhon Phanom, and 19 % at Kratie. Significant increases are still apparent in May, whereas these were relatively unaffected by the Xiaowan, Manwan and Dachaoshan scenario.

Decreases in wet season flows are also significantly greater than for the Xiaowan, Manwan and Dachaoshan Dam scenario, ranging from 30 % for January at Chiang Saen, decreasing to 17 % at Vientiane, 9 % at Nakhon Phanom, and 5 % at Kratie.

As with the previous scenario, these results should be treated as indicative only at this stage. Two issues have been identified with these changes.

(i) The impact of not fixing the flows removed by calibration, thereby underestimating the impact.

(ii) The rule curves are understimating the releases for mNuozhadu Dam, and need to be revised. The impact of this would be to increase the impacts in both the wet and dry seasons.

5.4.4 Impact of flow calibration effect

The method to calibrate flow at the mainstream affects the results reported in this study. A simple analysis of these effects was to apply the change in average monthly flow volumes at Chiang Saen reported in Table and Table (the no dams and Xiaowan, Manwan, Dachaoshan and Nuozhadu Dam scenario, and apply these changes to the no dam scenario results at Kratie.

There would not have been any changes in extractions between these points, so the absolute changes in flows should not have changed significantly. Routing was not considered in this simple analysis.

The percent flow changes were then recalculated. The results of this are reported in Table 5.16. The increase in dry season flows increased from 14.1 % to 20.7 % in March, and the decrease in wet season flow increased from 4.9% to 6.1% in July. These changes are significant, and the simulation model needs to be revised to remove the impact of these calibration nodes.

Table 5.14. Average monthly simulated flows (million cubic metres) for Xiaowan, Manwan, Dachaoshan and Nuozhadu dam development scenario

Monitoring site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Chiang Saen	4,802	3,332	3,497	3,435	3,980	4,820	9,010	12,932	12,690	10,787	7,851	6,014	83,214
Luang Prabang	5,406	3,775	3,944	4,382	5,826	7,528	14,958	21,835	19,585	13,719	9,572	6,998	117,305
Chiang Khan	5,103	3,472	3,760	4,591	6,945	9,004	16,656	24,378	22,564	14,952	9,679	6,812	127,671
Nong Khai	5,041	3,485	3,781	4,709	7,903	10,480	17,437	25,240	24,068	15,821	9,757	6,715	134,117
Vientiane	5,014	3,481	3,777	4,644	7,222	9,262	16,366	23,787	22,574	15,126	9,535	6,644	127,185
Nakhon Phanom	6,276	4,539	4,810	5,963	10,767	19,677	32,328	45,607	40,435	22,313	12,093	8,324	212,874
Mukhdahan	6,359	4,601	4,896	6,112	11,546	22,234	35,661	50,412	43,756	23,660	12,411	8,471	229,815
Pakse	7,000	4,987	5,253	6,659	12,975	26,236	44,165	66,630	59,284	31,809	15,502	9,943	290,105
Stung Treng	8,615	6,142	6,221	7,497	14,645	33,727	59,229	88,438	82,532	48,124	22,624	13,631	390,841
Kratie	8,518	6,077	6,190	7,589	15,108	34,170	59,808	89,401	84,167	49,038	22,763	13,556	395,789

Note: Means calculated 1986-2000 for January-June to remove effects of model warmup, and 1985-2000 for July-December

Table 5.15: Percent difference in average monthly flows for Xiaowan, Manwan, Dachaoshan and Nuozhadu dam scenario compared with year 2000 development scenario.

Monitoring site	J	F	M	A	M	J	J	A	S	A	N	D
Chiang Saen	54.8	39.8	47.3	40.9	5.0	-21.3	-29.8	-16.5	-9.6	4.2	23.5	42.0
Luang Prabang	46.2	34.2	38.9	29.5	4.8	-13.6	-20.1	-10.8	-6.9	2.6	17.9	33.9
Chiang Khan	46.8	29.2	30.2	24.9	4.8	-10.8	-18.2	-10.1	-6.3	2.0	17.1	34.8
Nong Khai	44.1	29.6	29.3	22.7	4.4	-8.6	-16.1	-8.1	-4.8	1.9	16.2	33.2
Vientiane	44.4	29.4	29.3	23.1	4.6	-9.8	-17.0	-8.5	-5.0	2.0	16.8	33.6
Nakhon Phanom	30.3	23.5	21.1	16.3	3.9	-3.9	-9.1	-5.1	-3.2	0.8	10.9	22.6
Mukhdahan	29.7	23.5	20.6	15.9	3.7	-3.3	-8.3	-4.7	-2.9	0.7	10.5	22.1
Pakse	24.8	20.3	18.2	13.9	3.5	-2.6	-6.7	-3.5	-2.1	0.7	8.0	18.2
Stung Treng	19.1	16.6	14.8	12.2	3.4	-1.8	-5.0	-2.8	-1.5	0.4	5.2	12.6
Kratie	18.9	15.8	14.1	11.8	3.3	-1.8	-4.9	-2.7	-1.5	0.3	5.1	12.7

Figure 5.23: Percent difference in average monthly flows for Xiaowan, Manwan, Dachaoshan and Nuozhadu dam scenario compared with year 2000 development scenario.

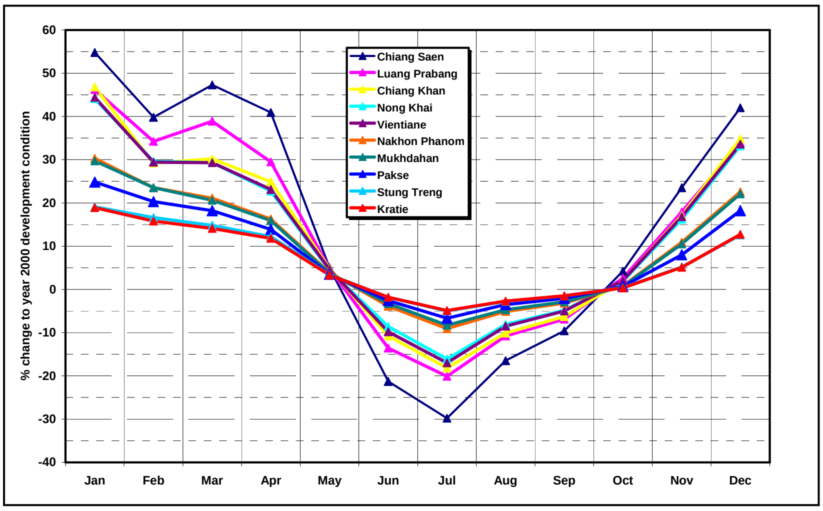


Table 5.16. Impacts of calibration nodes on flow difference estimates at Kratie for Xiaowan, Manwan, Dachaoshan and Nuozhadu development compared with year 2000 development conditions.

Month	Volume difference		% difference at Kratie	
	Chiang Saen	*Kratie*	*Model*	*Fixed losses*
January	1,700	1,352	18.9	*23.7*
February	948	828	15.8	*18.1*
March	1,123	764	14.1	*20.7*
April	997	800	11.8	*14.7*
May	190	480	3.3	*1.3*
June	-1,304	-627	-1.8	*-3.7*
July	-3,825	-3,102	-4.9	*-6.1*
August	-2,549	-2,516	-2.7	*-2.8*
September	-1,346	-1,301	-1.5	*-1.6*
October	430	163	0.3	*0.9*
November	1,493	1,113	5.1	*6.9*
December	1,779	1,526	12.7	*14.8*

5.5 Comparison with previous results

Previous studies of the hydrologic impacts of these storages estimated similar impacts of the Chinese Dams. Plinston and Daming's study reported similar patterns of impacts down to Mukdahan for the Xiaowan, Manwan and Dachaoshan scenario, except that the greatest dry season impact was for March, not January. Their method to calculate these, and the actual changes are not clear.

A similar analysis by Adamson predicts a similar pattern to Plinston and Daming's, with increases of the order of 50% in average dry season flows at Kratie, and decreases in the wet season flow less than 10%.

6 River flows, dai fish catches & inundated populations

by Hugh Cross, June 2004

6.1 Introduction

This chapter aims to:

1 Determine which years are most appropriate for adoption as "representative years" for spatial analysis of "normal", "dry" and "wet" conditions.

2 Establish relationships between Kratie flows, and peak Tonle Sap Lake levels and inundated area.

3 Establish relationships between parameters related to inundated area and fish populations.

4 Establish relationships between flows at Kratie and other locations, such as Phnom Penh, and the total peak inundated area.

6.2 Selection of representative years for spatial analysis

Analyses

Spatial data provide key information for the evaluation of scenario impacts. However, the number of possible analyses that can be performed increased dramatically as one considers the various combination of hydrologic factors of concern. These include a wide range of ecological, social and economic factors. Compounding these considerations are the various spatial scales that might need to be considered, including administrative districts, BDP sub-areas and countries. Hence there is a need to restrict the analyses to a few years that can characterise the impacts for typical 'dry', 'normal' and 'wet' years.

To this end, a number of years within the modeled period 1985 – 2000 have already been identified as potential candidates. The preferred years for map outputs are 1996-97, 1997-98 and 1999-2000.

The requirement of this task is to review the key spatial flood parameters, peak flood extent and duration, relative to key river flow characteristics. Two key flow parameters were selected that corresponded to the analysis conducted by the IBFM program (MRC, draft April 2004). These were:

- Kratie Peak annual monthly flow
- Kratie annual wet season flow (Jun – Nov)

Source Data

Data used are those simulated by the DSF for the "Year 2000 Development Conditions Scenario". Time-series data are available in the DSF by selecting that scenario. Spatial data at the time of this report are yet to be stored in the DSF.

The data were used for both the time-series and spatial analyses reported on in this report.

Spatial Flood Characteristics of Representative Years

Visual inspection of Figure 6.1, Figure 6.2 and Figure 6.3 indicated that an approximate representation of "dry", "average" and "wet" conditions were offered by using the years 1998, 1999 and 1996 respectively. Key spatial characteristics of the above selected representative years are set out in Table 6.1. For each of the wet season years, the following year is used as the corresponding dry season representative year. The data were derived from the spatial analyses described in sections 0, 0 and 0.

Table 6.1: Key spatial characteristics of wet season representative years

Parameter	1996 "wet"	1999 "average"	1998 "dry"	Mean 1985 – 2000	Standard Deviation
Maximum Inundated Area downstream Kratie (km^2)	64,336	60,649	58,340	60,968	2,408
Maximum Inundated Population downstream of Kratie (persons)	16,947,532	16,168,022	15,946,479	16,327,685	525,026
Tonle Sap Maximum Inundated Area (km^2)	15,933	14,566	12,802	14,363	1,162
Kratie Peak annual monthly flow (MCM)	123,426	102,355	76,941	95,079	15,712
Kratie annual wet season flow (Jun – Nov) (MCM)	398,200	385,195	264,231	345,987	58,063

Figure 6.1: Annual Maximum Flooded Area downstream Kratie (Yr 2000 dev 1985 – 2000)

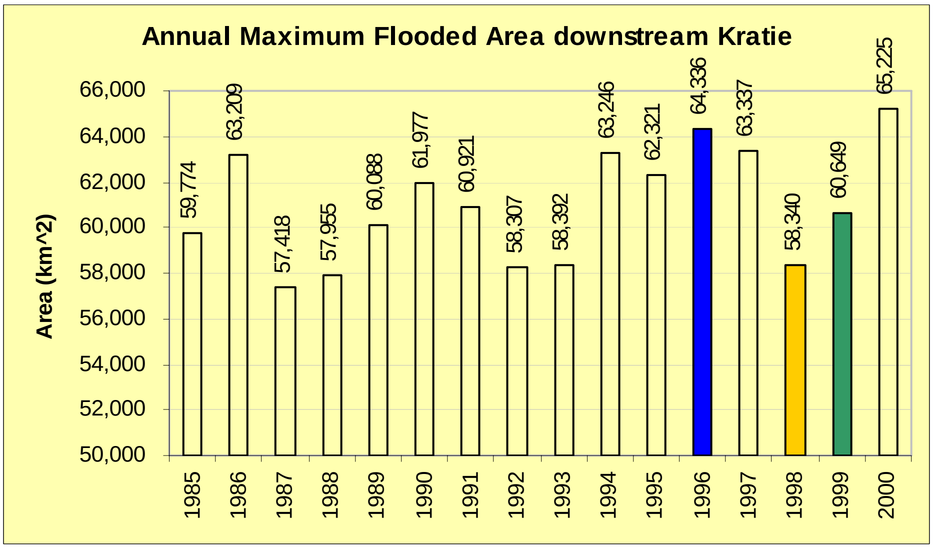


Figure 6.2: Annual Maximum Flooded Population downstream of Kratie (Yr 2000 dev 1985 – 2000)

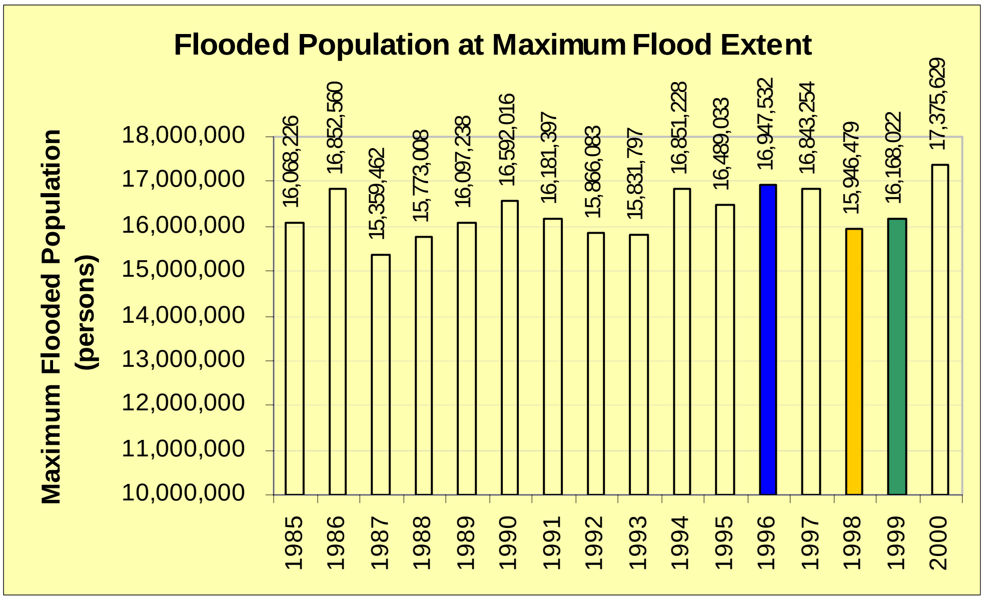
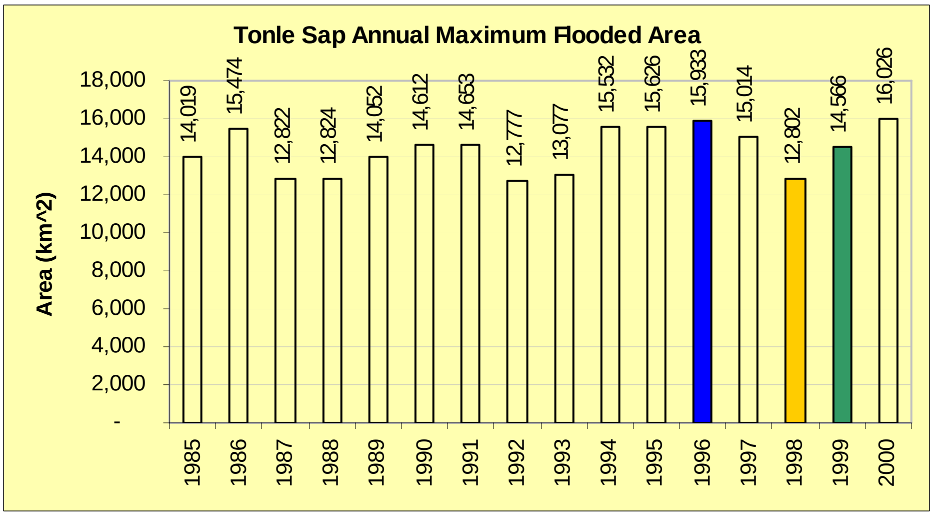


Figure 6.3: Tonle Sap Annual Maximum Flooded Area (Yr 2000 dev 1985 – 2000)



6.3 Tonle Sap Lake flooding

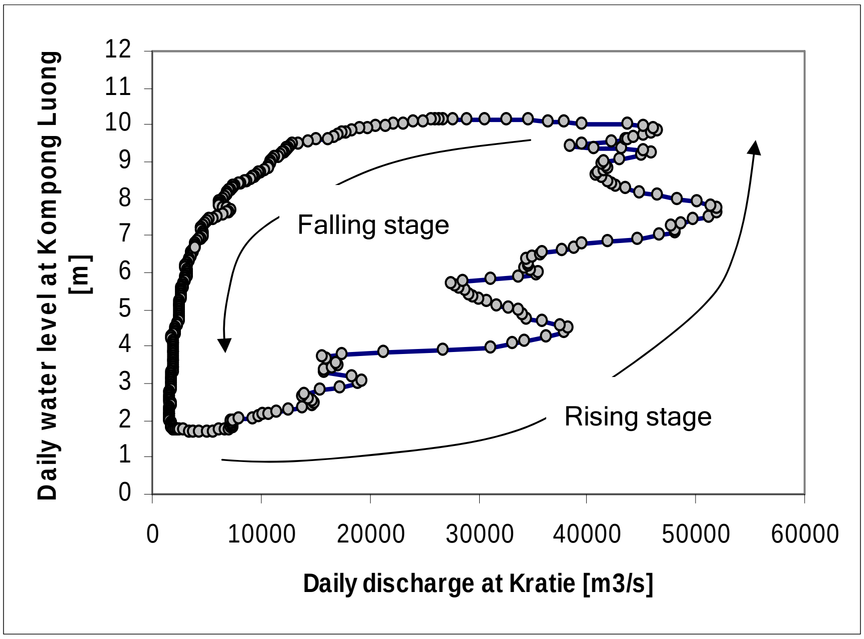
6.3.1 River flow and lake level relationships

Wet Season Tonle Sap Lake Levels & Flow Reversals

The time-series data and analyses reported on in this section were conducted by the Water Utilisation Project (WUP) for the report; "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2" (MRC, draft April 2004), hereafter referred to as the "IBFM Report No.2".

Figure 6.4 (from Annex C of the IBFM Report No.2) shows the complex relationship between flows at Kratie and water levels in the lake at Kampong Luong. Essentially the lake continually fills as long as its water level continues to be less than that of the river at the Chaktomouk junction (not shown in the figure). In 2002 this remained the case until it reached about 10 m, where upon it remained static for a time despite rapidly decreasing flows at Kratie (in part due to the travel time from Kratie to the Chaktomouk junction), then decreased at a relatively consistent rate. Consequently the IBFM Report No.2 report concludes that <u>daily</u> Kratie flows are a poor indicator of either flow reversal rates or water levels in Tonle Sap Lake.

Figure 6.4: Discharge at Kratie versus water level at Kampong Luong (Mike 11 simulated data for year 2002)

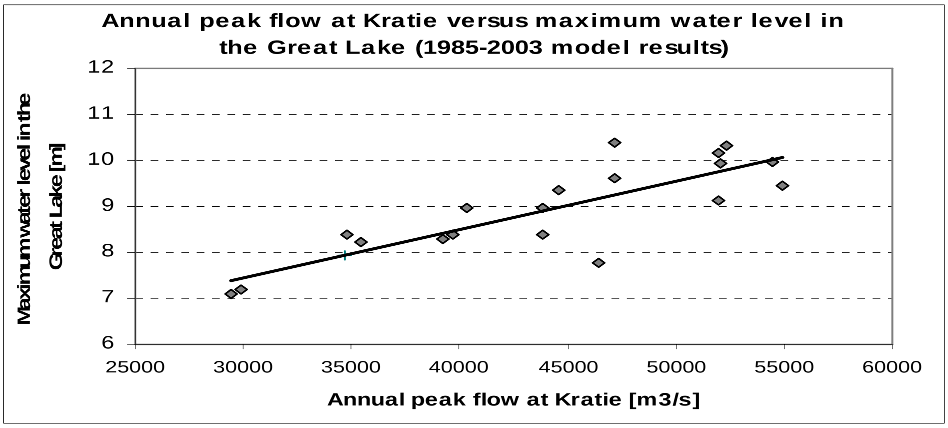


(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.3)

Figure 6.5 to 6.7 show various linear regression relationships also derived by the WUP-FIN study (MRC, 2004). Unfortunately the actual regression figures themselves are not presented, however visual interpretation indicates that the monthly September <u>volumes</u> 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.

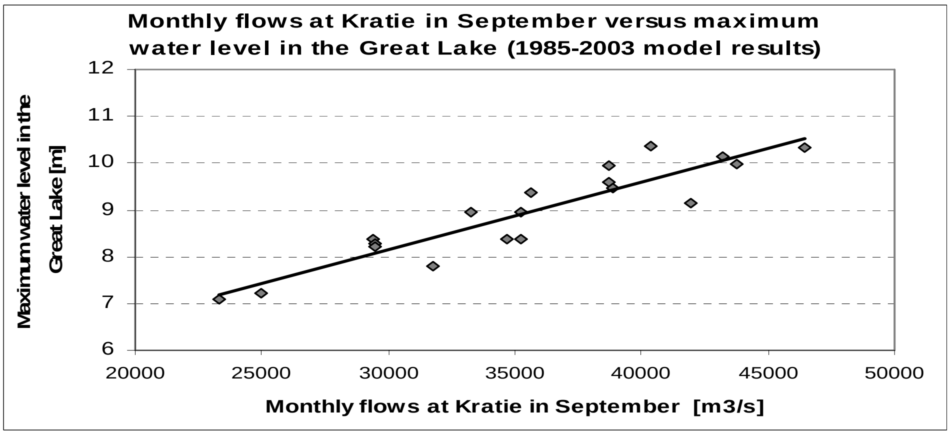
Figure 6.8 is presented for comparison with these Kratie-Tonle Sap relationships. With an r^2 value of 0.9735 it shows that the sum of all Tonle Sap wet season inflow volumes can be used to accurately predict the peak lake level.

Figure 6.5 Annual peak flow at Kratie versus annual maximum water level in the Great Lake. Results from 1985 -2003 simulation.



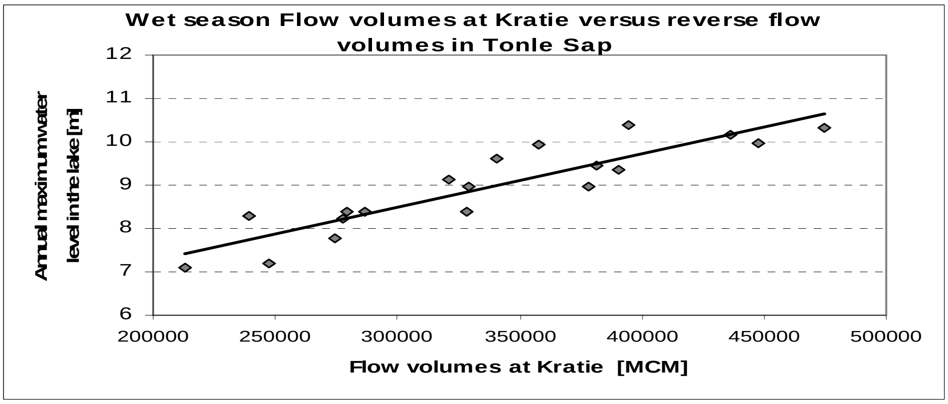
(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.20)

Figure 6.6 Monthly flows at Kratie (September values) versus maximum water level in the lake. Results from 1985 – 2003 simulation.



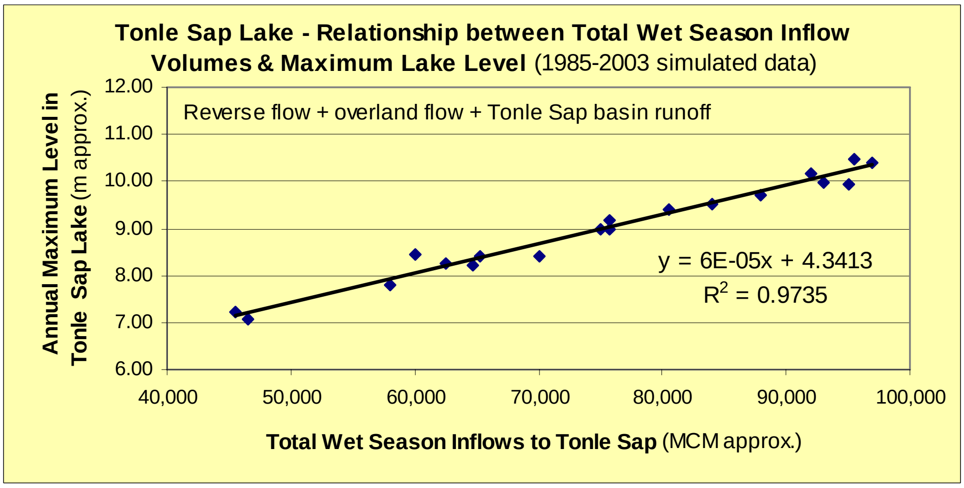
(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.21)

Figure 6.7 Wet season flow volumes at Kratie [MCM] versus annual maximum water level in the lake [m]



(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.22)

Figure 6.8 Total Wet Season Inflow Volumes verses Maximum Lake Level (1985-2003 simulated data)



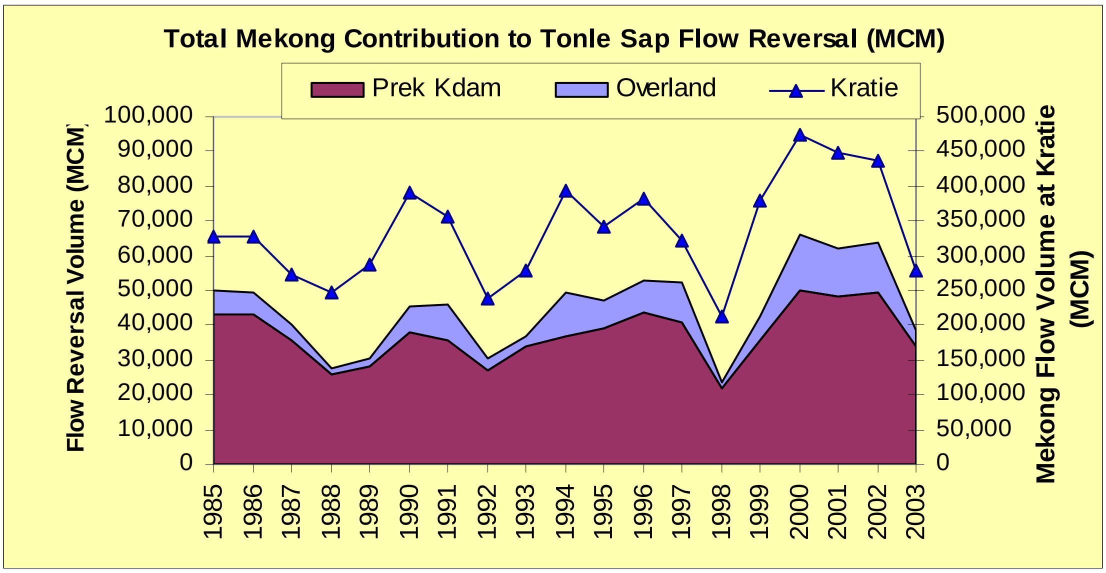
(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.6)

Figure 6.9 shows the relationship between wet season flow volumes at Kratie (1 June – 31 December) and reverse flows into Tonle Sap Lake. The reverse flows occur via both the Tonle Sap River (measured at Prek Kdam) and via direct overland (overbank) floodplain flows from the Mekong River to the lake, upstream of the Chaktomouk junction. It can be seen that there is a strong relationship between the magnitude of Kratie wet season volume and the total flow reversal, as would be expected, not withstanding the fact that 40% of the lake's volume on average is derived from local runoff[i].

Of note is the higher proportion of the flow reversal conveyed by overland floodplain flows in years with greater Kratie flow volumes. Averaging 16% over all years, overland flows can be up to 26% in wet years, but only 5% in very dry years. This also is to be expected given that higher river flood levels will result in a greater depth and extent of flooding. The IBFM Report No.2 report used September flows at Kratie to show this relationship (Figure 6.10).

The overland flow component may be an important part of the lakes ecological productivity and biodiversity as the area traversed by these flows near the lake include some of the largest areas of remaining flooded forest and other wetlands. However, as it is likely that these areas become inundated regardless of whether there is any overland flow and thus the source of water may not be that important relative to the lake level itself.

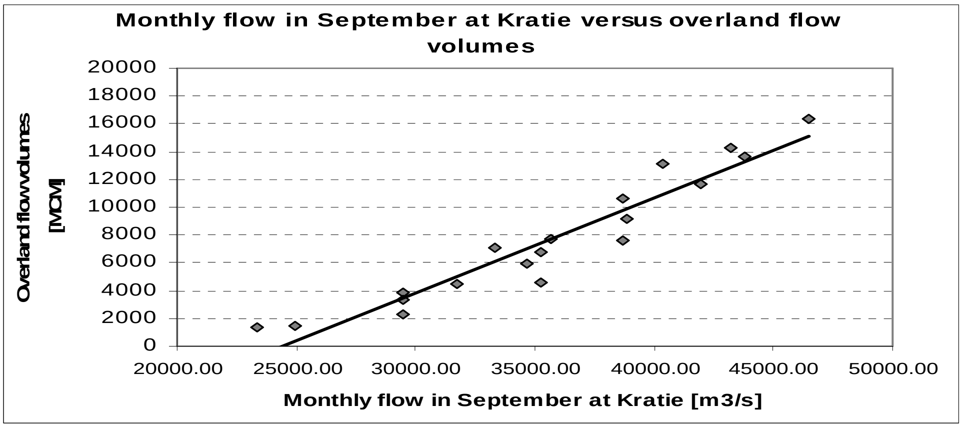
Figure 6.9: *Mekong River contributions to the Tonle Sap flow reversal via the Tonle Sap River and via overland flow direct to the lake*



(Source: *Flow data:* MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, derived from data in Table 9.37
Fish data: Hgor Peng Bun (2000) in Van Zalinge et al (2000). Management aspect of Cambodia's Freshwater Capture Fisheries. Fig.3.5, p42)

[i] MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, pC3.

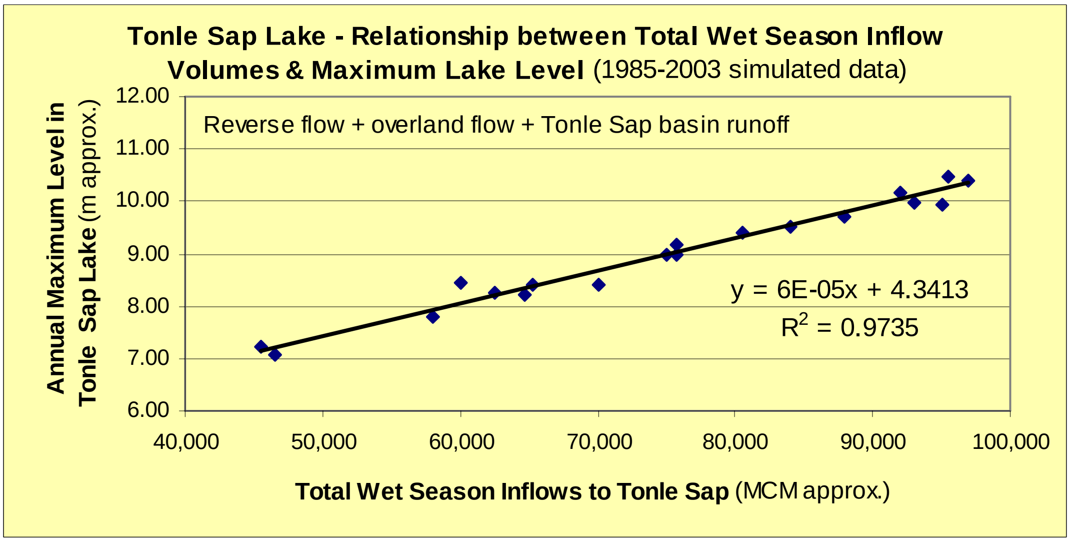
Figure 6.10 Monthly flows in September at Kratie versus overland flow (1985 to 2003)



(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.28)

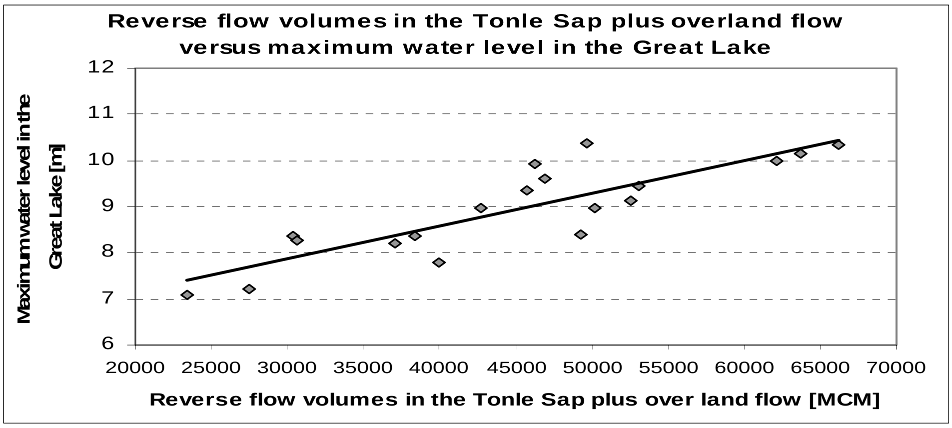
Figure 6.11 shows the relationship between the total wet season inflow volumes and maximum Tonle Sap Lake levels. The relationship in this figure is clearly better than that shown in Figure 6.12 which presents the same relationship but without local Tonle Sap basin runoff. Clearly the scatter in the second relationship is 'explained' by the local basin inflows to the lake.

Figure 6.11 Total volumes entering the lake during wet season versus maximum water level in the lake. Simulation results from 1985-2003.



(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C. Figure 9.6 regenerated from visual interpretation of data values to determine regression value)

Figure 6.12 *Annual Reverse flow volumes entering Tonle Sap Lake versus maximum lake water level (simulated data 1985 – 2003)*



(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.23)

6.3.2 Acceptable wet season Tonle Sap Lake levels & flow reversals

Taking all of the above into account, the MRC (draft April 2004, page C24) report recommends that priority for (planning scenario) evaluations of Article 6B of the Mekong Agreement re *acceptable Tonle Sap flow reversals* and *maximum lake levels*, is the Tonle Sap total annual flow reversal volume at Prek Kdam. Of secondary importance for evaluations is the use of annual wet season volumes at Kratie because Article 6B uses Kratie as the mainstream reference station to determine "acceptable natural reverse flow".

The table below shows the change thresholds for maximum annual lake levels and the corresponding threshold for total inflows. A specific Mekong River flow or level threshold can not be specified due to the large contribution to the lake's levels from its own catchment (40% or 30,000 MCM on average).

Lake threshold	Parameter threshold (1 standard deviation)
Maximum Tonle Sap Lake level	1.00 m (mean = 8.95m)[i]
Corresponding Tonle Sap Lake total wet season inflow volume threshold:	16,000 MCM (mean = 75,000 MCM)[ii]

[i] Source is MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Table 9.36. Both the mean and standard deviation values are from 1985-2003 modeled data for Kampong Luong

[ii] Computed from visual interpretation of data values in Figure 9.6, Annex C of MRC (draft April 2004) report.

Minimum Tonle Sap Lake Levels

The IBFM Report No.2 concluded that dry season Mekong River flows influence the dry season water level in Tonle Sap Lake, but that wet season river levels and lake levels do not. Higher dry season Mekong River levels produce a backwater effect that slows Tonle Sap River flows and hence lake draw-down.

In turn, these minimum lake levels in the dry season play a part in determining the strength of the flow reversal in the following wet season. Lower levels give rise to greater differences in water levels between the lake and rising Mekong River, thereby generating a greater reverse flow volume.

As for maximum lake levels, one standard deviation is used in the MRC report as the test for a significant change in lake water levels and corresponding river discharges or river levels. The corresponding values are:

Lake threshold	Parameter threshold (1 standard deviation)
Minimum Tonle Sap Lake level	0.25 m (mean = 1.67m)[i]
Corresponding river thresholds:	
Mekong River level at Chaktomouk	?1.0 – 1.5 m[ii]
MekongRiver average daily March/April flow at Chrui Changvar	5,000 m^3/s

A dry season flow at Chrui Changvar of 5000 m3/s (or a monthly water level at Chaktomouk in March/April of 2.25 m) will raise the minimum lake water level by one standard deviation, which is 0.25 m.

[i] Source is also MRC (draft April 2004), Annex C, Table 9.36. The mean value is from 1985-2003 modeled data, whilst the standard deviation is from 1996-2003 historical data, also for Kampong Luong.

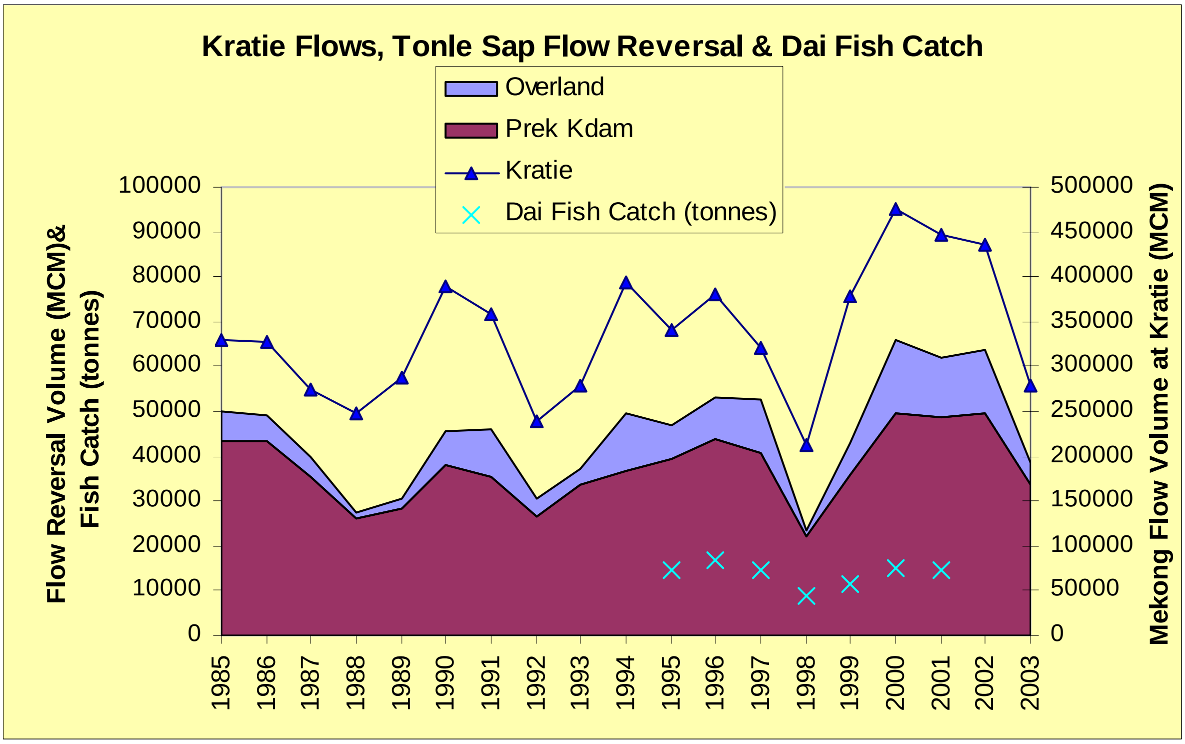
[ii] These are the figures quoted in the report, but from data elsewhere in the report should read "2.0 – 2.5m"

6.4 Flooding-fish catch relationships

6.4.1 Tonle Sap flood depths

Figure 6.13 presents the total tonnage of fish catch in the Dai fishery catch each year during the Tonle Sap outflows. Hence for instance the figure for 1995 actually represents fish caught over the end of 1995 and the beginning of 1996. There is clearly a relationship between the fish catch and lake levels.

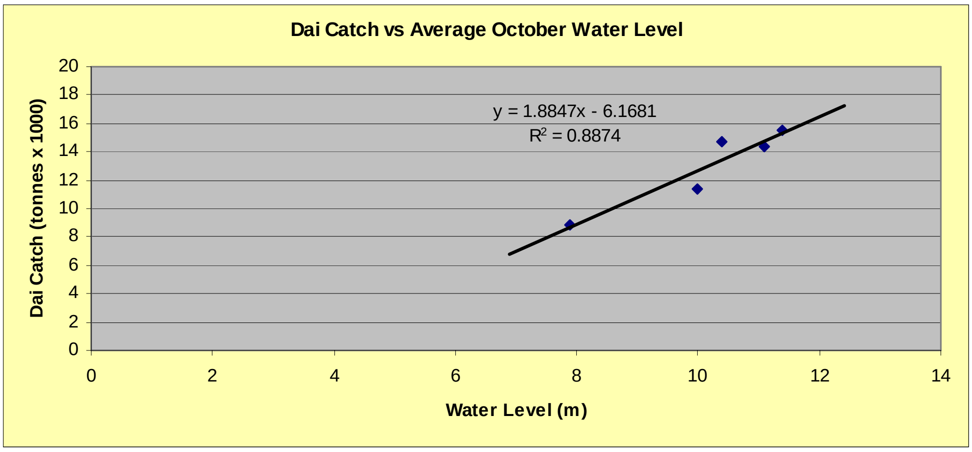
Figure 2.13: *Mekong River contributions to the Tonle Sap flow reversal via the Tonle Sap River and via overland flow direct to the lake*



(Source: *Flow data:* MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, derived from data in Table 9.37
Fish data: Hgor Peng Bun (2000) in Van Zalinge et al (2000). Management aspect of Cambodia's Freshwater Capture Fisheries. Fig.3.5, p42)

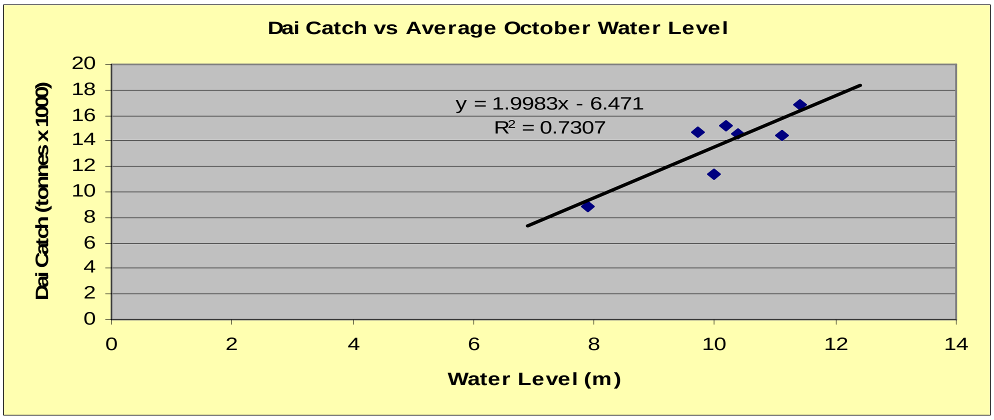
Hgor Peng Bun (2000) presented this fishery relationship as a comparison of Tonle Sap Lake levels in October verses the Dai fish catch from 1995-96 to 1999-00. A regression value of 0.8874 in Figure 6.14 demonstrates a strong relationship. Revision of the 1996-97 catch and addition of catch data for 2000-01 and 2001-02, reduces the regression value to 0.7307 (Figure 6.15). Visual observation of Figure 6.9 shows that fish catches were down in these most recent years, despite higher than average lake levels.

Figure 6.14: Dai fish catch verses average October water levels (1995-96 to 1999-00)



(Source: Hgor Peng Bun (2000) in Van Zalinge et al (2000). Management aspect of Cambodia's Freshwater Capture Fisheries. Modified from Fig.3.5, p42)

Figure 6.15: Dai fish catch verses average October water levels (1995-96 to 2001-02)



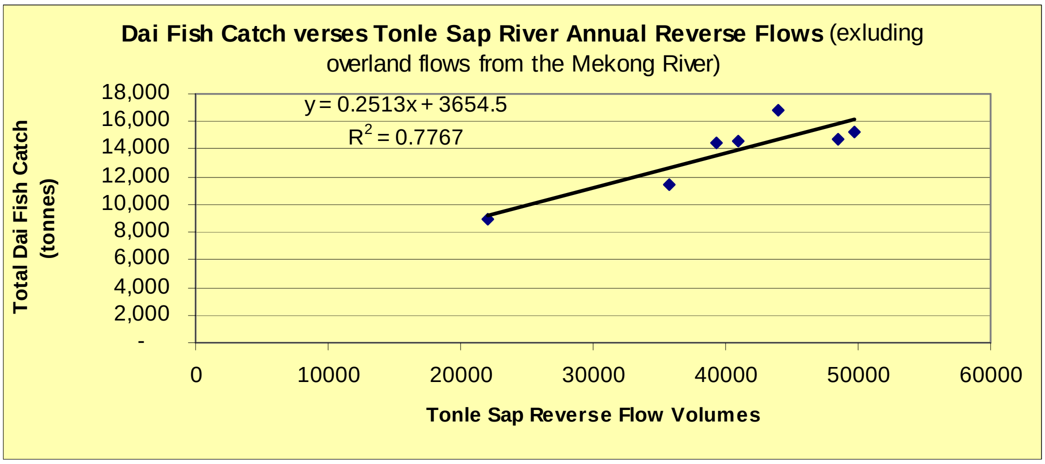
(Source: *Flow data:* MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, derived from data in Table 9.37
Fish data: Hgor Peng Bun (2000) in Van Zalinge et al (2000). Management aspect of Cambodia's Freshwater Capture Fisheries. Fig.3.5, p42)
Year 1996/97 data revised by Ngor Peng Bun (2000). Dai fisheries in the Tonle Sap River; Review of the data census of 1996-1997. Presented at the 2nd MRC Fisheries Program technical symposium, Phnom Penh, 13-14 December 1999. 9pp

This may indicate that another factors, other than peak lake levels, are becoming important in determining fish catch. It may be a reflection of a downward trend in fish catches due to over fishing, increased fish catches in other areas, or other factors, such as reduced fishing effort by people involved with the Dai fisheries.

As an alternative to the October lake water level, the Dai fish catch can be compared to other hydrologic variables, such as the Tonle Sap reverse flows during the lake's filling phase (Figure 6.16). This regression of 0.7767 is slightly stronger than that for the October lake levels over the same period (Figure 6.15), however, if the overland flow component (from the Mekong River) is added, the regression weakens to 0.7149.

In conclusion, both the October lake level and flow reversal relationships, offer similar levels of prediction of Dai fish catches. Both are likely to worsen if pressures such as fishing in other locations impact on fish numbers caught at the Dai fisheries on the Tonle Sap River.

Figure 6.16: Dai fish catch verses Tonle Sap River reverse flows excluding overland flows from the Mekong River (1995-96 to 2001-02)

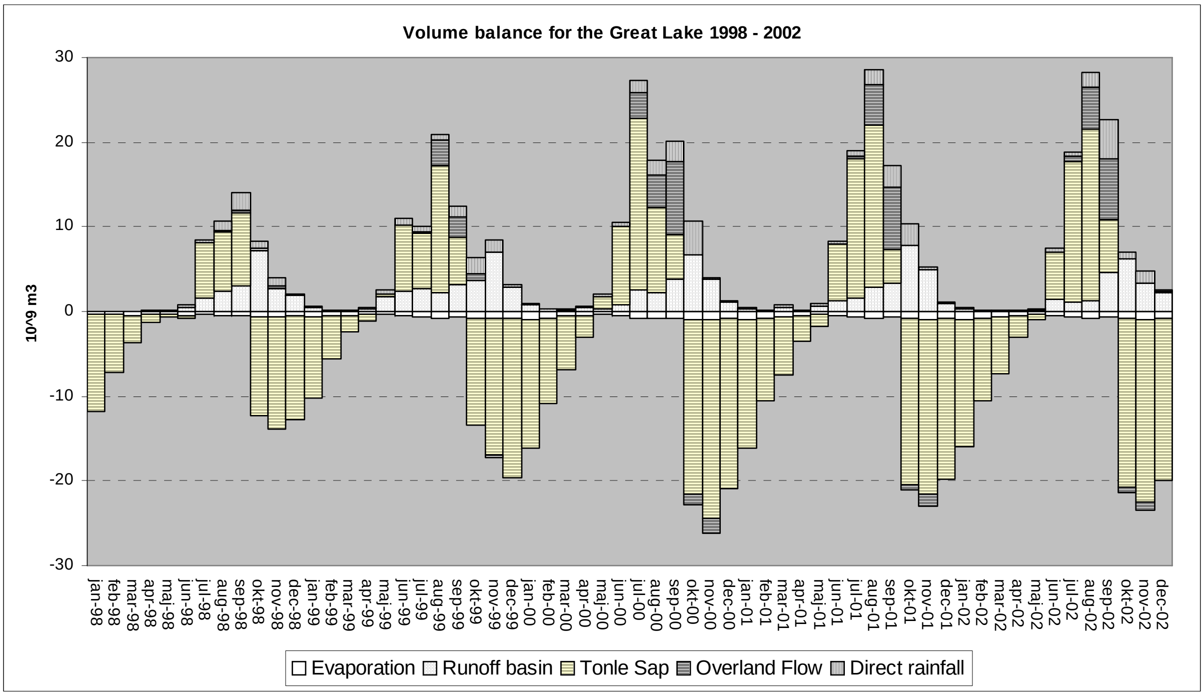


(Source: F*low data:* MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, derived from data in Table 9.37
Fish data: Hgor Peng Bun (2000) in Van Zalinge et al (2000). Management aspect of Cambodia's Freshwater Capture Fisheries. Fig.3.5, p42)

A water balance volume analysis of the lake's filling and emptying is provided in Figure 6.17. It shows the size and timing of inflows from various sources and outflows, again by component. Significantly, it is evident that the overland flow component discussed above is relevant only during the filling cycle. Only in the largest flood years does this component make any contribution to draining the lake and then only for a brief and relatively insignificant period at the beginning of the emptying phase. In magnitude it is barely greater than evaporation.

The ecological consequence of this is that virtually all outflows from the lake and therefore, all fish migration and drift of nutrients, exit via the Tonle Sap River. Sustainable management of the highly efficient Dai fisheries along the Tonle Sap River is therefore extremely important, as evidenced by the stronger correlation between the river's reverse flows and the Dai fish catch noted above (see Figure 6.15 and Figure 6.16). Were a correlation to be made between Tonle Sap outflows and the Dai fisheries (which is when the fishing actually occurs), it would be interesting to observe the result.

Figure 6.17: Water balance for the Great Lake, 1998-2002. WUP-JICA study



(Source: MRC (draft April 2004) "Water Utilisation Program Start-up Project – Integrated Basin Flow Management Report No. 2", Annex C, Figure 9.4)

6.4.2 Tonle Sap flooded area relationships to river flows

Procedure

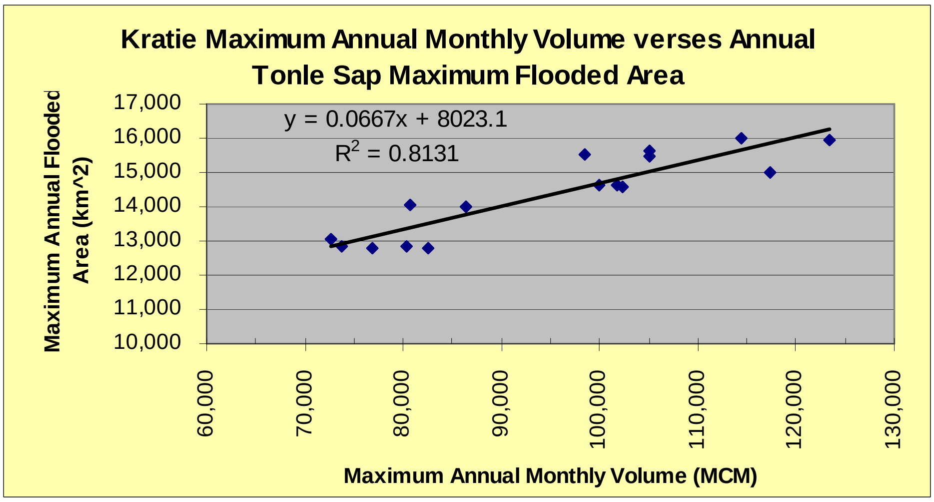
The procedure below assumes that the user first conducts similar operations for the whole Cambodian and Vietnamese floodplain areas covered by the ISIS model:

1. Create a master *Tonle Sap mask* with its eastern boundary at National Road No.5. Do this by creating a new theme and drawing a polygon feature over the area required.
2. Convert this shape file to grid using "Theme", "Convert Theme to Grid" function.
3. Reclassify the zero values to "1" and save as a permanent grid.
4. Use this grid mask to cut the *adjusted maximum flood grid* theme by multiplying it with the *grid mask* (use "Analysis", "Map Calculator"). The result is a temporary grid of inundation depths for the Tonle Sap Lake area only. Convert to a permanent grid (use "Theme", "Convert to Grid").
5. Classify the *Tonle Sap Maximum Inundation grid* map using the *classification file* previously created for classifying the flood map for the whole area (see section 0). Load the legend that was previously created and saved for classified flood depth grids.
6. Make the *classified Tonle Sap Maximum Inundation* theme "active" then select "Analysis", "Summarise Zones" to obtain the statistics of flooded area. Export to MS Excel to sum the flooded areas across all depth classes.

River flow – flooded lake area relationships

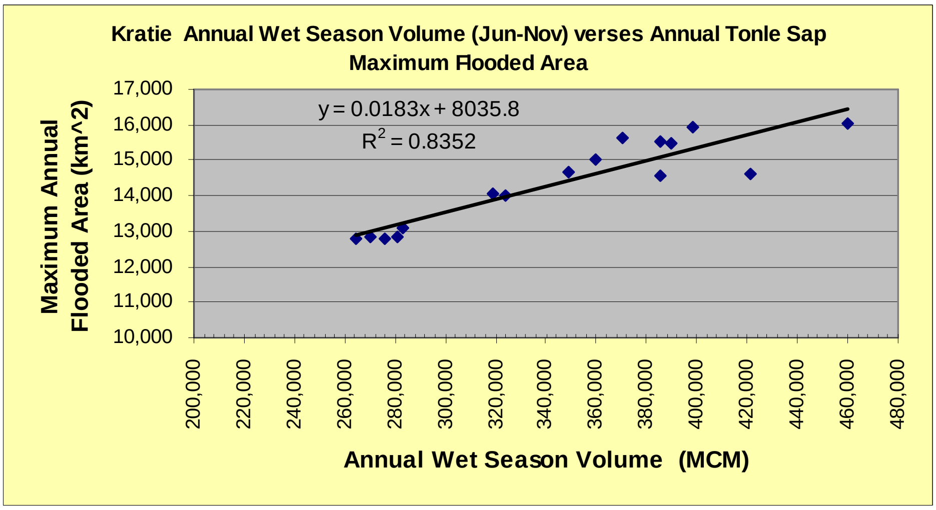
The annual maximum Tonle Sap flooded area was tested against the Kratie peak monthly flow volume and wet season flow volume. Both linear regression values slightly exceed 0.8, indicating a strong relationship similar to that found for the relationship between these Kratie flows and lake levels.

Figure 6.18: Kratie Maximum Annual Monthly Volume versus the Annual Maximum Flooded Area in Tonle Sap Lake (DSF simulated data 1985 – 2000)



(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format)

Figure 6.19: Kratie Annual Wet Season Volume verses the Annual Maximum Flooded area in Tonle Sap Lake (DSF simulated data 1985 – 2000)

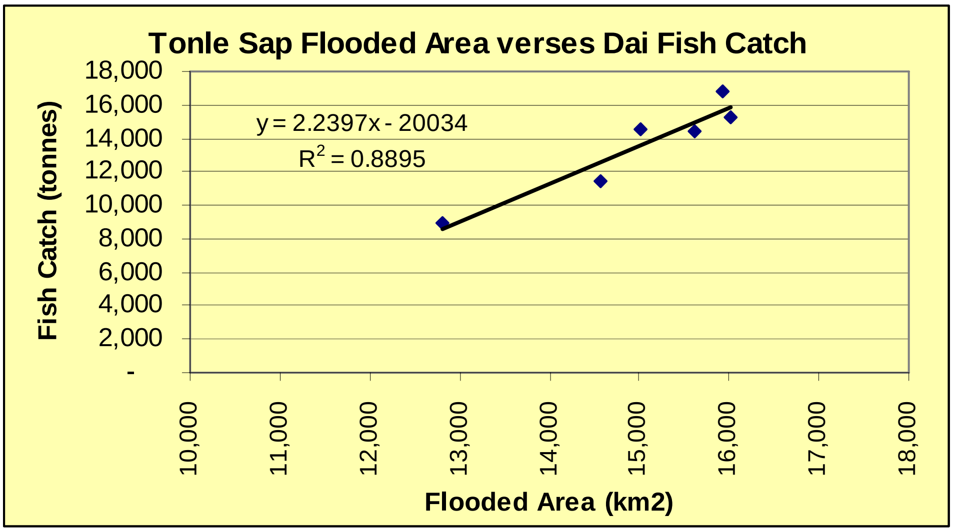


(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format)

Flooded Lake Area – Dai Fish Catch relationship

The relationship between the annual Dai fish catch (November to February) and peak flooded area in Tonle Sap Lake is shown in Figure 6.21. A strong relationship is indicated by the r2 value of 0.8895. Whilst this is slight stronger than that observed for the relationship between fish catch and lake depths, the period is one year less, so the results are not directly comparable.

Figure 6.20: Annual Maximum Flooded area in Tonle Sap Lake verses Dai Fish Catches (1995 – 2000)



(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format)

6.4.3 Fish and aquatic animal productivity per unit area

The MRC's Fishery Division has undertaken a number of studies that attempt to determine the yield of fish and other aquatic animals from inundated floodplain areas[i]. One of these, Dubeau *et al* (2001), relates to Fishing Lot No.18 and Piem Chumniek Canal, on the Tonle Sap River floodplain in Kampong Tralach District which covers 82.5 km² (8,252ha).

The study used two methods to estimate the annual fish yield per hectare based on catch data from the above area:

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

[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 .

The range in each estimate is a function of differences in flooded area depending on the length of the critical flood duration that is adopted (all areas flooded more than 0.1m deep were considered). The differences between the two estimates are due to Estimate A using rougher fish catch estimates based only on the number of fishers, whilst Estimate B using more sophisticated methods that reflect seasonal variations in fishing practices, including fishing effort. Accordingly it would seem better to use the Estimate B values.

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. This might suggest that it would be prudent to use the lower value of 243 kg/ha/year.

6.5 Generation of functional relationships from model outputs

6.5.1 Procedures

Maximum flood extent maps

The procedure for generating these maps is as follows:

1 Run ISIS Flow in the DSF for the period required (generally a calendar year or water year). Then run DeltaMapper when prompted at the end of the ISIS run. Accept the default depth and duration grid files, but it is best not to run the "contouring" function as it adds significantly to the run time. Contours can be created much more quickly in ArcView. Save the 'flt' grid files it generates in the Knowledge Base for that scenario.

2 *Comment:* ISIS generates a 'csv' file for each year (or other period for which the ISIS model was run) that contains all the daily flow values for all 5,000 or so nodes in the ISIS model. DeltaMapper interrogates this file to produce an 'flt' file for each of the default output maps, i.e. in the case of flood maps it produces the maximum flood extent, and three flood duration maps for each of the following depth thresholds; 0.5m, 1.0m and 2.0m.

3 Create a "View" in ArcView for the year (or other period) for which ISIS was run. This will help keep track of temporary grid files that are created for some of the operations set out below.

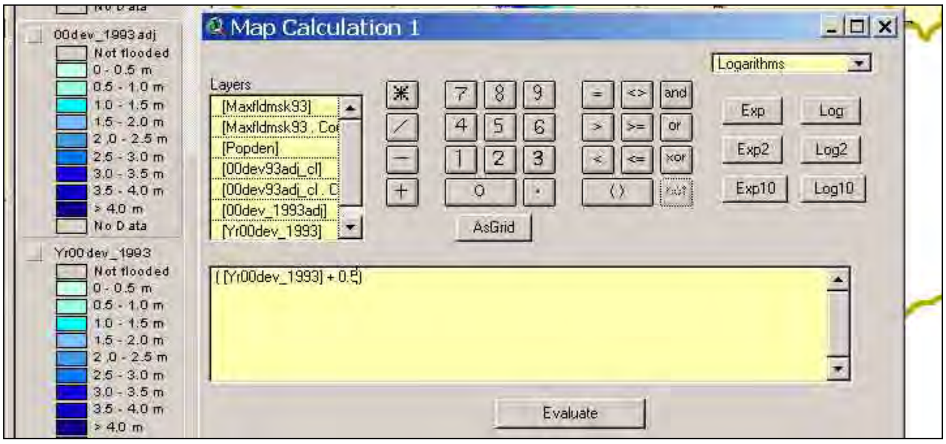
Comment: Ensure that you have created a directory path that contains no gaps in the sub-directory names. The names can be longer than 8 characters, but seem to create problems when they exceed about 20 to 25 characters. The most common problem is that you can not see grid files below sub-directories with either long names or names with gaps in them. Use a dash or underscore to separate words, e.g. *E:\Mekong_AV_files\Year2000dev\Year2000*

4 Turn on the "Spatial Analysis" and "Geoprocessing" extensions, then import the 0.5m depth map into ArcView. Use "File", "Import Data Source" and select "Binary Raster" file type. When prompted select the option to open the imported

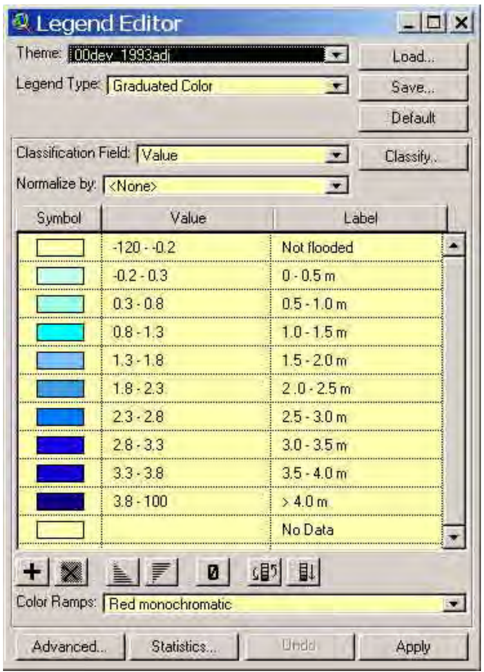
grid in the current view (note, ArcView does not display any icon or progress bar for the file conversion).

Comment: Unless you have the appropriate extensions on, the "Import Data Source" option will not be available.

5 Using "Analysis", "Map Calculator", add 0.5m to the imported grid to bring values up to the true maximum depth, as per the example below. If you have imported the 1.0m grid, then add 1m. When prompted, save the new grid file in the appropriate directory using an short, but explanatory name. Names longer than about 12 characters will not be accepted, but you can try.



Comment: No zero depth, or "true depth" grid is provided for in the DSF default settings as the DSF only produces depth grids for the duration thresholds that are assumed to be important. Zero to 0.5m depth of flooding was considered to be of little use as the depths are relatively insignificant in terms of impacts on human communities or most ecological functions. Therefore the minimum depth that a duration was considered useful, was 0.5m. However, the Modeller user can ask the DSF Administrator to change the default DSF DeltaMapper values if required.



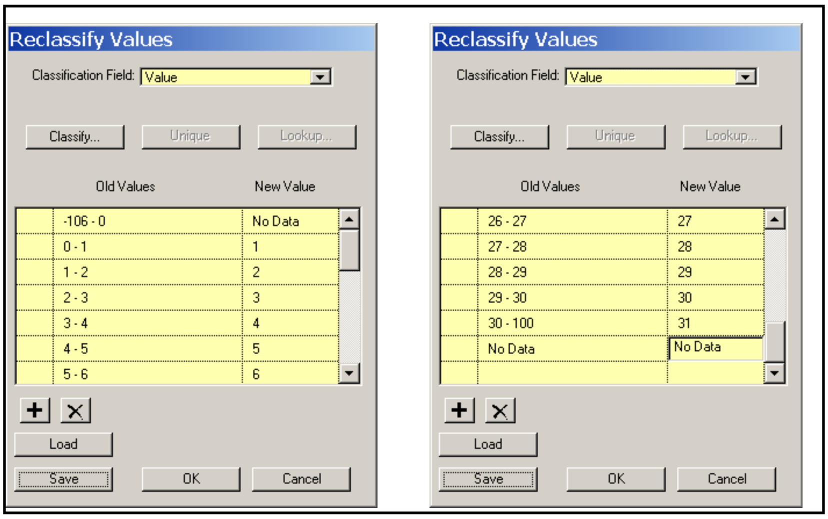
6 Re label the legend as per the example below by double clicking the theme legend. Until now the imported maps will have been displayed using legends automatically created by ArcView. Be sure to note the minimum and maximum values so that you capture these values in your legend. The large negative values are non-real values generated as an artifact of the DeltaMapper processing. They should be ignored.

'*Comment:* You will note that the labels used in the example correspond to grid depth values that are 0.2m less than the labeled value. The reason for this is that ArcView 3.1 used in this example has trouble displaying the legend correctly for non-integer values.

By running the contouring tool you can generate a map that will display correctly, however, once the grids are classified they will display correctly (see subsequent steps below).

Once you are satisfied with the legend, save the legend as a "Legend file" in a location and with a name (eg. "maxdpth.avl") that can logically be found and used for other years, not just this year's flood map. One level up from the current year's sub-directory is logical, but you might use a specially named directory. The advantage of using one level up is that you can set the working directory[i] to that sub-directory and thereby minimise moving up and down sub-directories for operations set out below.

7 Classify the depth map by selecting "Analysis", "Reclassify", after first making the theme active. In the adjacent example, the original non-integer values have been classified into 31 one metre depth categories, plus two "No Data" categories (only the lower and higher values are shown in the figure). Select the option to open the new grid in the current view when prompted.



Note: Save the classification as a file by using the "Save" function <u>before</u> running the classification. This ensures that the same classfication classes are used for each year.

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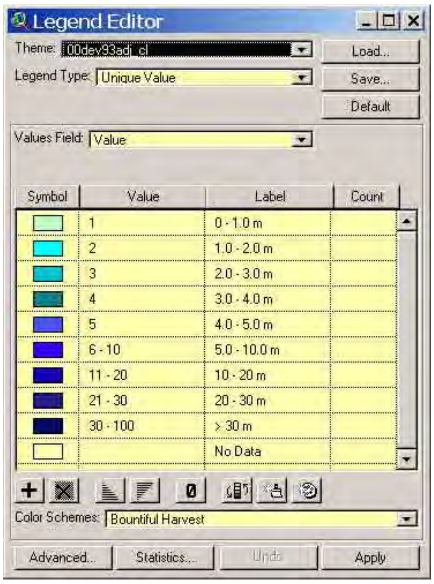
[i] Select "File", "Set Working Directory". It helps to copy the path to the clip board first by copying the address bar of Windows Explorer, or similar, so that it can simply be pasted in.

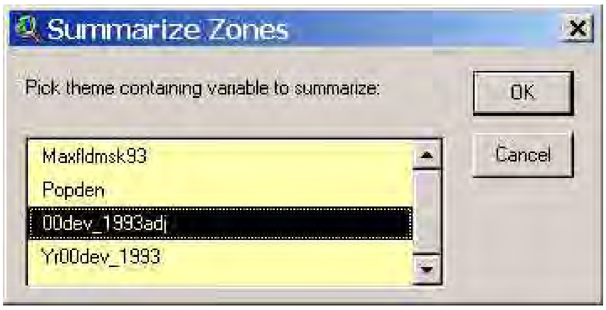
Comment: The purpose of classifying the original grid is to enable statistics to be generated for each depth class. The initial grid produced by this process is a temporary grid. It is only viewable in the current "View" and if "Deleted" from the View, will in fact be deleted permanently, unlike permanent themes.



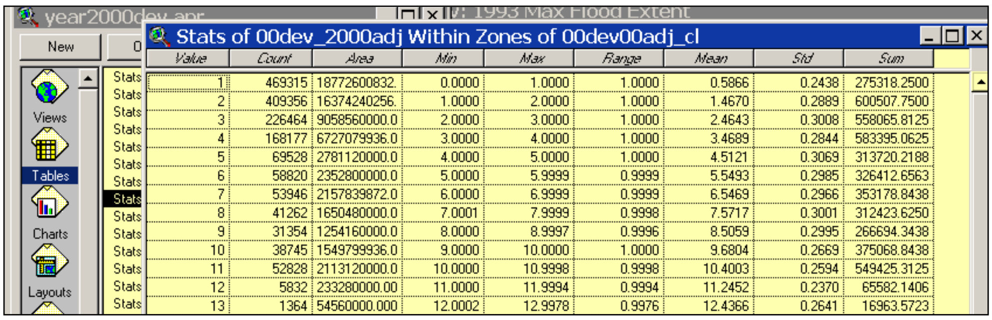
8 With the temporary grid active, convert it to a permanent grid by selecting "Theme", "Convert to grid". Save this permanent grid in the appropriate directory, then re-label the display by double clicking the legend and setting the required categories. As in the adjacent example, not all the categories need to be displayed individually.

Comment: More than one legend can be saved for alternate use with a particular type of flood map to highlight different features as required.

9 Now that the flood map has been classified, the statistics of the area within each flood depth category can be obtained by selecting "Analysis", "Summarise Zones". Make sure that the classified depth map is "active", select the original flood depth map (adjusted for depth) then click "ok". The values for this grid will be summarised by the active classified depth map theme in a newly created table, as per the example below.



Comment: ArcView will automatically create a chart of the data if the number of categories is less than 25.



Stats of 00dev_2000adj Within Zones of 00dev00adj_cl

Value	Count	Area	Min	Max	Range	Mean	Std	Sum
1	469315	18772600832.	0.0000	1.0000	1.0000	0.5866	0.2438	275318.2500
2	409356	16374240256.	1.0000	2.0000	1.0000	1.4670	0.2889	600507.7500
3	226464	9058560000.0	2.0000	3.0000	1.0000	2.4643	0.3008	558065.8125
4	168177	6727079936.0	3.0000	4.0000	1.0000	3.4689	0.2844	583395.0625
5	69528	2781120000.0	4.0000	5.0000	1.0000	4.5121	0.3069	313720.2188
6	58820	2352800000.0	5.0000	5.9999	0.9999	5.5493	0.2985	326412.6563
7	53946	2157839872.0	6.0000	6.9999	0.9999	6.5469	0.2966	353178.8438
8	41262	1650480000.0	7.0001	7.9999	0.9998	7.5717	0.3001	312423.6250
9	31354	1254160000.0	8.0000	8.9997	0.9996	8.5059	0.2995	266694.3438
10	38745	1549799936.0	9.0000	10.0000	1.0000	9.6804	0.2669	375068.8438
11	52828	2113120000.0	10.0000	10.9998	0.9998	10.4003	0.2594	549425.3125
12	5832	233280000.00	11.0000	11.9994	0.9994	11.2452	0.2370	65582.1406
13	1364	54560000.000	12.0002	12.9978	0.9976	12.4366	0.2641	16963.5723

10 Export the statistics by selecting “File”, “Export…” and using “Dbase” format. Save the file, then open it in MS Excel to sum the statistics for all depth categories.

Comment: Of course it is not necessary to create so many categories of depth to obtain the total flooded area. If only the total area is required, then the initial flood map can be classified into “0” and “1”, for not flooded and flooded areas respectively.

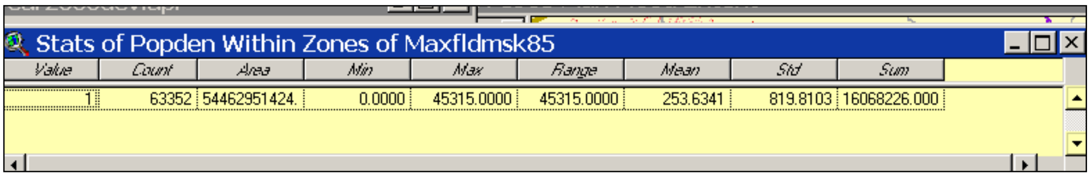
Number of Flooded People at Maximum Flood Extent

To calculate the number of people flooded at maximum flood extent, the following steps are performed:

1 Using the same View as that used above for the Maximum Flood Extent analysis, add the MRC’s theme for population density within the Lower Mekong Basin, i.e. “Popden”.

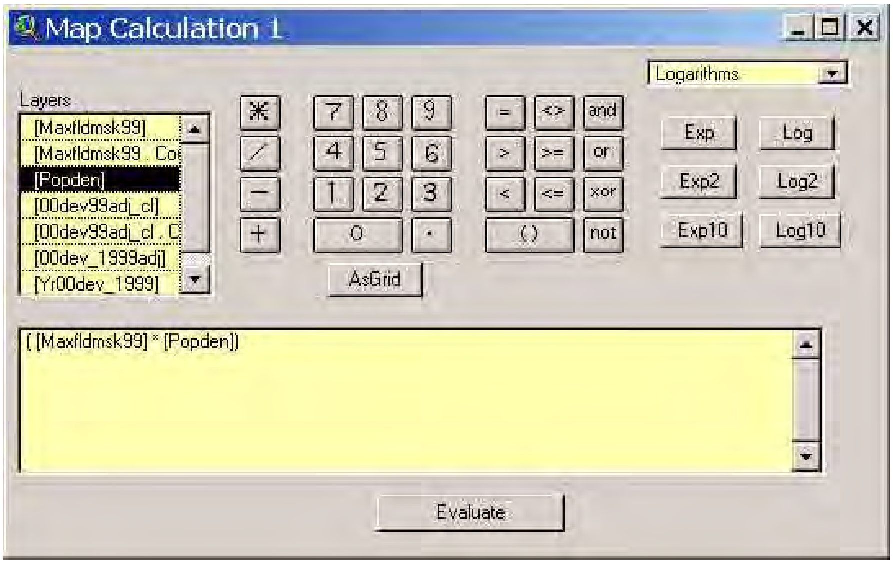
2 First prepare a flood mask from the maximum flood inundation theme (e.g. 00dev99adj) by *reclassifying* the values to ‘1’ or ‘No Data’, as per the steps described above. Similarly, convert the initial temporary grid theme to a ‘permanent grid’, labeling it as “Maxfldmsk85” or similar.

3 If only the total inundated population values are required, make the flood mask active then select “Analysis”, “Summarise Zones”. Select “Popden” and click “ok”. Export the data from the resulting table as previously for the flood areas. Note, that since the mask contains no sub-division, there is only one line of data in the table for the whole inundated area. The value for “Sum” is the total inundated population, whilst the “Area” is the total inundated area in square metres.

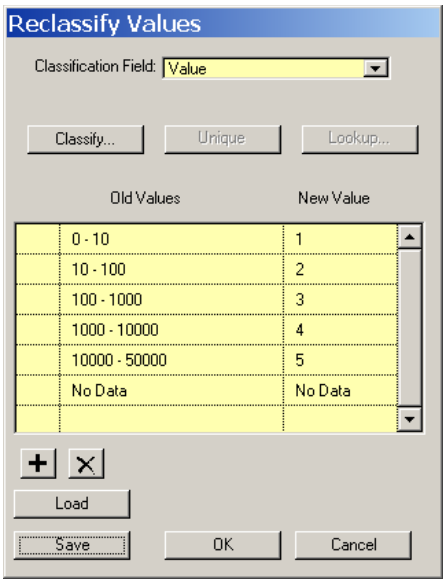

Stats of Popden Within Zones of Maxfldmsk85

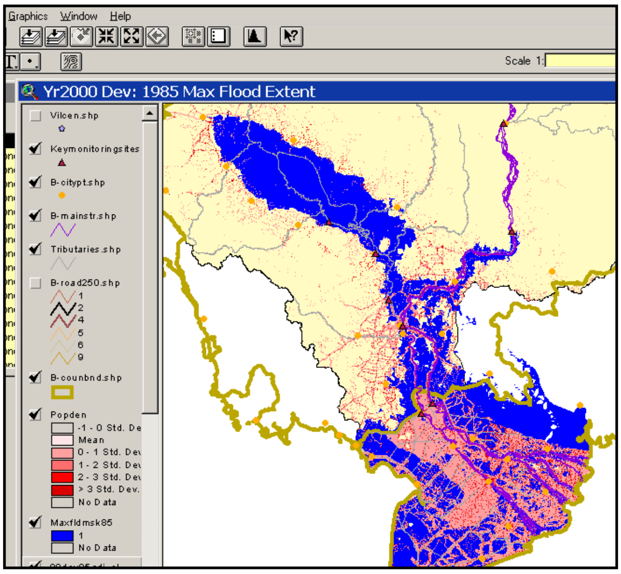
Value	Count	Area	Min	Max	Range	Mean	Std	Sum
1	63352	54462951424.	0.0000	45315.0000	45315.0000	253.6341	819.8103	16068226.000

4 If flood information is required for a range of population densities, then perform the “Map Calculation” below to produce a grid of the population inundated at maximum flood extent. Convert it to a permanent grid.

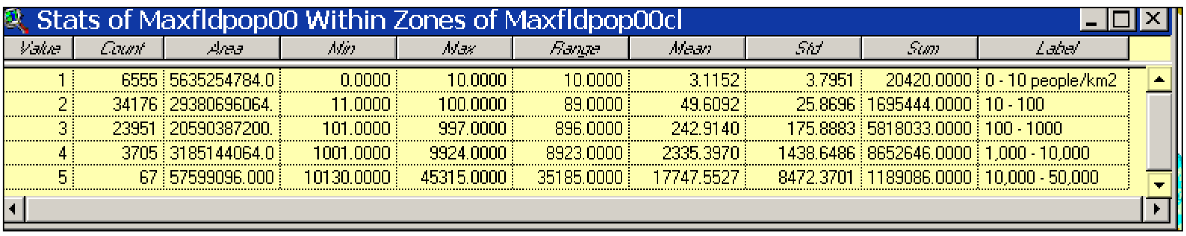


5 Classify the newly classified "inundated population" theme, as was done for the maximum flood extent map. This will allow the 'Summarise Zones' function to be used to generate a table of population inundated in each zone. An example of a re-classification is shown below ("old values" are population density in persons/km²). The right hand figure below shows the population density theme overlaying the flood mask.





Results of a classified approach to determining maximum flooded population by population density class.


Stats of Maxfldpop00 Within Zones of Maxfldpop00cl

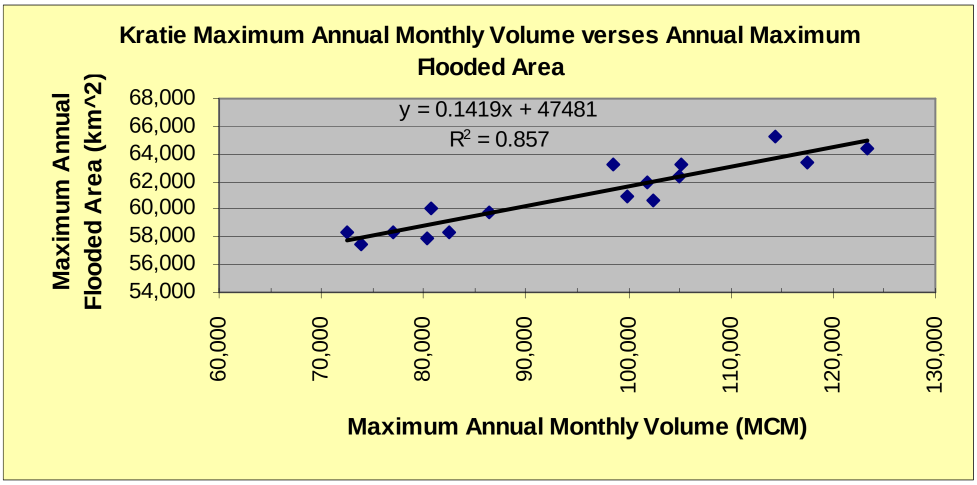
Value	Count	Area	Min	Max	Range	Mean	Std	Sum	Label
1	6555	5635254784.0	0.0000	10.0000	10.0000	3.1152	3.7951	20420.0000	0 - 10 people/km2
2	34176	29380696064.	11.0000	100.0000	89.0000	49.6092	25.8696	1695444.0000	10 - 100
3	23951	20590387200.	101.0000	997.0000	896.0000	242.9140	175.8883	5818033.0000	100 - 1000
4	3705	3185144064.0	1001.0000	9924.0000	8923.0000	2335.3970	1438.6486	8652646.0000	1,000 - 10,000
5	67	57599096.000	10130.0000	45315.0000	35185.0000	17747.5527	8472.3701	1189086.0000	10,000 - 50,000

6.5.2 Relationships

Maximum Flooded Area downstream Kratie

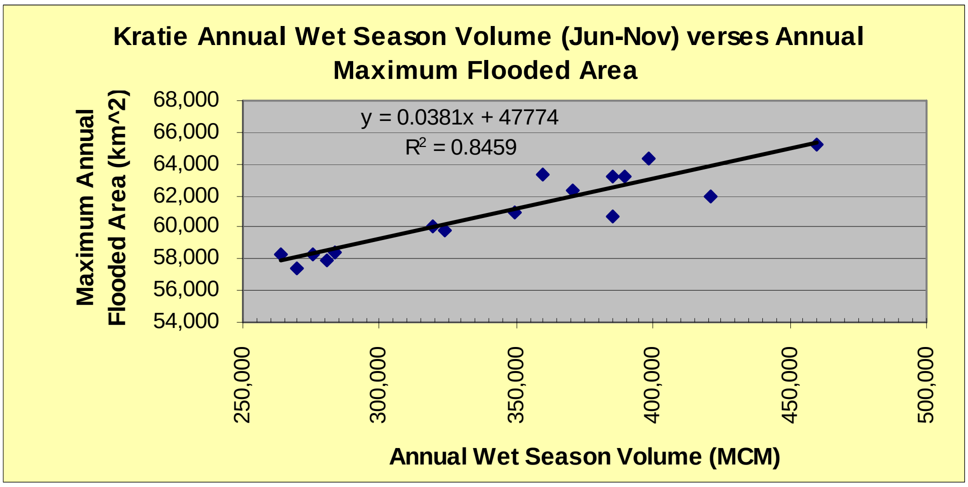
Figures 6.21 and 6.22 present the relationships between Kratie flows and maximum inundated area from Kratie downstream to the sea. Both provide a similar r² value of 0.85 indicating a strong relationship.

Figure 6.21: Kratie Annual Maximum Monthly Volume verses Annual Maximum Flooded Area downstream Kratie (DSF simulated data 1985-2000)



(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format)

Figure 6.22: Kratie Annual Wet Season Volume (Jun-Nov) verses Annual Maximum Flooded Area downstream Kratie (DSF simulated data 1985-2000)

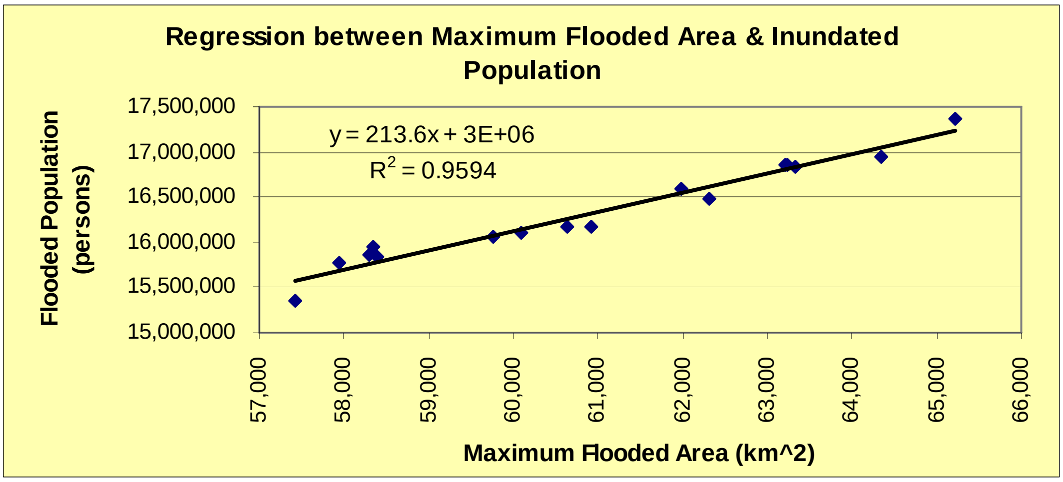


(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format))

Maximum Flooded Population Downstream Kratie

Figure 6.23 presents the relationship between the annual maximum inundated population and the area inundated downstream of Kratie. A very high r^2 value of 0.9594 indicates a strong relationship between the two as might be expected. Numbers of people inundated range from 15,359,462 to 17,375,629, i.e. by about 2 million, a substantial difference between the driest and wettest floods of the past 16 years.

Figure 6.23: Kratie Annual Maximum Monthly Volume verses Annual Maximum Flooded Area downstream Kratie (DSF simulated data 1985-2000)



(Source: Spatial analysis of DSF spatial output data for the "Year 2000 Development Scenario" using ArcView and MS Excel. Maps & tabular data provided separately in each applications' file format)

7 Infrastructural development

by Hugh Cross, March 2005

7.1 Introduction

Background

The Basin Development Planning Division (BDP) of the Mekong River Commission is currently performing a range of tasks to assist the riparian countries of the Lower Mekong Basin (LMB) formulate plans for the sustainable development for the basin's water related resources. To meet the goal of sustainable development, as articulated in the 1995 Mekong Agreement, the basin plans will need to utilise the principles of integrated water resource management to balance the multiplicity of objectives for different sectors and for each country.

One of the key areas that impacts the success of agricultural, industrial and urban development in Cambodia and Viet Nam, is the ability to manage the prevailing flood risk. That risk is a significant factor over most of the Mekong floodplain, including the area around Tonle Sap Great Lake. Thus there is a strong incentive to lower or even eliminate the risk to ensure the benefits of development are not compromised.

Against this objective is the recognition that annual inundation of the floodplain is an essential component of the high biodiversity and fisheries productivity exhibited by the LMB's aquatic ecosystems. Maintenance of those existing benefits, with the very great consequences for human health, livelihoods and economic well being, is also a key objective of each country's strategic planning.

Part of the work being conducted BDP for basin planning is the investigation of a range of scoping scenarios using the MRC's Decision Support Framework (DSF). Their purpose is to help define the likely impacts that could eventuate from particular combinations of developments. Those scenarios, however, do not include one that addresses the potential impact of future floodplain embankments, because there was insufficient information from which to forecast a likely future condition.

Purpose

Arising from the background presented above, the primary purpose of this report is to:

- Review likely major changes to the floodplain (embankments, roads, flood protection works, colmatage) in four main zones (north of Chaktamuk; around Tonle Sap; area between Mekong and Bassac south of Phnom Penh; Cambodian floodplain east of the Mekong);

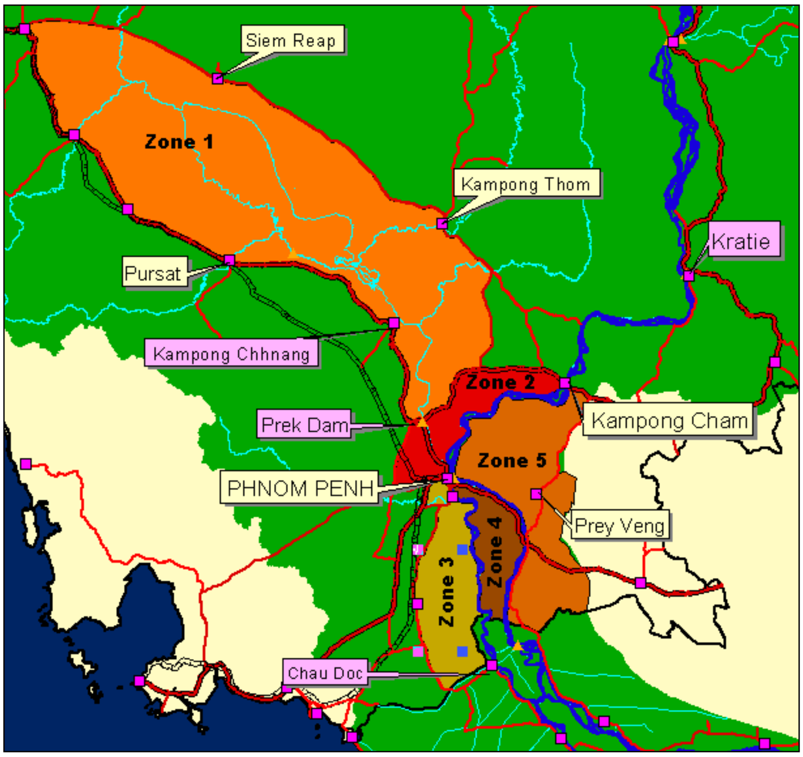
- Review existing model results (from World Bank scenario, JICA modelling);

- Comment on likely significance of changes to floodplain in terms of flow patterns; and

- Make recommendations on how to proceed with modelling of floodplain in Phase 2

Only the Cambodian portion of the Mekong floodplain is addressed as this is where the more significant changes are likely to occur; almost the entire Vietnamese portion of the floodplain has already been developed for agriculture and aquaculture. The floodplain zones mentioned in the first requirement are shown in Figure 7.1. Whilst zone 3 is not necessarily mentioned in the TOR, it is included in the review along with zone 4.

*Figure 7.1: Mekong River floodplain zones in Cambodia **(after WUP-JICA)***



7.2 Existing and future structures

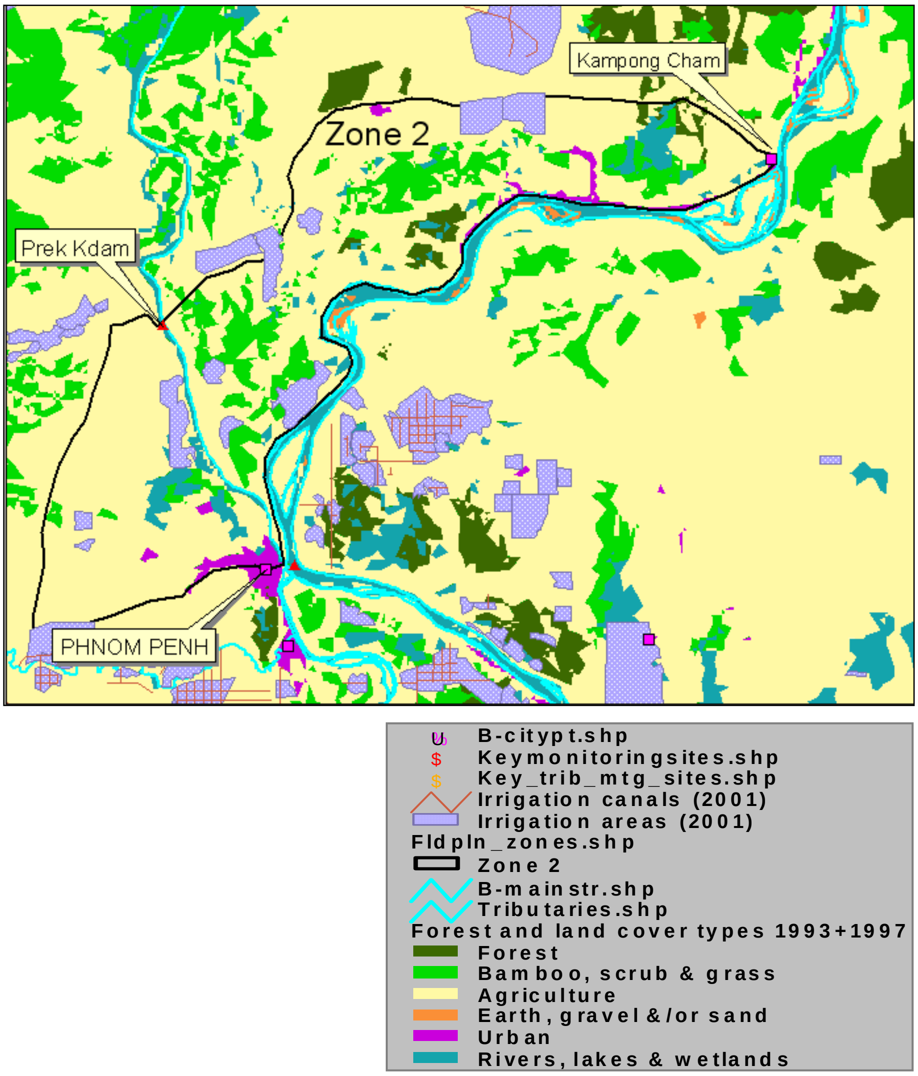
7.2.1 North of Chaktamuk (Zone 2)

This area covers the right bank of the Mekong, from Kampong Cham to Chaktamuk, the junction of the Tonle Sap, Bassac and Mekong Rivers, adjacent to the city of Phnom Penh (Figure 7.1). Together with the top part of Zone 5, it is the most upstream part of the floodplain.

Urban and industrial areas

This zone includes the northern part of Phnom Penh, the largest population centre in the Cambodian floodplain (Figure 7.2). Other urban areas are located at Kampong Cham and a strip of development adjacent to the Mekong River to the west of Kampong Cham. The area, however, is not really urban land per se, but rather is a more closely settled area of rural development, where each kampong (village) stretches into another as a form of ribbon development along key roads, generally those that are located on higher ground and are therefore less prone to flooding.

Figure 7.2: Landuse in zone 2 ***(mapped from 1993 & 1997 satellite imagery)***



Phnom Penh itself is largely protected from flooding by a series of raised main roads and to a lesser extent, by low levees. The situation in other urban areas, such as Kampong Cham, is not known. The linear development along the river is unlikely to have any flood protection works.

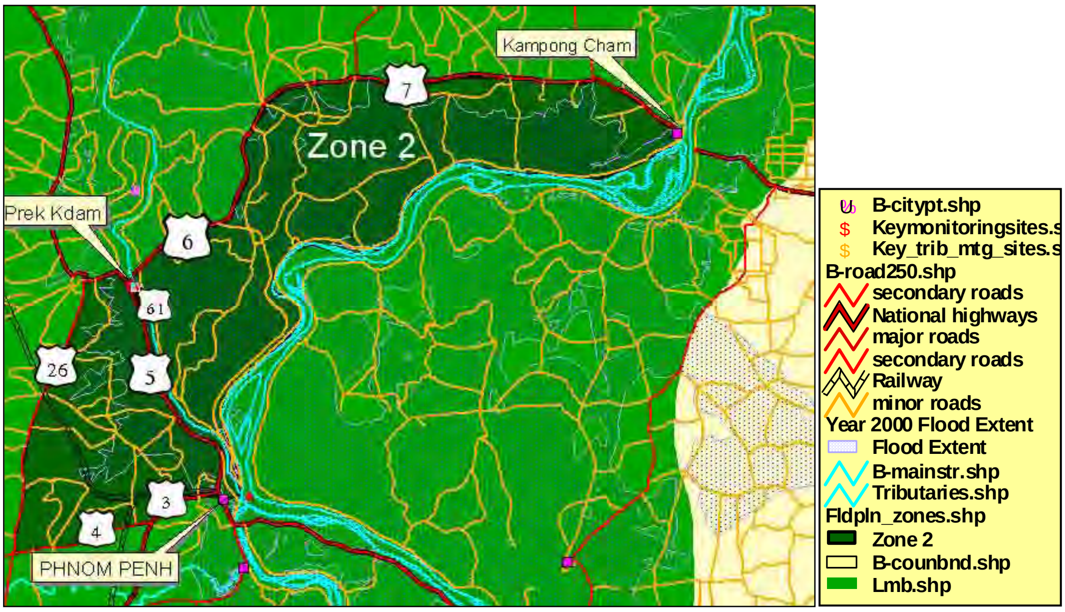
Land fill is relatively common in all areas undergoing development, particularly in the capital. Internal roads are sometimes raised above ground level by as much as 3 m in low lying areas, but more typically are only marginally higher. New housing often seems to "compete" in being higher that the roads to avoid flooding from local stormwater runoff, if not the river.

Peripheral industrial areas extend a substantial distance from Phnom Penh, generally beyond the area of residential development and are almost always constructed on land fill, typically 1.5 to 3 m higher than ground level. Because industrial development parallels main and secondary roads, this is where land fill is likely to continue in the future and exacerbate any blockages caused by those road embankments.

Roads and railways

Most significant of the existing structures in this area are the main roads of the Cambodian national highway system. These include National Road R3, R4, R5, R6, R7 and R26 as shown in Figure 7.3. R6 and the northern end of R5 are used to delineate the western limit of this area and span the floodplain entrance to the Great Lake. West of R6 is considered part of the Tonle Sap Great Lake system (zone 1). The peak flood extent in year 2000 shows that the floodplain is bounded by R26 in the west and R7 in the north. The only Cambodian rail lines are shown by the double black lines leading west from Phnom Penh, the splitting to Battambang in the west and Sihanoukville in the south.

Figure 7.3: Zone 2 showing major roads and railways in the area north of Chaktamuk



Both main roads and railway lines are elevated on fill for much of their length, certainly in low lying areas, where embankments may be up to 6m higher, although 2 to 4m is more typical.

The ribbon development referred to in the previous section on urban and industrial areas applies to many of the main, secondary and tertiary roads. The greater the traffic, the greater is the propensity for development to extend along the road. In most cases this starts with cheap housing on round poles, but as affluence increases, becomes partially then completely, based on earth land fill either side of the road. This has the effect of consolidating the road's effect on flood behaviour and reduced future opportunities for remedial works to enlarge waterway openings.

Agricultural works

Rain Fed Rice

Much of the agricultural areas shown light yellow in Figure 7.2 are fed by rain falling directly onto the paddy, or by rain with some input of locally sourced overland storm runoff.

To contain the depth of water needed to ensure sufficient moisture for the crop throughout its growth period, the rain fed paddy fields are surrounded by narrow, low earth bunds, constructed by hand. Typically these are no more than 0.6 m high, with the highest ones being about 1 m.

Figure 7.4: Typical earth embankments associated with rain fed rice

Floating Rice

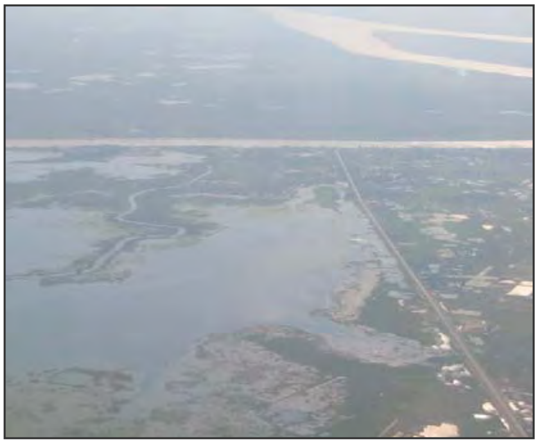
No information is available to determine if there are any areas of floating rice in this zone. However, its management requires no higher earth embankments than does rain fed rice.

Colmatage Canal Systems

Research did not indicate the presence of any colmatage canal systems in this zone.

Irrigation Schemes

By contrast to rain fed paddy areas, irrigation areas obtain water from tributary rivers, lakes, or the Mekong mainstream. At least 10 separate irrigation works, shown in stippled blue-grey in Figure 7.2, are contained in Zone 2:



Khum Lovea pump station	Somrong
Samrong pump station	Ampou Deap
Toul Cham Reservoir	Beung Dan Pur
17 April Reservoir	Tuk Phoor Reservoir
Por Kambaur	no name

Most of these features appear to be reservoirs that supply irrigation areas with water. Whilst the actual location of those irrigations areas is not available, they are likely to lie within or adjacent to the features shown. The reservoirs are typically contained by earth embankments generally less than 6 m high. None the less, they cover significant areas and are of more than sufficient height to block and redirect floodwaters.

No major water supply or drainage canals are shown supplying irrigation areas in Zone 2. These can be as much as 5 or 6 m in low lying areas. In addition, each irrigation area will have a system of primary, secondary and tertiary canals within its boundaries. The largest of these can exceed 2 – 3 m, but are generally less.

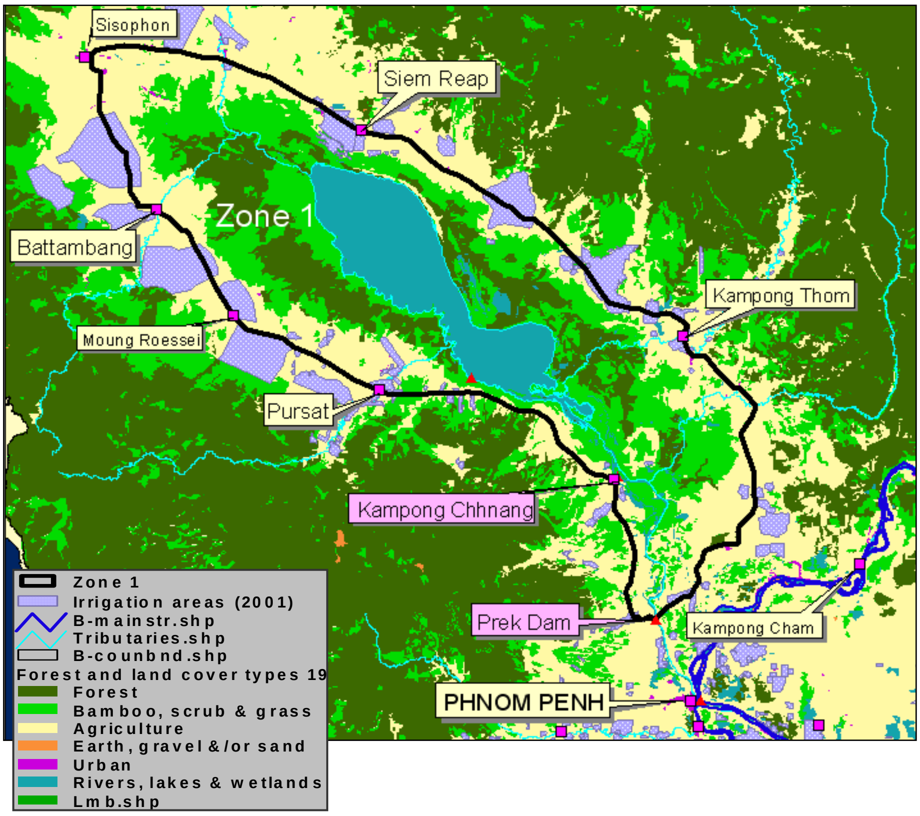
7.2.2 Tonle Sap and surrounds (Zone 1)

Largest of the five zones, zone 1 covers the entire area of the Tonle Sap Great Lake and its associated floodplains west and north-west of Prek Kdam (Figure 7.1).

Urban and industrial areas

Relatively insignificant areas of urban and industrial landuses are present in this zone and in almost every case are associated with the towns shown in Figure 7.5. Because the populations are very much smaller than for Phnom Penh, the scale of development and associated infrastructure is also much less. There are no known flood mitigation works.

Figure 7.5: Landuse in zone 1 *(mapped from 1993 & 1997 satellite imagery)*



In any case, the pattern of flooding within zone 1 is dominated by the filling of the Great Lake by Tonle Sap reverse flows (average of 60%) and by local tributaries. This causes water levels to rise in the lake which progressively expands during the wet season to inundate more and more of the surrounding floodplain. In a large flood year, such as the year 2000, most of the area within zone 1 was flooded (Figure 7.6) by such backwater.

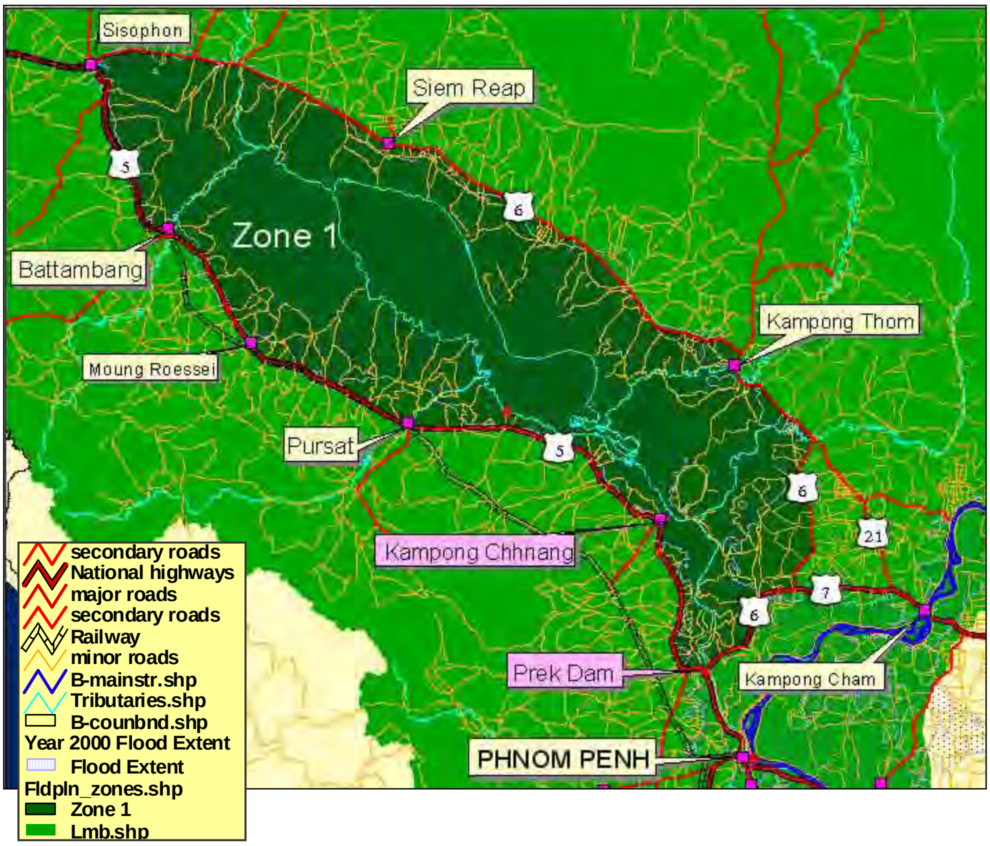
In such a ponded situation, the impact of embankments and land fill on raising flood levels is of no consequence, apart from their impact on detaining local runoff, or in the case of towns on tributary rivers, blocking tributary floodplain flows, thereby leading to locally elevated flood levels over quite small areas. Nor is land fill an issue in terms of the reduced floodplain storage, because the volume occupied by such fill is insignificant relative to the total wet season volume of the lake.

Roads and railways

Zone 1 is bounded and defined by the main roads, R5 and R6, but there are no other main or secondary roads within it (Figure 7.6). The Phnom Penh to Battambang railway jointly forms part of the western and southern boundaries of the zone. It is likely that the considerable height of these main roads and railway embankment (typically 2 to 6 m) serve to partially confine the expansion of the lake in larger flood years, not withstanding the presence of bridges and culverts.

On the other hand, the many small roads leading towards the lake are either at ground level or within 1 m of it and therefore pose no noticeable blockage to the passage of floodwaters from tributaries, nor the gradual expansion of the lake in the wet season.

Figure 7.6: *Roads and railways in the Tonle Sap & surrounding area (Zone 1)*



Agricultural works

Rain Fed Rice

Rice crops further from the lake, and removed from irrigation project areas near gravity fed tributary supplies, appear to be of this type. As was outlined for zone 2 above, embankments associated with this type of cropping are generally less than 0.6 m high. They pose minimal impediment to the wet season expansion of the Great Lake, and in any case, being further from the lake, are often not inundated by it.

Floating Rice

Large areas of floating rice surround the lake in a band that, on average, experience suitable conditions for its growth. Floating rice is actually rooted, but has an ability to grow many meters high, thereby keeping its leaves at and above the water surface.

Embankments of a similar height and design to those used for rain fed rice are used, i.e. generally less than about 0.6 m. These have minimal impact on the extent and duration of flooding.

Recession Rice

The colmatage canal systems adjacent to the Bassac River in zone 2 are replaced by a not dissimilar concept of recession rice around the Great Lake. As the name implies, recession rice is planted in areas inundated by the lake at its peak wet season levels, but exposed as it recedes. The earliest crops are planted near the outer extremities of flooding, with additional crops being added successively through to the end of the wet season as more land is exposed.

To ensure that adequate water is available for crop growth, and to suppress weeds, water is retained in recession crop areas by embankments. Planted later than rain fed rice, these crops require greater amounts of water and so the embankments can on average be higher, although exact figures are not available.

It appears that recession rice is gradually assuming a greater importance in the Tonle Sap area, relative to floating rice.

Irrigation Schemes

Relatively small areas of the zone are currently part of irrigation schemes (Figure 7.5). Most areas lie wholly or largely outside the zone's limits and are gravity fed from tributary rivers. Schemes within the zone are subject to higher flood risks in wet season and transition months (those between the beginning and end of wet season). They also present difficulties in draining tail water due to the their minimal elevation above even dry season lake levels.

No information is available on embankment heights, but in general, the major embankments are higher than in rain fed and recession rice areas. In large floods, the embankments, supply and drainage canals, may reduce flooding to some degree within and adjacent to the schemes. The extent to which this occurs is largely a function of the operational practices, which are likely to involve opening regulators in the wet season to allow inundation, then close them on the recession of the flood, much as is done for recession rice. This would augment the supply of water from the tributaries and provide opportunities for the capture of fish.

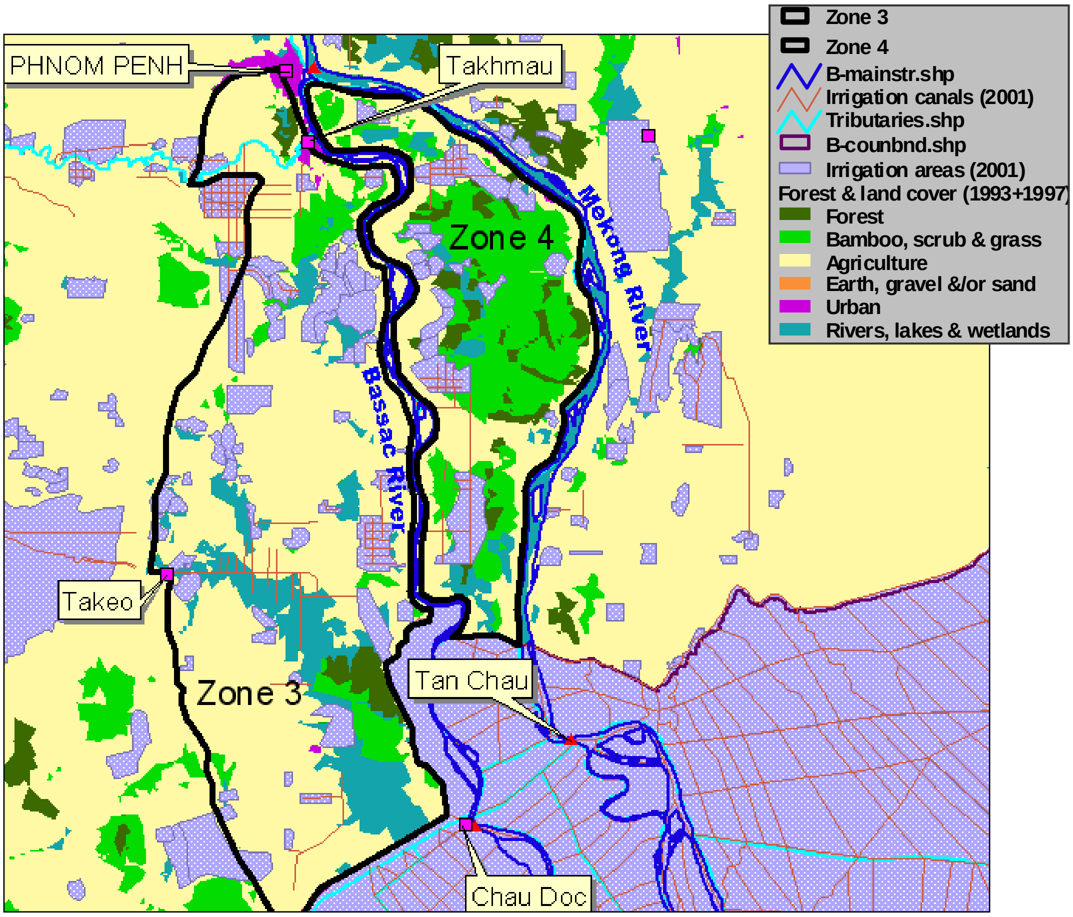
7.2.3 Area south of Phnom Penh (Zone 3)& area between the Bassac & Mekong Rivers (Zone 4)

These two zones extend south from Phnom Penh to the Vietnamese border, covering the entire floodplain west of the Mekong River. Zone 4 covers the area between the Mekong and its distributary, the Bassac River, whilst zone 3 covers the remainder, to the west of the Bassac to the beginning of the slow rise towards the coastal mountains.

Urban and industrial areas

As shown in Figure 7.7, the only urban area of note is Phnom Penh and an extension of it along the western bank of the Bassac. There are few other urban areas, the remainder of the population being distributed between numerous kampongs, the larger of which are most congregated along the higher ground adjacent to the Mekong and Bassac Rivers.

Figure 7.7: Landuse in zones 3 & 4 (representing 1993 & 1997 conditions)

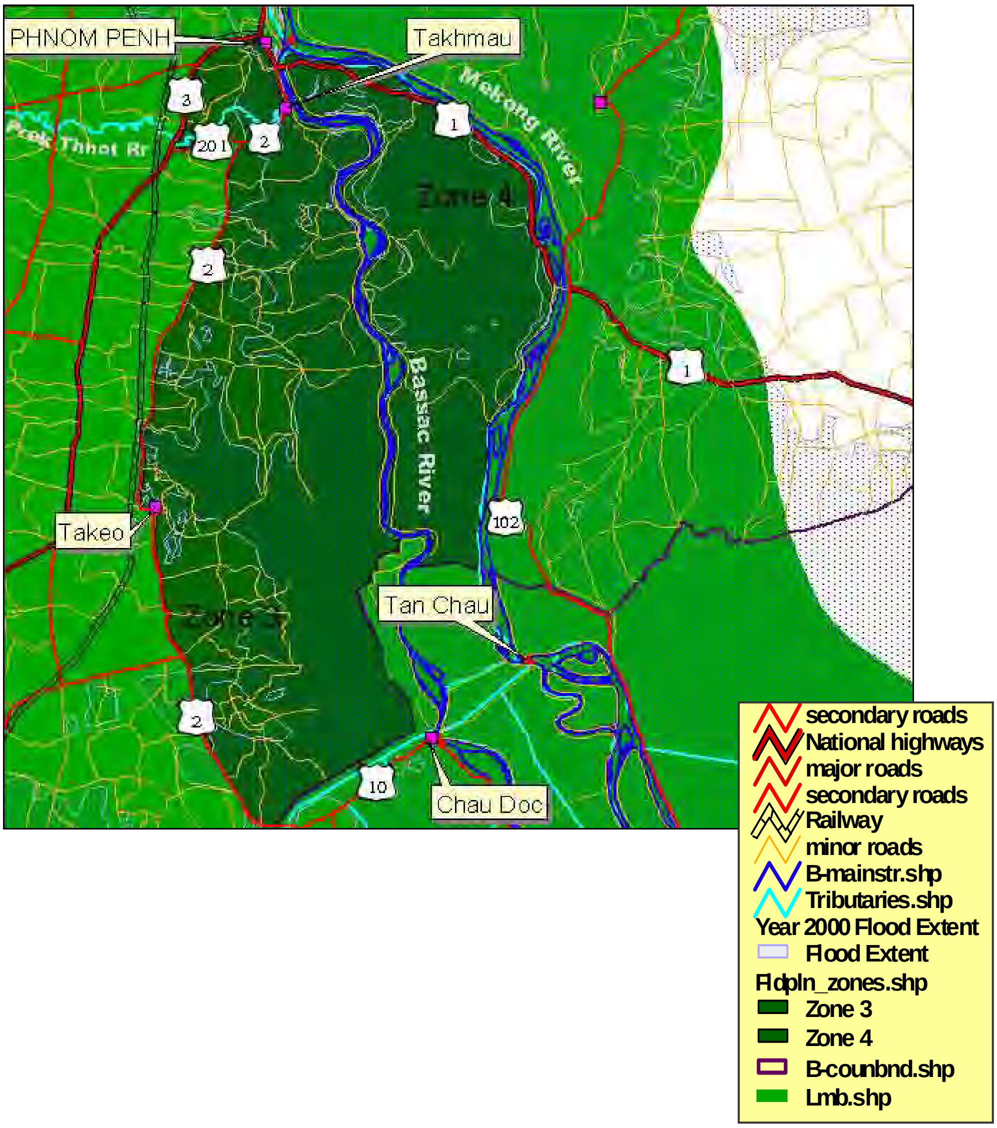


Phnom Penh and its outlying residential and industrial areas are associated with roads and land fill that block most if not all flood waters entering zone 3 from the north discussed previously in section 0.

Roads and railways

In the west, zone 3 is bounded by national roads R3, R201 and R2. Except in the south, these roads do not confine even a large flood, such as occurred in year 2000. Towards the southern end of National road R2, the flow can be impeded, however, as at this location flows naturally spill from the Mekong towards the sea.

Figure 7.8: Roads and railways in areas south of Phnom Penh (Zones 3 & 4)



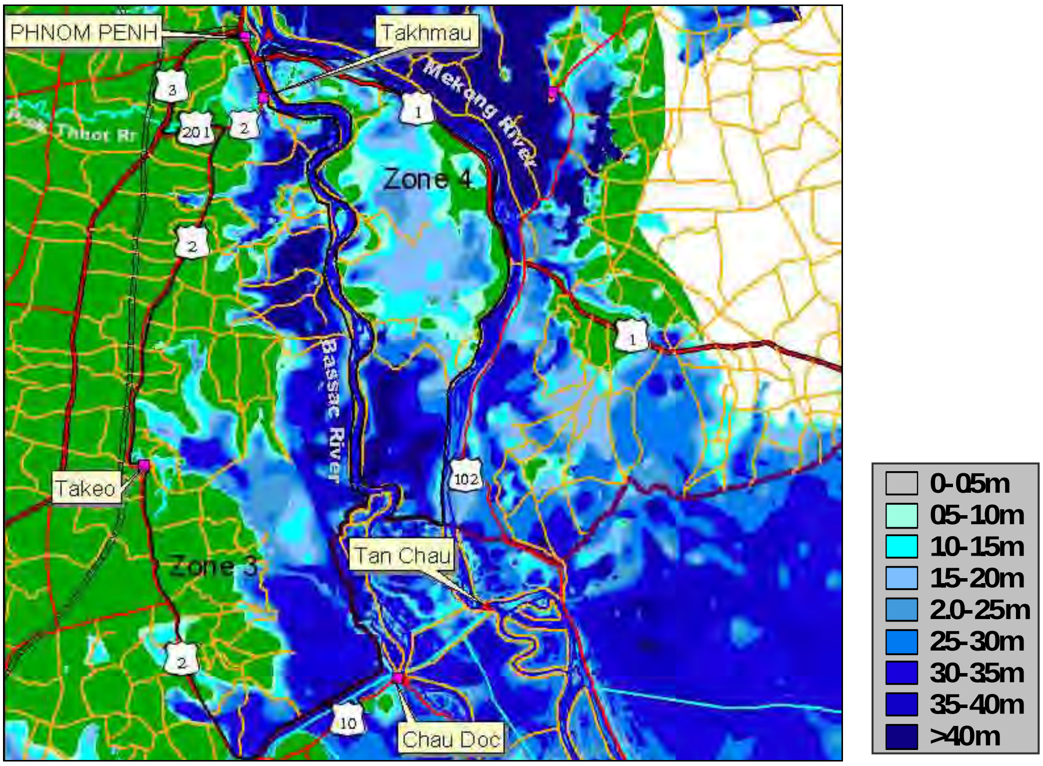
National road R2 also bisects the northern end of the zone just south of the Prek Thnot River and can be expected to influence flood behaviour upstream and downstream of it.

No other main or secondary roads traverse the centre of either zone and even the minor roads are confined to higher ground. The centre of zone 4, and the south-east portion of zone 3, are largely free of roads, primarily because of the high flood depths (Figure 7.9Figure 7.9), but probably also because of the drainage of water from the colmatage system into these areas.

The natural levee along the right bank of the Mekong River from Phnom Penh to the bridge over the Mekong, is now elevated by the embankment of national road R1. Typical embankment heights are not to hand for this stretch of road.

Where minor roads traverse deeper flood areas, it can be expected that the road embankments have been raised above the surrounding floodplain. Even though they will be submerged during the peak of many annual flood events, those transverse to the flow of water will be likely to raise flood levels upstream and to impede drainage on the recession of the flood.

Figure 7.9: Year 2000 peak flood depths south of Phnom Penh relative to the location of roads (Zones 3 & 4)



Agricultural works

Rain Fed Rice

Based on the pattern of flooding, it is likely that rain fed rice areas are predominantly in areas that either are not subject to flooding, or are flooded to relatively shallow depths, i.e. the western half of zone 3 and the north half of zone 4. This is because rain fed rice is grown in the wet season and flood depths in excess of 0.5 m will damage the crop. Depending on the growth stage, flood durations of between one day and one week will cause substantial losses.

Embankments are assumed to be of the same height as has been observed in other rain fed areas close to Phnom Penh, i.e. generally < 0.6 m. These have minimal impact on flood extent, particularly when compared to road embankments.

Colmatage Canal Systems

Also referred to as 'polders', colmatage canals utilise the natural levee that flanks most of the Mekong River from Kratie to the sea. This levee has been built up by preferential sediment deposition over geological time scales during flood events; coarser grained material is deposited close to the river, leading to greater depths of sediment than further away from the river. Whilst well defined in some areas, this levee may be indistinguishable in others, or even absent. Commonly it will be broken by natural openings where water drains back to the river at the end of each annual flood. One area in which the natural levee is very apparent is in the area between the Mekong and Bassac Rivers, downstream of the Chaktamuk junction at Phnom Penh where these two rivers diverge.

Local farmers have made use of the difference in elevation to manage flooding of their crop lands. During the wet season floods either over top the levee, or water is allowed to enter the floodplain via regulators or openings cut through the river levee. This water may be allowed to flow through the farm systems until towards the end of the wet season when some water is retained behind constructed embankments, i.e. the colmatage canal system, for irrigation extending into the dry season.

The effect of these systems on flooding has been assessed by the WUP-JICA project and is discussed in section 0.

Irrigation Schemes

Of the 44 named irrigation projects located in zones 3 and 4 (shown in Figure 7.7), most are located in areas of higher ground. Many are irrigation reservoirs serving adjacent irrigation areas. The larger areas closest to the Bassac and Mekong Rivers are often located behind colmatage canal areas and may receive their water from them.

As with other areas, embankments associated with the major internal canals, as well as the external supply and drainage canals, can on average be higher than those in rain fed areas. They may therefore interfere with the natural distribution of floodwaters, as discussed further in section 0.

As is the case in zone 5, flooding in the southern portions of these two zones are also influenced by the extensive irrigation in Viet Nam. Commencing at the border, irrigation extends unbroken for the entire southern boundary of both zones. The first embankments are those associated with the primary irrigation supply channels for the most northerly Vietnamese irrigation areas; the Vinh Te and Hong Ngu channels are located within a few hundred metres of the border and can have a visible impact on flooding in satellite images.

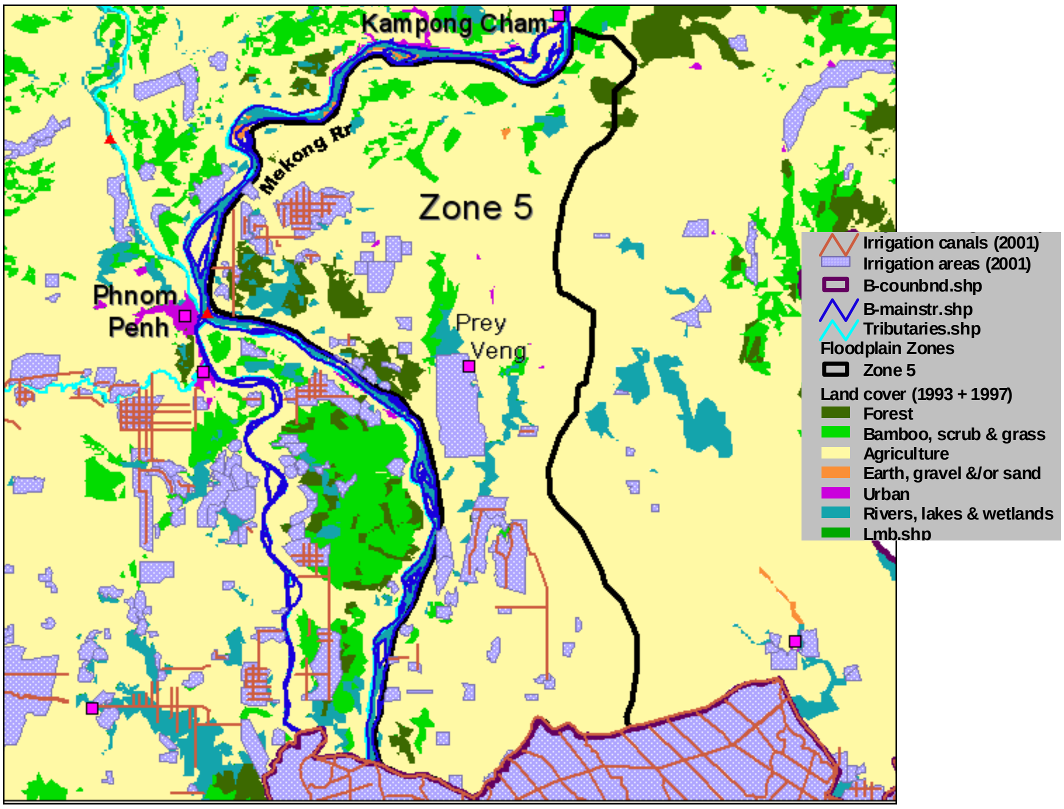
7.2.4 East Cambodian Floodplain (Zone 5)

Zone 5 is the second largest floodplain zone and the largest of those outside of the Tonle Sap area. It covers the entire left bank floodplain of the Mekong, from Kampong Cham to the Vietnamese border (Figure 7.1).

Urban and industrial areas

As can be seen from Figure7.10, apart from Prey Veng, zone 5 contains no real urban or industrial areas, although it does contain many kampongs ranging in size from under 500 people to over 5,000 in a few cases. Consequently, flood mitigation works are absent, although land fill can be expected to be associated with many of the larger kampongs.

Figure 7.10: Landuse in zone 5 (mapped from 1993 & 1997 satellite imagery)

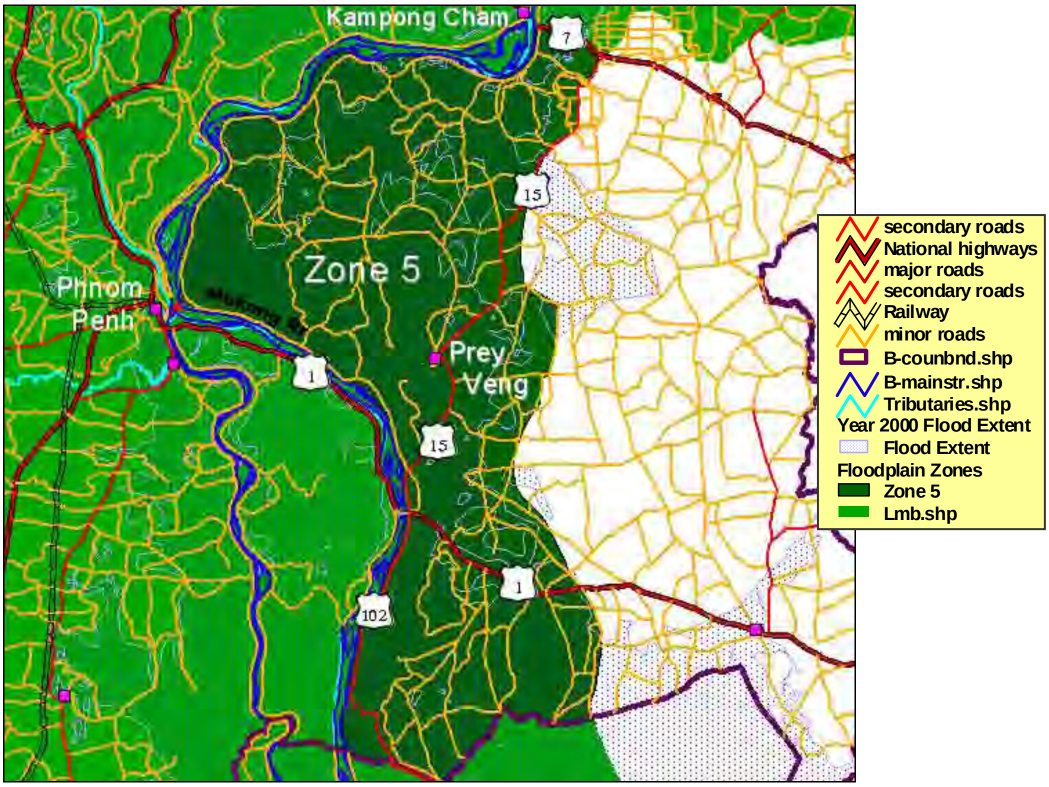


Roads and railways

Most significant of the major roads is national road R1, which bisects the zone in the south and is known to have an impounding effect on flows. At its northern end, adjacent to Kampong Cham, the upstream limit of the zone is delineated by R7, another major road with significant embankments perpendicular to the prevailing flow. A significant secondary road, R15, crosses the zone in a diagonal fashion and is likely to present an obstruction to flow in the south, near its junction with R1. Another important road is R102, running south from R1 along the left bank of the Mekong River. Prior to crossing the Vietnamese border, which it parallels for a distance, it bends east away from the river to the east. There are no railways in the zone.

The distribution of minor roads is relatively even throughout the zone, except in areas subject to deeper levels of flooding immediately to the east of the river's natural levee. Many of the minor roads are also perpendicular to the prevailing flow directions and therefore may also contribute to impacts on the distribution of flood waters.

Figure 7.11: *Roads network in the eastern Mekong floodplain (Zone 5)*



Agricultural works

Rain Fed Rice

As for other floodplain zones, rain fed rice is likely to be more common in areas that are either free of flooding, or are only subject to relatively shallow, short duration flooding in most years. Areas in proximity to the irrigation projects in Figure7.10, which in general are located in areas subject to deeper flooding, are more likely to be supplied with irrigation water.

Floating Rice

No information is available as to whether floating rice is grown in this zone.

Irrigation Schemes

At least 46 named irrigation works are located in zone. Some are dams and reservoirs, whilst others are irrigation areas. As most of the dams are located in lower lying areas, in most years they capture water from the wet season floods for use in the following dry season. In smaller flood years some may only capture rain water from local runoff. In either case, the embankments can alter flood patterns in the wet season, although information is not available on their exact dimensions or embankment heights.

It must be noted that perhaps one of the greatest impacts on flooding in zone 5 is the extensive irrigation in Viet Nam, which covers the entire area just across the border from the Cambodia. Two primary irrigation supply channels, run the entire length of the southern boundary, just downstream of the border; the Hong Ngu canal in the west and Cai Co –

Long Khot canal in the east. Embankments associated with these channels present a considerable impediment to the passage of flood waters, as can sometimes be seen in satellite imagery. Rubber dams are used in at least one location to control the passage of floodwaters into downstream areas.

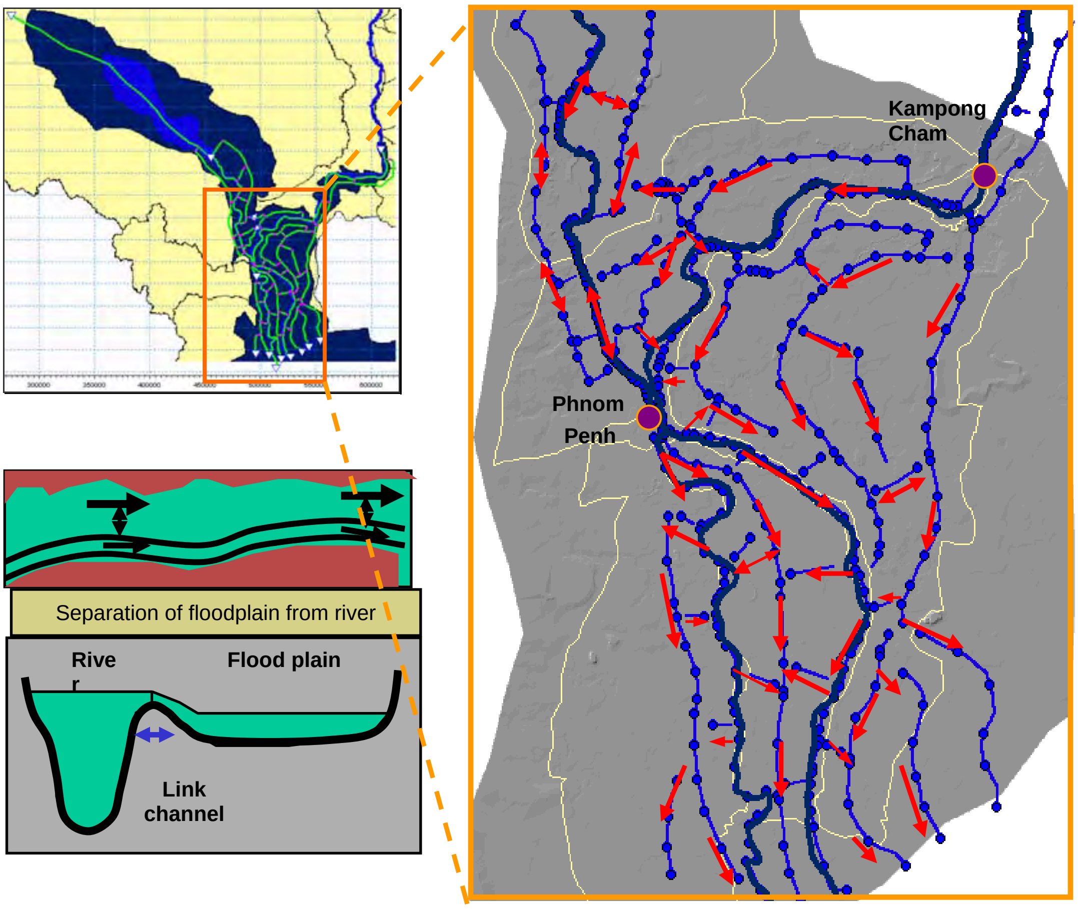
7.3 Impact of embankments on flood behaviour

7.3.1 WUP-JICA hydraulic studies

Schematisation

The Tonle Sap Lake and Vicinities (TLSV) hydraulic studies, conducted as part of the WUP-JICA project, present a detailed analysis of the dynamics of flood behaviour the Cambodian floodplain. Figure 7.12 presents the Mike 11 schematisation of river and floodplain flow paths. Red arrows show the flow directions, which in the Tonle Sap River and its floodplain, are bi-directional.

Figure 7.12: Flow directions along the WUP-JICA schematised flow network



(Source: after TLSV Floodplain Modelling Workshop II presentation 2003)

It is important to note that the TLSV model is only quasi-2 dimensional, as it is effectively a series of one dimensional flow paths linked at end points and occasionally by spills from points mid-way along their length. Thus in the simulations, flow can only pass from one flow path to another via these pre-defined links.

Although such simplification limits the model's ability to replicate all the features of the observed flood pattern, it retains the key features that account for most flood behaviour characteristics. Of these, one of the most important is the separation of the river from its floodplain by the natural levee and typified by the cross-section in Figure 7.12. Thus once water spills onto the floodplain through a low point, it is effectively trapped there and generally can not return to the river except by similar low points, often many tens of kilometres downstream.

Key flood behaviour characteristics

The TLSV studies (MRC, 2004b) break the Cambodian floodplain down into the five zones that have been used in the structure of this report (Figure 7.1). The following conclusions were made with respect to the flood dynamics of filling and draining:

The pattern of flood filling is similar in zones 2 and 5, and in zones 3 and 4

Drainage patterns in

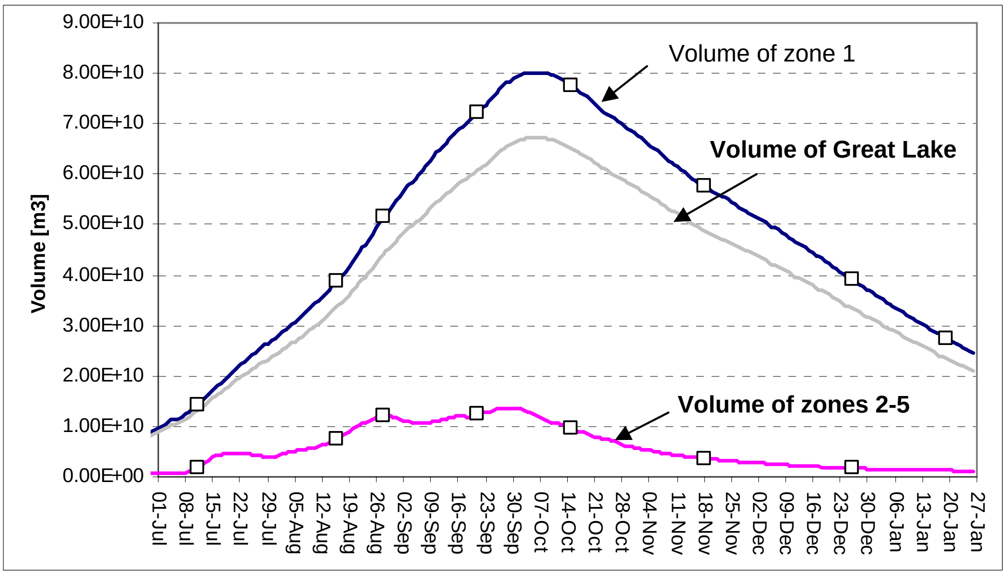
- Zone 1 – exhibit a very slow recession of large volumes (the Great Lake retains half its stored wet season volume at the end of November, whereas flows from floodplains outside of the Great Lake area are largely completed by this time)
- Zone 2 – shows slow recession
- Zone 5 – shows rapid recession
- Zones 3 and 4 – are in-between

Other key flood behaviour observations include:

- Approximately 30 % of the discharge at Kampong Cham is diverted to the flood plains between Kampong Cham and Chrui Changvar (just upstream of the Chaktamuk junction). Of this amount about 60% is diverted to the left bank and 40% to the right bank on average, although proportions differ at different flow stages
- The flow volumes flowing through the flood plains (zones 2 – 5) are an order of magnitude larger than the actual storage of water within them
- The storage capacity of the flood plains is 15-20 % of the capacity of the Great Lake and associated plains
- The flood plains between Mekong and Tonle Sap Rivers (i.e. the downstream end of zone 2) show a slow release of stored flood water
- The flow regulating function (i.e. the reduction of the flood peak and an attenuated flow recession) of the flood plains is small compared to the regulating function of the Great Lake

To demonstrate the above observation of the difference in flood storage volumes, Figure 7.13 shows the difference between three areas, the Great Lake itself, all of zone 1 (which includes the Great Lake), and the rest of the Cambodian floodplain (zones 2 to 5). It is evident that the floodplain areas contribute comparatively little to the maintenance of dry season flows in the Mekong downstream of Chaktamuk.

Figure 7.13: Cambodian floodplain and Tonle Sap Great Lake flood storage volumes



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

From the above observations, the TLSV study identified the following flood management issues of concern:

1 Flood storage:

The Great Lake provides the largest storage capacity

The flood plains in zones 2 to 5 store about 20% of rising stage flow volumes and about 15% of the volume during peak flows

The flood volumes on the plains (zones 2 to 5) are not important themselves

2 Floodplain flow:

The distribution of flows between river and flood plain along the Vietnamese border is crucial

A reduction in floodplain flows between Kampong Cham and Chrui Changvar in Cambodia could increase water levels in Phnom Penh

Infra-structural projects that affect the flow exchange between rivers and flood plains must be evaluated carefully as the hydraulic impact can be significant

Isolated bridges and embankments are the main controls on the flood plains. Changes to them have large impacts on the flow distribution and inundation pattern on the flood plains

Hydraulic effect of bridge openings along national road R1;

- Significant water level gradient is observed during peak flow
- Present bridge openings act as bottlenecks for downstream flows and increases upstream water levels

The focus in zones 2 to 5 is therefore

- flood extent and depth
- the flux of water through the flood plains
- the velocity field on the plains and in flow controls
- obstacles for flow

The authors of the TLSV study recommended that the management focus be on:

- flood extent/depth rather than volumes on the flood plains
- the importance of the through-flow on the plains and how this is controlled by manmade structures
- velocity aspects on the plains and at bridges/culverts

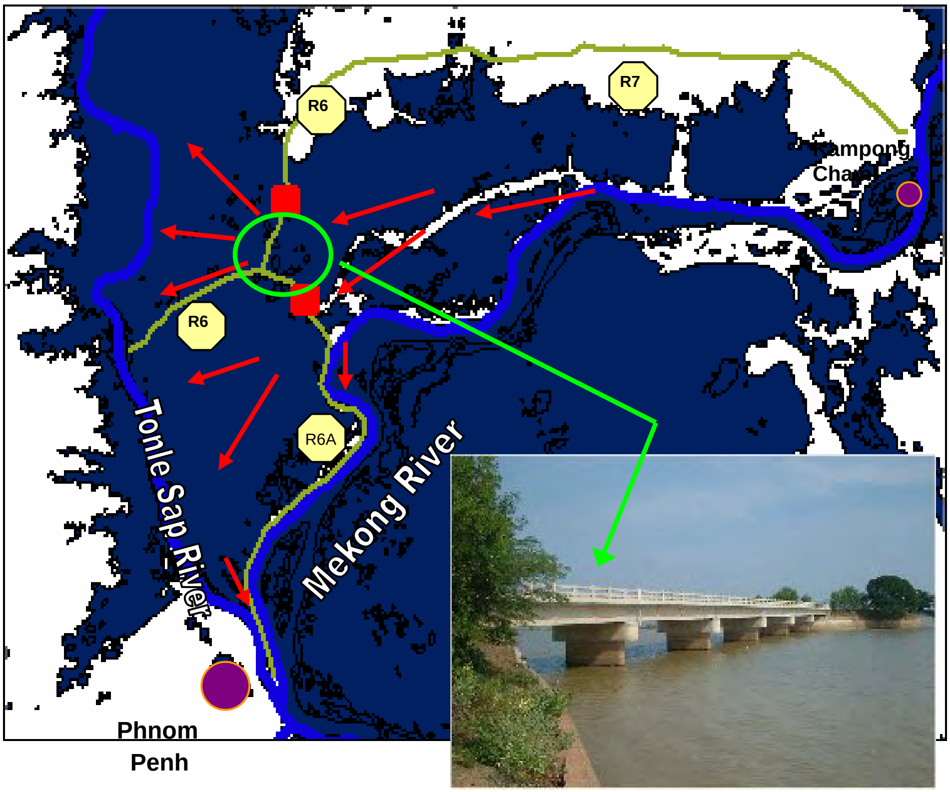
Existing impacts

Impact of National Roads R6 and R6A (Zone 2)

As mentioned in section 3, the main embankments affecting zone 2 are national roads R6 and R6A. Road R7 skirts the northern boundary of the floodplain, but generally only influences the extent of large floods at a few locations.

According to the TLSV schematisation, all flood water entering zone 2 can only exit to the Mekong via two locations in the lower third of the reach between Kampong Cham and Phnom Penh, at the locations shown in Figure 7.14. However, large volumes also exit to the Tonle Sap River, but in doing so must pass through or over R6 and R6A. Such is the embankment height of R6, that all flows pass though a series of bridges and culverts, with no over topping. Failure of gabions on one of the bridge abutments in the year 2002 flood demonstrated the significant head differences across national road R6. Bridge and culvert openings are similarly critical in R6A, but it is believed that over topping can occur.

Figure 7.14: Drainage of flood waters from zone 2 – via bridges in national roads



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

Other conclusions were reached through a historical analysis of the impacts of road development at various points in time since the 1920s, when the first significant embankments were constructed. The key findings (using the year 2000 hydrograph) include:

- Most of the current impact on flood flows was caused by the construction of national road R6 (labelled R61 at its western end in the TLSV study) across the entrance to the Great Lake at Prek Kdam in the late 1920's

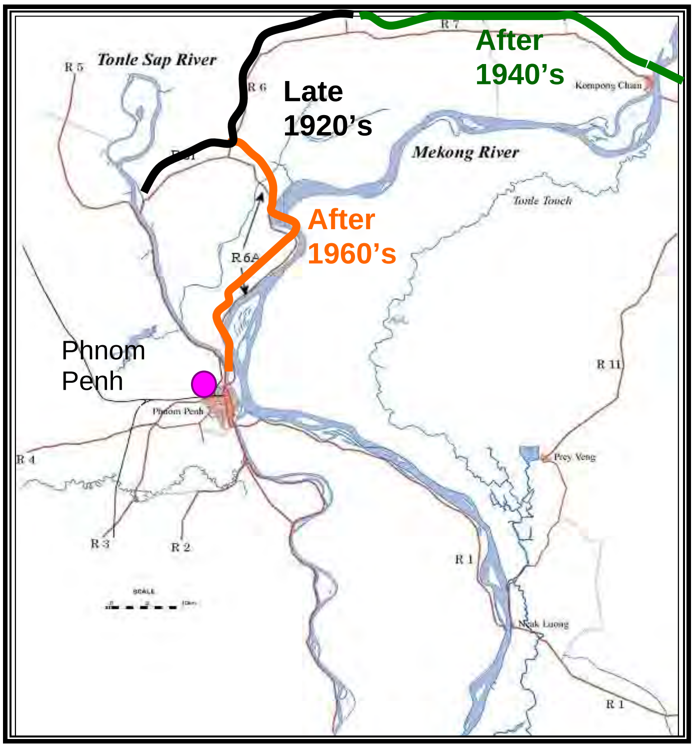
- Volumes entering zone 2 are now half that which occurred in the 1920s

- 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 (14 mcm verses 44 mcm)

- The total volume entering the Great Lake is now 62 mcm verses 70 mcm previously (11% less) and of this, 48 mcm now enters via the Tonle Sap River, whereas previously it only conveyed 27 mcm, a 78% increase

- The volume draining from the Great Lake at Prek Kdam is now only 22 mcm, almost 30% lower than the previous 31 mcm (but in both cases the 'normal' flow draining the lake is 40 mcm less than the reverse flows, due to evapo-transpiration and seepage in the lake)

Figure 7.15: 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))

Changes in Zones 3 and 4

Whilst no specific studies were conducted for these zones, the TLSV study's historical investigations of the effects of national road R6 (discussed in the previous section) concluded that flow volumes in the Bassac River are now one third higher than in the 1920's (increased from 38 mcm to 60 mcm), with a corresponding decrease in Mekong mainstream flows downstream of Phnom Penh (315 mcm reduced to 296 mcm).

These changes are possibly due to higher mainstream water levels at the Chaktamuk junction, due to the above mentioned reductions in floodplain flows in zone 2. Flows entering the Tonle Sap River are now much higher as a consequence, which drives the increased reverse flow volumes also noted above. It is logical to conclude that these higher water levels lead to an increased 'spill' of water from the Mekong into the Bassac, at the lower end of the Chaktamuk junction, as the separation is much less than the width of the river (which is about 2 km).

Higher wet season flow levels in the Bassac are likely to be causing greater levels of flooding in the adjacent flood plains, particularly that to the west of the Bassac (zone 3), which is not influenced directly by Mekong. Zone 4 flooding, whilst also influenced by higher Bassac levels, are in part compensated by lower Mekong River water levels.

Impact of National Road R1 in Zone 5

TLSV studies show that blockages caused by major roads, such as National Road No.1 near Neak Luong, just east of the Mekong, can increase water upstream water levels by over half a metre.. Increasing the total width of the bridges by a factor of three (from about 150 m to 450 m) decreases water levels by as much as 40 to 50 cm for a distance of up to 20 km upstream, but it must be noted that by removing the throttling effect it also increases levels downstream by up to 20cm for some 5 to 10 km.

Modelled scenarios

All five embankment scenarios are evaluated using the year 2002 flood event.

Zone 2 – Right bank embankment from Kampong Cham to Phnom Penh

This scenario exacerbates the impact of the existing roads, as discussed in the section 0 above; flow that would have entered the Great Lake from the zone 2 floodplain is totally eliminated. Peak flood levels about 0.2 m higher at the Chaktamuk junction lead to greater reverse flows in the Tonle Sap River, but overall the total reverse flow volume is reduced leading to a reduction in peak Great Lake levels of about 0.3m.

Flood depths and extent are increased in zone 5 through a combination of increased flow volumes entering it between Kampong Cham and Phnom Penh, but also due to higher levels in the Mekong River downstream of the Chaktamuk junction, which impound flows exiting the zone.

Zone 5 – Left bank embankment from Kampong Cham to Phnom Penh

By preventing flood waters entering the upper part of zone 5, flow volumes in the Mekong River and right bank (zone 2) are increased by about 23,000 mcm. Of this, some 15% is conveyed by the floodplains in zone 2. Flooding in the upper part of zone 5 is not totally eliminated because the natural topography and levee impound local rainfall.

Peak water levels at Chaktamuk are increased by 0.2 – 0.35 m, causing the reverse flow volume to increase by about 1,000 mcm and Great Lake levels to rise by 0.35m. Flows downstream Chaktamuk (at Koh Norea) are increased by about 20,000 mcm, leading to increased flows entering the Bassac, but this only increases flooding in the upper most portions of the Bassac floodplain in zone 3. There is no apparent difference in the zone 4 or the lower half of zone 5.

Zones 2 & 5 – Left and right bank embankment from Kampong Cham to Phnom Penh

With flows confined to the Mekong mainstream from Kampong Cham to Phnom Penh, peak water levels are about 0.5 m higher at Chaktamuk, resulting in lake levels some 0.35 m higher. That they are no higher than in the preceding scenario, containing only the left bank levee, is due to the absence of floodplain conveyance in zone 2. The rate of inflow via the Tonle Sap River alone is inadequate in the time available for flows in the lake to match those in the Mekong River.

This is also reflected in the observation by the TLSV project that the peak year 2002 flood level in the Great Lake is achieved two weeks later than under baseline conditions. Clearly, restricted entrance conditions into the Great Lake (no floodplain flows) delay peak lake levels even in the presence of higher flows at Chaktamuk.

Zones 2 & 1 – Widening of bridges through National Road R6

As discussed in section 0, national road R6[1] has a considerable impact on the passage of flood waters into the Great Lake due to inadequate bridge openings and embankment crest levels that generally preclude overtopping. A hydraulic gradient of almost 0.9 m currently exists across the road at peak flood times.

Were the bridges openings to be doubled, the difference would only decrease to 0.6 m, indicating that even greater improvements could be warranted. Even this improvement would increase floodplain reverse flow volumes by about 4,000 mcm, whilst decreasing Tonle Sap River reverse flow volumes by 1,000 mcm, providing a net improvement of 3,000 mcm.

Zones 3 & 4 – Re-establishment of colmatage channel system along the Bassac River

The current colmatage system along the Bassac River is not as extensive as it once was and apparently it not assumed to exist at all in the TLSV baseline case. Assuming that it is re-established along the entire upper part of the Bassac along both its banks, the impacts are quite considerable on flooding and on flow volumes at Chau Doc.

Firstly, peak river flow rates downstream of the colmatage systems can more than double, due to the reduced floodplain storage during the peak flood period. Within the reaches of the Bassac adjacent to the colmatage canals, river levels would be correspondingly higher, which would allow water levels in the colmatage canals to also be maintained some 2 m higher. That additional floodplain storage reduces the volume of floodplain flows entering the lower parts of zones 3 and 4. Volumes at Chau Doc are subsequently reduced.

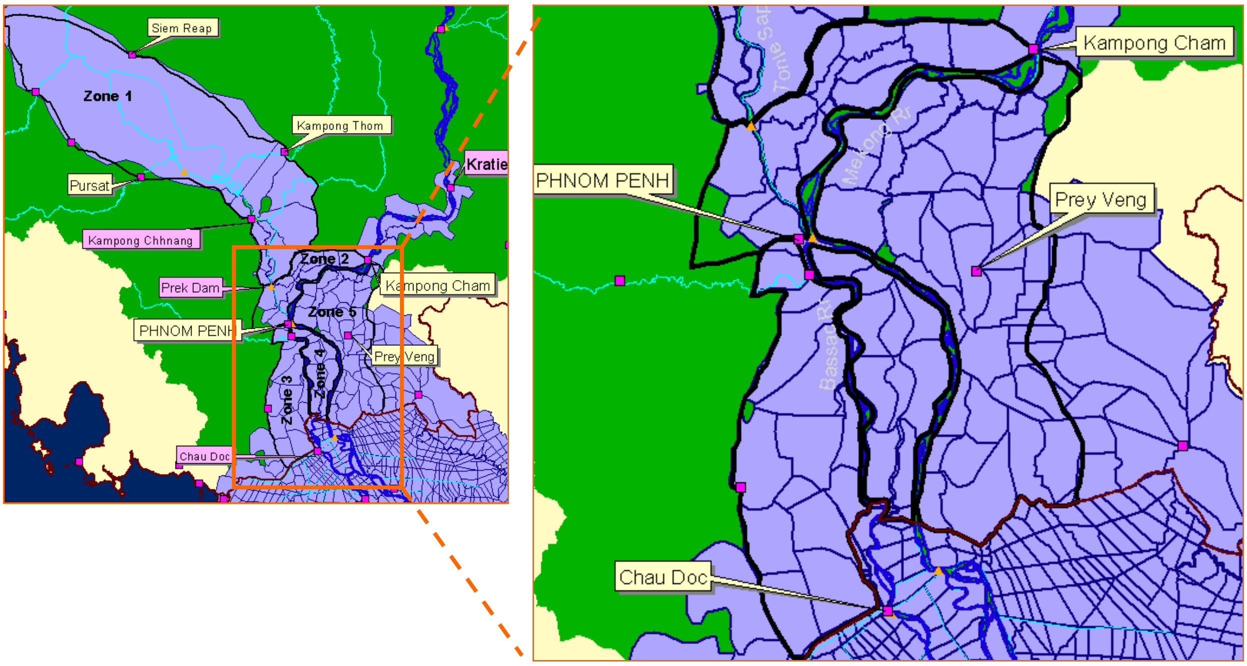
7.3.2 World Bank embankment scenario analysis

Schematisation

The iSIS model contained in the MRC DSF (Decision Support Framework) is a 2 dimensional cell model. As with TLSV quasi-2 dimensional model, it computes flows and water levels at each time step using unsteady state computations, such that the dynamic interaction of all flows are taken account of. Being a 2-D cell model, this means that the water level in any one flood or river cell is determined relative to those to which it adjoins.

[1] National road R61, mentioned in the TLSV report as part of the blockage to the entrance to the Great Lake, is according to GIS information held in the MRCS-TSD, a road that runs along the left (northern) bank of the Tonle Sap River.

Figure 7.16: iSIS 2-D hydrodynamic model schematisation showing flood cells



Nodes are defined on each cell boundary with another cell. Consequently the flow directions are not pre-determined, but are the result of the model's determination of relative water levels across those nodes at any one time.

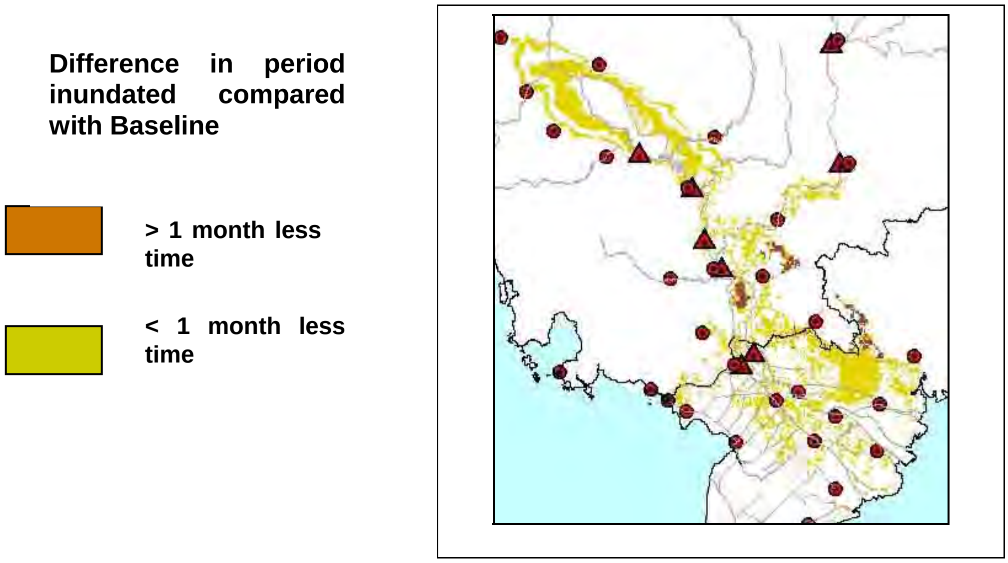
Major road, rail and other embankments are included in the schematisation, firstly through the delineation of flood cells bounding them, and secondly by the parameters employed to represent the flow dynamics between them. Many minor structures and even some major structures for which inadequate information was available, are not directly modelled, but are subsumed in the overall calibration via other parameters.

Scenario Analyses

One of the five development scenarios considered by the World Bank (World Bank, 2004) was that involving the construction the protection of 130,000 ha of agricultural land between Kampong Chan and Phnom Penh embankment. The exact location of the intervention(s) was not recorded in the report and it is unclear whether it involves the left and/or right banks, and whether the embankments were continuous or ring levees.

None the less, the resulting difference in flood durations is presented in Figure 7.17. Most affected areas experience flooding for up to one month less, but three areas show changes of greater than one month, two of which lie in the LMB. The first is directly south of Kampong Cham in zone 5, whilst the second is in the northern part of zone 4 between the Bassac and Mekong Rivers.

Figure 7.17: Year 2000 flood duration changes – World Bank embankment scenario compared to baseline conditions



The fact that flood durations are reduced in the Tonle Sap area would appear to indicate (from the TLSV findings) that at least some embankments were assumed in the area between the Tonle Sap and Mekong Rivers in the southern end of zone 2.

7.3.3 DSF demonstration scenario analysis

In the final testing of the DSF, a series of demonstration scenarios were evaluated, one of which was an embankment along the left bank of the Mekong between Kampong Cham and Phnom Penh, similar to that considered by the TLSV project and discussed in 0.

The simulated flood depth maps are shown in Figure 7.18 and the changes between them in Figure 7.19.

Figure 7.18: Baseline and embankment peak year 2000 flood depths (DSF demonstration scenarios)

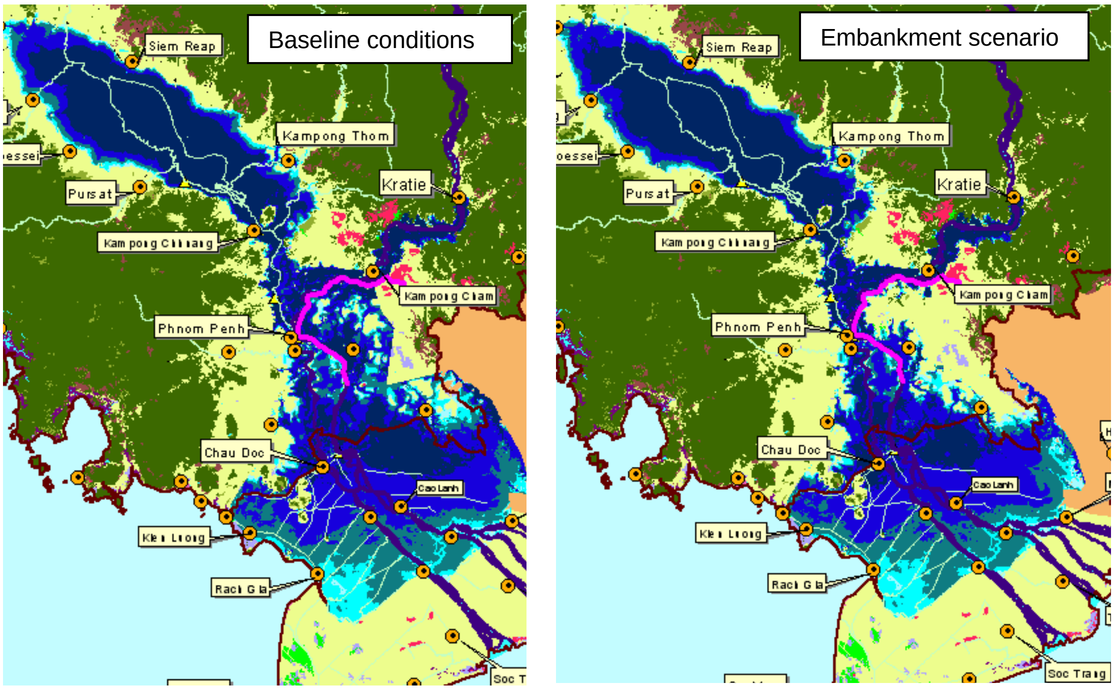
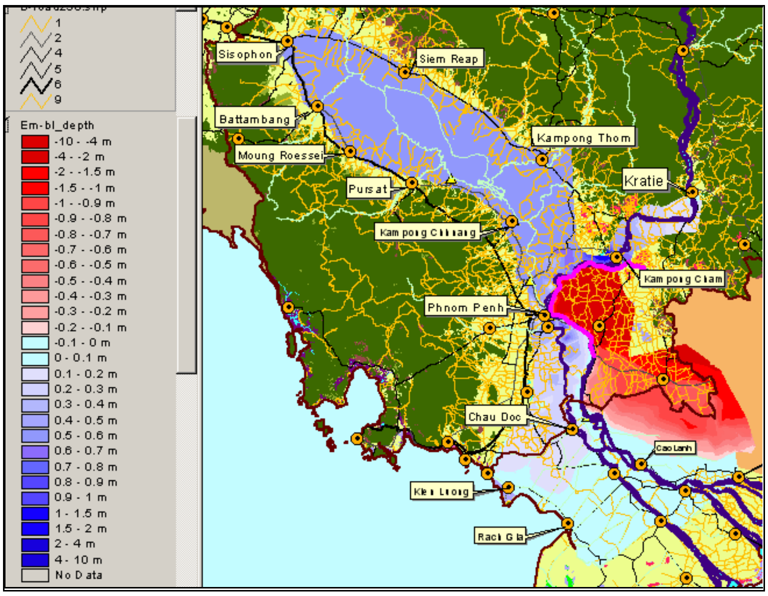


Figure 7.19: Year 2000 peak flood depth changes – embankment scenario compared to baseline conditions (DSF demonstration scenarios)



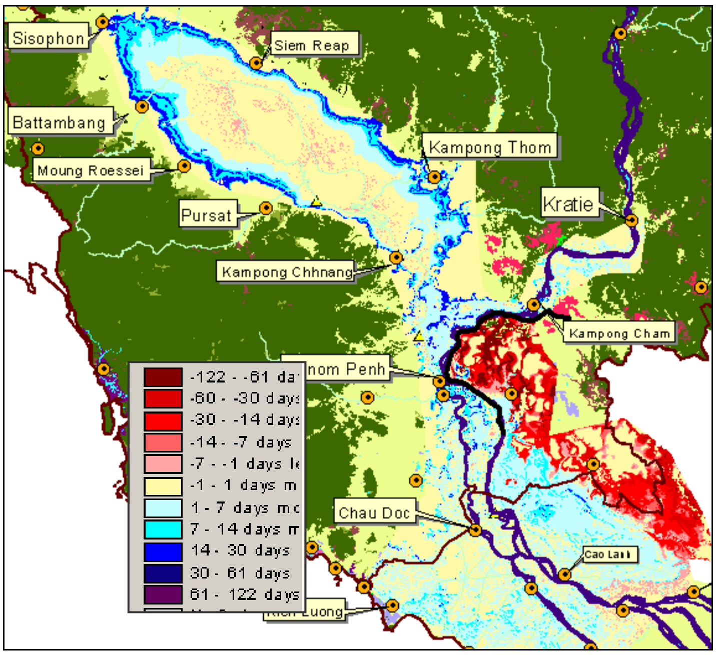
The triangular (yellow) intrusion below Kampong Cham in the Baseline map and difference maps is due to an error in the demonstration TIN (Triangulation Interpolation Network) and should be ignored.

Levels are as much as 2 m lower over large areas of Cambodia and Viet Nam protected by the embankment and in some areas more than 4 m lower. These reductions are offset by increased water levels in the remaining inundated areas from Kratie downstream. They are most severe (>1 m) in the vicinity of Kampong Cham where it can be seen the flow is highly constricted between the new embankment and the high ground to the north of the river. Height increases in Tonle Sap Lake are less, but substantial, being 0.5 – 0.55 m higher over the whole lake.

Compared to the 0.35 m increases in Great Lake levels simulated by the TLSV embankment scenario, the increases modelled by the DSF demonstration scenario are somewhat greater (by about 25cm), but otherwise are in general agreement. Given that the interventions may not be quite the same and that the DSF results were produced by the iSIS scoping model, not the final model, the two findings show the same trends.

The DSF testing also included an analysis of flood duration differences for depths in excess of 0.5m, for which the difference map is presented in Figure 7.20. The durations are more than one to two months shorter in the areas just south of the embankment, representing a complete removal of flooding in some areas. In the Great Lake and in a widening fan downstream of Phnom Penh, the trend is opposite. Durations increase around the margins of the lake due to the higher lake levels. The amount by which durations are increased south of Phnom Penh is more complex, representing the more complex pattern of flood depths in this area.

Figure 7.20: Year 2000 flood duration changes – embankment scenario minus baseline (DSF demonstration scenarios)



7.4 Significance of floodplain changes

7.4.1 River flows

According to estimates by the TLSV project (MRC, 2004b), only about 15% of the total wet season flood storage is provided by the floodplain areas outside of the Tonle Sap Great Lake and its surrounding areas (zone 1). Hence, relative to the impact of the Great Lake on areas downstream of Chaktamuk, the primary hydraulic function of those areas is the conveyance of flood waters rather than detention.

However, with respect to their impact on peak flood flows upstream of Chaktamuk, the comparison is irrelevant; their conveyance and storage is sufficient to substantially lower peak wet season flow rates. For instance in 2002 flows were reduced by 25% between Kampong Cham (51,000 m/s^3)and Chrui Changvar, just upstream of Phnom Penh (38,000 m/s^3).

A further reduction in peak flows is caused by the three-way divergence of flows at Chaktamuk, with some 7,300 m/s^3 of the 38,000 m/s^3 entering the Tonle Sap River and 5,200 m/s^3 into the Bassac. These proportions would be altered by any new embankments upstream, as discussed further below.

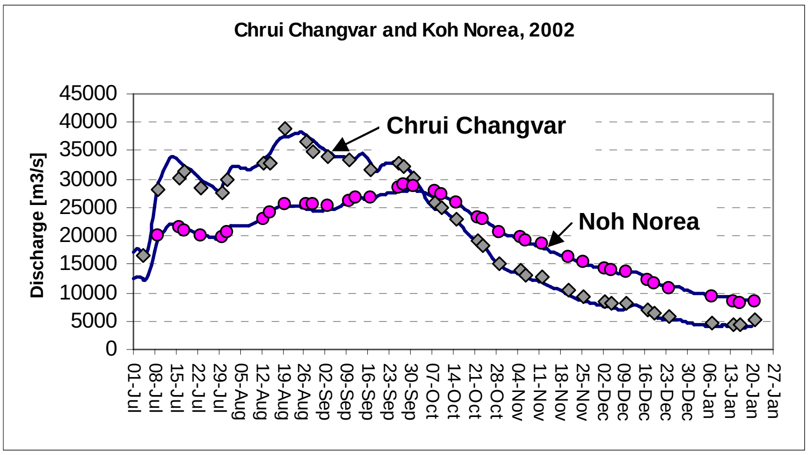
The TLSV project notes that in the 2002/2003 dry season, flows draining the Great Lake via the Tonle Sap River contributed about 40% to 60% of the total flow downstream of Chaktamuk, from November to March and about 20% to 40% in April. This total flow includes the Bassac and Mekong and is what enters Viet Nam.

Figure 7.21 shows a comparison of Mekong River flows at Chrui Changvar & Koh Norea, which even without considering flows in the Bassac River, are substantially higher downstream of Chaktamuk due to the Tonle Sap's contribution.

The maintenance of dry season flows downstream of Phnom Penh is therefore largely contingent on maintaining the wet season flow volume in the Great Lake.

Scenario evaluations performed by the TLSV and World Bank projects clearly demonstrate the vital importance of the upper floodplain areas (upstream of Phnom Penh) to the Tonle Sap and floodplains' reverse flow volume and therefore the lake's peak wet season volume. Whilst embankments along the left bank of the Mekong in the northern part of zone 5 upstream of Phnom Penh will increase flow reverse volumes and hence Great Lake volumes, those on the right bank in zone 2 from Kampong Cham to Phnom Penh, will reduce them.

Figure 7.21: Comparison of Mekong River flows at Chrui Changvar & Koh Norea (upstream & downstream of Chaktamuk, respectively; 2002)



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

Finally, whilst not conclusive, analysis of the TLSV scenario involving reinstatement of the colmatage canal system may cause flow volumes and levels to be reduced at Chau Doc.

7.4.2 Flooding

Embankment impacts on river and floodplain flows, as noted in the preceding section, have corresponding impacts on flood levels and consequently, flood extent and duration. A summary of the likely impacts of potential embankment situations is provided below:

Zone 1 – Tonle Sap & surrounds	Potential Flood Impacts:
▪ Embankments in the lake area to the west of Kampong Chhang	➢ no impacts beyond local exclusion or impoundment of flood waters ➢ no impacts on lake levels as the lake volume is vast compared to the small areas that might be excluded
▪ Embankments east of Kampong Chhang	➢ have a real potential to further restrict floodplain conveyance and hence reduce reverse flow volumes, leading to lower peak lake levels
Zone 2 – north of Chaktamuk	
▪ Right bank embankments (i.e. northern side of Mekong)	➢ reduced flooding in zone 2 ➢ reduce reverse flow volumes into the Tonle Sap floodplain and river, thereby reducing levels in the Great Lake
Zones 3 & 4 – south of Phnom Penh	
▪ Re-instatement of colmatage canals	➢ increased flood levels in the Bassac River and any unprotected floodplain areas ➢ possible increases in flood levels in the lower Bassac

▪ New embankments for agriculture, roads or other purposes	➢ increases in upstream flood levels if transverse to the flow direction, possibly by 50cm or more if the embankments are above general flood level and inadequate openings are provided
▪ New land fill for urban and industrial purposes near Phnom Penh	➢ will further restrict flooding into the upper end of zone 3 on the right bank of the Bassac River
▪ New or enlarged embankments in Viet Nam	➢ any additional blockage of flood flows into Viet Nam, or within a few tens of kilometres downstream of the border, is likely to increase flood levels in zones 3 and/or 4
Zone 5 – eastern Mekong floodplain	
▪ Left bank embankments (i.e. southern side of Mekong)	➢ reduced flooding in the northern half of zone 5 ➢ increased flooding in zone 2, the Great Lake and areas downstream of Phnom Penh along the Mekong and Bassac
▪ New embankments for agriculture, roads or other purposes	➢ increases in upstream flood levels if transverse to the flow direction, possibly by 50cm or more if the embankments are above general flood level and inadequate openings are provided
▪ Enlarge bridge openings in main roads, such as National Road R1	➢ reduced flood levels by as much as 50 cm for distances of up to 30 km upstream ➢ some increase in flood levels downstream; up to 20 cm for 5 to 10 km downstream is possible
▪ New or enlarged embankments in Viet Nam	➢ any additional blockage of flood flows into Viet Nam, or within a few tens of kilometres downstream of the border, is likely to increase flood levels in zone 5

7.4.3 Ecological impacts

The changes in flows and particularly flood inundation patterns, discussed above, can have significant impacts on the riparian ecology. These impacts can be summarised as being as function of changes in:

- Peak flooded area and depths
- Flood duration
- Habitat type inundated
- Lateral connectivity between the river or permanent water bodies, and the floodplain
- Water quality

With respect to the first three, impacts on fish and other aquatic organisms are direct consequences of those changes, however the magnitude of the impact will depend on the species concerned. Lateral connectivity is critical to the capture fisheries of the LMB. Consequently, where embankments are built along the natural levees of the Mekong, Tonle Sap and Bassac Rivers they can have adverse consequences not only on flooding, but on the movement of fish to and from the floodplain. Fish undertaking lateral migrations to and from the floodplain will often not pass through road culverts due to behavioural inhibitions associated with dark confined areas. Bridges appear to have much fewer impacts of fish migrations.

It is not only active migration of adult fish that is important, passive drift of nutrients and especially eggs and larvae, are essential considerations in lateral migration. As a result, the areas that may be most important for maintaining lateral connectivity, are the left and right banks of the Mekong River between Kampong Cham and Phnom Penh. It is in this reach that the bulk of flows exit the Mekong mainstream (some 15%) and enter either zone 2 or zone 5, taking with it passive drift and adult fish[1] actively seeking feeding and spawning opportunities on the floodplain.

Most of this water does not return to the mainstream for a very long time due to the long distances to the floodplain exits and the slower travel times of water on the floodplain, relative to that in the river. This time lag is probably an essential feature that allows sufficient time for phytoplankton and zooplankton to grow, and for fish larvae to develop to the stage where they can survive lower food availability and higher predation in the mainstream. Most of the flows entering zone 5 exit back to the mainstream south of Prey Veng, whilst the remainder continues as part of the floodplain flow into Viet Nam.

Indeed this long detention time in shallow, vegetated floodplain habitats, is one of the greatest benefits of the Great Lake, and since about 1/5th of the Mekong's flow just upstream of Chaktamuk can enter the lake, it is likely to take with it an equal volume of passive organic drift. Worryingly, as discussed previously, the TLSV studies indicate that the amount of floodplain reverse flow volumes from the floodplain areas of zone 2 to the Great Lake, have already decreased to just one third their natural levels. This is likely to have serious implications for the survival of fish larvae apart from anything else.

Water quality impacts include those that can develop over time in impounded waters of mesotrophic and eutrophic nutrient status. When impounded by embankments, muddy flood waters can clarify through settlement of the suspended sediment. The improved light penetration and low turbulence can lead to the development of excessive algae or macrophyte growth. However, such problems have not been recorded in the LMB, except in wetland areas receiving town sewage effluent.

Having considered the likely impacts on flows, flooding and ecosystems, the question arises, what are drivers that lead to the construction of new embankments, or cause existing embankments to be increased in height? These issues are addressed in the next section along with an outline of the potential socio-economic impacts.

7.4.4 Socio-economic drivers and impacts

Urban areas, by virtue of the prevailing population densities and value of infrastructure, are the most sensitive to increases in flood depths and durations. Urban and industrial areas are of limited occurrence in the Cambodian floodplain outside of Phnom Penh and a handful of towns, but to these areas must be added the large number of kampongs scattered across the floodplain (Figure 7.22).

[1] Active downstream fish spawning migrations begin from deep holes in the Mekong in the vicinity of Kratie and often end in lateral migrations onto the floodplain, anywhere from Kratie downstream and including the Great Lake

Planners and inhabitants of large urban centres such as Phnom Penh take it as axiomatic that the flood risk must be reduced or eliminated. For the most part, Phnom Penh is protected from flooding. With the slow but gradual improvement in standards of living in rural areas comes a higher exposure of assets to the prevailing flood hazard, effectively increasing the flood risk. What was acceptable before is becoming less so and rural expectations are increasingly approximating those of city dwellers.

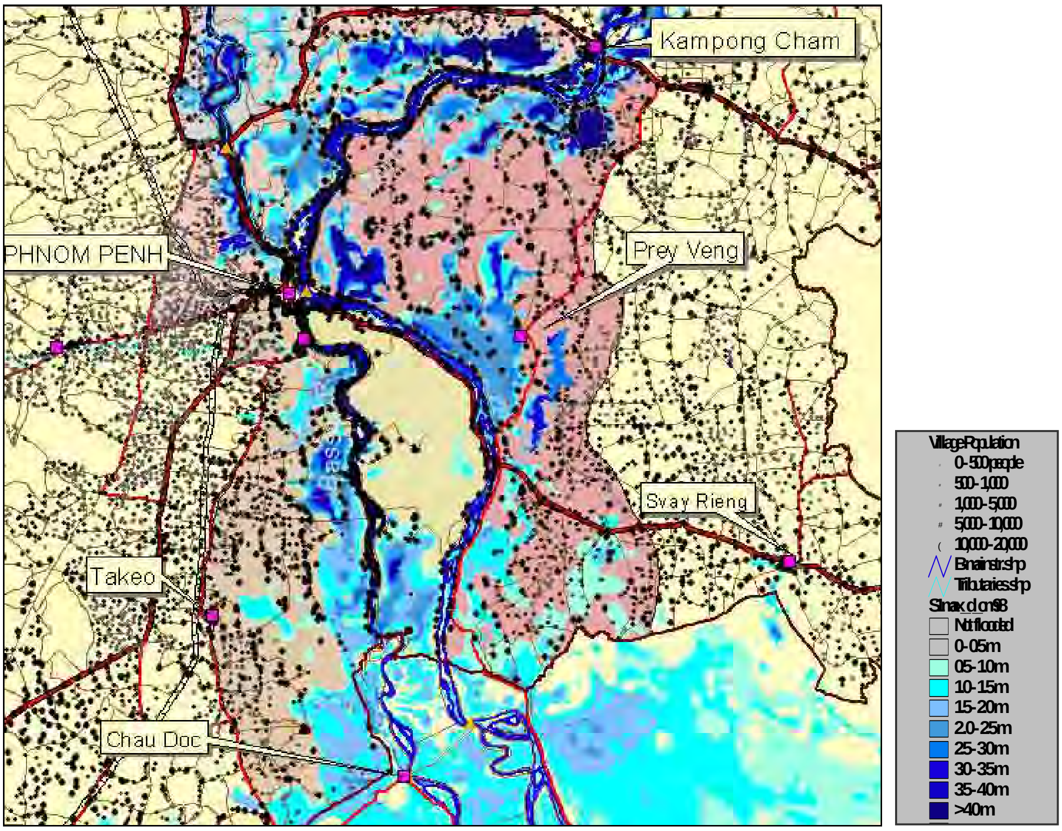
Rural people also need to be able to transport their agricultural, fish and other products to city and town markets, and to obtain supplies there. So whilst short duration flooding may be acceptable, longer floods begin to create hardship, as no income is generated, food supplies run short and children can not get to school.

Against this, is the current high level of poverty and dependence on natural resources directly supported by the river and its flood regime. Most significant of these functions is the widespread availability of fish and other aquatic animals that can be caught locally, or purchased at very low prices. Indeed, the prices are the lowest of any available source of protein and calcium, such that the health of many people hinges on the availability of cheap fish and aquatic products. The maintenance of capture fisheries require a certain amount of flooding, hence reductions in flood depths, extent and durations are of concern. So, on the one hand reduced flooding is desirable, but on the other, human socio-economic well being very much depends on it.

Not withstanding these recognised links to a sound ecology and sustainable fishery, the threats from embankments are for the most part cumulative in nature. Embankment proposals derive from a multiplicity of project origins, agencies and district or provincial bodies, and there is no overarching view of the likely consequences of the sum total of embankments over time.

From the above, and in the absence of explicit planning that recognises and deals with the trade-offs associated with minimising flood risk, whilst maintaining the existing benefits of flooding, it might be presumed that population density and growth will be amongst the prime drivers of new and higher embankments. These factors are likely to result in new and upgraded roads to service them, as well as new agricultural projects to provide food and employment. Certainly, the higher the population, the higher the road density, as can be seen in Figure 7.22.

Figure 7.22: Village population (BDP Scenario 1: Baseline conditions)



So, of the various embankment types, it is roads and agricultural irrigation works that would seem to pose the greatest threat. Already, roads have had the effect of reducing the total Tonle Sap reverse flow volume by some 11% and the zone 2 floodplain contribution to that flow, by about 70%. And almost the entire length of the levees along the main rivers are capped by roads, many of them main or secondary roads with substantial embankments across low sections that may be reducing lateral fish migrations and floodplain flooding.

8 Issues and priorities

8.1 Opportunities

The various practical DSF applications have demonstrated the need and the value of a set of powerful tools to be applied for a broad range of baseline analyses and impact predictions. An obvious opportunity exists for mainstreaming this tool for its intended use for decision-support within MRC's various programmes and activities to promote water-related development initiatives.

Impact analysis is an integral part of any large-scale project cycle. Project development and promotion can be highly supported by a detailed and comprehensive baseline reference, by transparent and well documented tools, and by a relevant approach that is consistent from one application to another.

8.2 Constraints

In any river basin there is a need of continued expansion of the basic data. In this connection, the MRC monitoring of flow and water levels provides a critical contribution. A need of improved flood information (for example about inundation areas and depths) is being produced under the MRC Flood Management and Mitigation Programme, and should, in time, be applied for an upgrading of the DSF. Similarly, new data are produced under the MRC water quality monitoring programme.

Regarding basic cause-effect relationships, improved knowledge would be highly valuable about various aspects of basin-wide importance, such as (for example)

- salinity intruision in the Delta;
- consumptive and 'semi-consumptive'[1] water use for irrigation;
- sediment balances and morphological dynamics of the entire river system, and of the Tonle Sap in particular; and
- a broad range of relations between hydrology, habitat quality, fish productivity, biodiversity, and social and socio-economic implications.

There is a scope for continuously improving the validity of the baseline reference.

Many studies are in progress that will contribute to the general understanding of such complex, yet important relationships. In parallel, an effort must be made to synthesize and assemble the various achievements, in order to span the discrete disciplines and facilitate the integrated analyses that can further extend the basis for decision-making.

1 here, 'semi-consumptive' refers to volumes of water that are retained for subsequent release

9 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).

10 Findings and recommendations/ lessons learnt

The analyses have demonstrated

- the value of detailed and comprehensive information about flow rates, water levels and water balances in connection with multi-sector decision-making;
- the open-ended need of knowledge about basic cause-effect relationships; and
- the value of a holistic perspective of the diverse advantages and trade-offs in connection with physical interventions.

It is recommended to

- expand and consolidate the DSF knowledge-base and tools inter-actively with practical applications;
- streamline the linkages between the DSF and the other components of the MRC information system;
- further promote and support the national use of the DSF, for the sake of broadening the knowledge-base and enhancing its value.

In an institutional perspective, the use of the DSF should be consolidated, with continued efforts to make the tools practical and accessible, improved documentation, and continued training.

11 Relevance

11.1 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.

11.2 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, with their comprehensive and consistent description of present and future flows and water balances, are highly relevant in connection with State of the Basin reporting.

12 Concluding general outlook

The analyses presented in this report should be maintained and further developed to reflect new knowledge and new development needs.

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.

A potentially highly valuable DSF application would be a study of the general water availability in The Lower Mekong Basin, with subsequent dissemination of results to all water resources management bodies and all users of surface water.

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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