Best Practice Guidelines for Integrated Flood Risk Management in Basin Development Planning

The Flood Management and Mitigation Programme,
Component 2: Structural Measures & Flood Proofing in the Lower Mekong Basin

May 2010
Final Report, Volume 3D

Deltares
Enabling Delta Life — Delft Hydraulics

ROYAL HASKONING

UNESCO

Mekong River Commission

Flood Management and Mitigation Programme

Structural Measures and Flood Proofing in the Lower Mekong Basin

Best Practice Guidelines for Integrated Flood Risk Management in Basin Development Planning

Volume 3D

May 2010

Published in Phnom Penh, Cambodia in September 2013 by the Mekong River Commission, Office of the Secretariat in Phnom Penh

Citation:

Royal Haskoning, Deltares, UNESCO-IHE, The Flood Management and Mitigation Programme, 'Component 2: Structural Measures and Flood Proofing in the Lower Mekong Basin', May 2010, Final Report, Volume 3D "Best Practice Guidelines for Integrated Flood Risk Management in Basin Development Planning". 70 pp.

Editors: Ms. Tiffany Hacker, Dr. David Lampert, Mr. David Smith

Editors have applied, to the extent possible, the MRC standard for names of rivers, villages, districts and provinces. However some names in maps, figures and tables could not be timely adjusted as a result of the picture-format used by the authors.

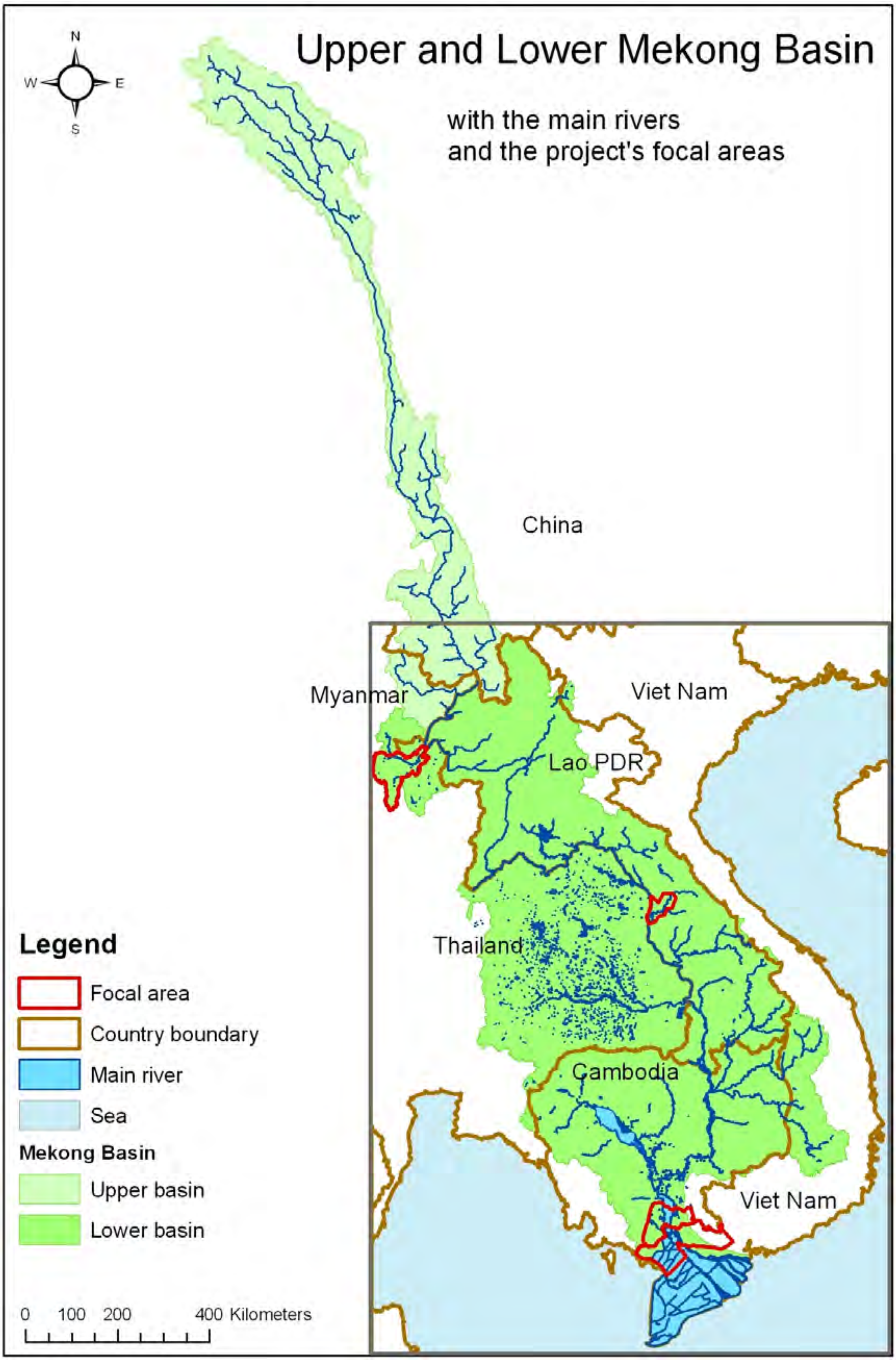
Office of the Secretariat in Phnom Penh (OSP)
576, National Road #2, Chak Angre Krom,
P.O. Box 623, Phnom Penh, Cambodia
Tel. (855-23) 425 353. Fax (855-23) 425 363
Office of the Secretariat in Vientiane (OSV)
Office of the Chief Executive Officer
184 Fa Ngoum Road,
P.O. Box 6101, Vientiane, Lao PDR
Tel (856-21) 263 263. Fax (856-21) 263 264
Website: www.mrcmekong.org
Email: mrcs@mrcmekong.org

TABLE OF CONTENTS

APPENDIX

LIST OF FIGURES

LIST OF TABLES


Upper and Lower Mekong Basin
with the main rivers
and the project's focal areas
N
W
E
S
China
Myanmar
Viet Nam
Lao PDR
Thailand
Cambodia
Viet Nam
Legend
Focal area
Country boundary
Main river
Sea
Mekong Basin
Upper basin
Lower basin
0 100 200 400 Kilometers

ABBREVIATIONS AND ACRONYMS

BDP	Basin Development Plan/Planning/Programme
BPG	Best Practice Guidelines
EC	European Commission
DDMFSC	Department of Dyke Management and Flood and Storm Control (MARD)
EU	European Union
FMM	Flood Management and Mitigation
FMMP-C2	Flood Management and Mitigation Programme, Component 2 (MRC)
GEV	Generalised Extreme Value distribution (hydrology)
GIS	Geographic Information System
HH	Household(s)
IFRM	Integrated Flood Risk Management
IKMP	Information and Knowledge Management Programme (MRC)
IWRM	Integrated Water Resources Management
LMB	Lower Mekong (River) Basin
LMD	Lower Mekong (River) Delta
MARD	Ministry of Agriculture and Rural Development (Viet Nam)
MRC(S)	Mekong River Commission (Secretariat)
PDR (Lao)	(Lao) People's Democratic Republic
NMC	National Mekong Committee
PoR	Plain of Reeds (Viet Nam)
RFMMC	Regional Flood Management and Mitigation Centre
UK	United Kingdom
TNMC	Thai National Mekong Committee
UNESCO-IHE	Institute for Water Education (IHE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO)
USA	United States of America
WUP	Water Utilisation Programme

GLOSSARY

Best Practice Guideline (BPG)	An information resource/tool to be adapted according to each country and project context. In the context of FMMP-C2 BPG's can for instance be a reference to summarize an annexed set of tools or data collection method; a process that is to be followed step by step; a checklist to evaluate and improve national guidelines such as construction guidelines/building codes.
Colmatage	The natural deposition of particles suspended in water on land areas, usually on river floodplains and deltas, coastal lowlands, and flooded meadows.
Damage curve	The functional relationship between inundation characteristics (depth, duration, flow velocity) and damage for a certain category of risk.
Direct damage	All harm which relates to the immediate physical contact of flood water to people, property and the environment. This includes, for example, damage to buildings, productive assets, loss of crops and livestock, loss of human life, immediate and immediately foreseeable and calculable health impacts to the population in the flooded area and ecological harm.
Exposure	A measure of the people, assets and activities threatened by a flood hazard.
Flood control	A structural intervention to reduce a flood hazard.
Flood damage	Damage to people, property and the environment caused by a flood. It includes direct as well as indirect damage.
Flood damage risk (= Flood risk)	The combination or mathematical product of the probability of the flood hazard and the possible damage that it may cause. This risk can also be expressed as the *average annual possible damage* or *expected damage*. If it is expressed in a financial measure, it is the expected net present value using economic valuations with different measurement assumptions.
Flood hazard	A flood that may *potentially* result in damage. A hazard does not necessarily lead to damage.
Flood hazard map	Map of the predicted or documented extent/depth/velocity of flooding with an indication of the flood probability.
Flood proofing	A process for preventing or reducing flood damages to infrastructure, buildings and/or the contents of buildings located in flood hazard areas.
Flood risk management	Comprehensive activity involving risk analysis, and both identification and implementation of risk mitigation measures.
Flood risk management	Actions that are taken to reduce the probability of flooding or the

measures	possible damages due to flooding or both.
Flood risk map	Map of the predicted extent of different levels/classes of *average annual possible damage* due to flooding.
Hydrological hazard	A hydrological event (discharge) that may result in flooding.
Indirect damage	All non-direct damage which relates to the disruption of economic activity and services due to flooding including impacts on the non-flooded areas.
Integrated flood risk management	The approach to flood risk management that focuses on the full chain of a meteorological hazard leading to flood damages and considers combinations of structural and non-structural solutions to reduce that damage.
Meteorological hazard	A meteorological event (storm) that may result in a hydrological hazard and, eventually, in flooding.
Return period	Recurrence time, average time interval between subsequent events in which conditions are exceeded. When designing a structure, the return period is usually larger than the projected lifetime, because, for instance, if both would equal 50 years, the structure would have a 64% probability of failure during its lifetime. In statistical analysis an event with a return period of N years is likely, on average, to be exceeded only once every N years.
Resilience	The ability of a physical system and of a human social system (at the level of community or society) to cope with the damaging effect of floods.
Susceptibility	The opposite of resilience: the inability of a human social system (at the level of community or society) to cope with the damaging effect of floods.
Vulnerability	The potential damage that flooding may cause to people, property and the environment.

REFERENCE SYMBOLS FOUND IN THE TEXT

The Flood Management and Mitigation Programme Component 2 (FMMP-C2) guidelines contain symbols in the left margins for quick reference. The symbols are of two types. They indicate:

A. Type of text/content;
B. A project stage.

The goal of the symbols is to help readers to scan the text to look for theory, examples, or applications or to try to find information needed for work at specific project stages.

A) Text/Content Symbols: The report texts are categorised into four groups as follows:

i) Project background/Report information
FMMP-project information and background,
or explanation of the report structure or content.

ii) Theory
The theory behind the proposed/applied methods and guidelines.

iii) Example
Examples of the proposed/applied methods and guidelines.

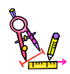
iv) Applications and Guidelines
Methodology and theory adapted/applied to the Lower Mekong Basin (LMB), including guidelines. The guidelines are applied in one of the five project stages described below (B).

B) Project Stage Symbols: A project usually consists of five phases (see Section 1.5). FMMP-C2 covers only the second phase: Planning/Development/Design. This phase can be subdivided into five stages:

i) Preliminary/pre-feasibility study stage 

ii) Feasibility study and overall planning stage 

iii) Preliminary design stage 

iv) Detailed design and detailed planning stage 

v) Construction/bid documents stage 

Any part of a guideline falling outside the scope of the five phases is marked with a white cross: 

Sometimes more than one symbol may apply to a section.

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Guide to the reporting structure of the Flood Management and Mitigation Programme - Component 2, Structural Measures and Flood Proofing

Component 2 on Structural Measures and Flood Proofing of the Mekong River Commission's Flood Management and Mitigation Programme was implemented from September 2007 till January 2010 under a consultancy services contract between MRCS and Royal Haskoning in association with Deltares and Unesco-IHE. The Implementation was in three stages: an Inception Phase and two Implementation Stages. During each stage a series of outputs was delivered and discussed with the MRC, the National Mekong Committees and line agencies of the four MRC member countries. A part of Component 2 - on 'Roads and Floods' - was implemented by the Delft Cluster under a separate contract with MRC. Component 2 prepared five Demonstration Projects which have been reported separate from the main products.

The consultancy services contract for Component 2 specifies in general terms that, in addition to a Final Report, four main products are to be delivered. Hence, the reports produced at the end of Component 2 are structured as follows:

Volume 1	**Final Report**
Volume 2	**Characteristics of Flooding in the Lower Mekong Basin**
Volume 2A	*Hydrological and Flood Hazards in the Lower Mekong Basin;*
Volume 2B	*Hydrological and Flood Hazards in Focal Areas;*
Volume 2C	*Flood Damages, Benefits and Flood Risk in Focal Areas;*
Volume 2D	*Strategic Directions for Integrated Flood Risk Management in Focal Areas.*
Volume 3	**Best Practice Guidelines for Integrated Flood Risk Management**
Volume 3A	*Best Practice Guidelines for Flood Risk Assessment;*
Volume 3B	*Best Practice Guidelines for Integrated Flood Risk Management Planning and Impact Evaluation;*
Volume 3C	*Best Practice Guidelines for Structural Measures and Flood Proofing;*
Volume 3D	*Best Practice Guidelines for Integrated Flood Risk Management in Basin Development Planning;*
Volume 3E	*Best Practice Guidelines for the Integrated Planning and Design of Economically Sound and Environmentally Friendly Roads in the Floodplains of Cambodia and Viet Nam*[1]*.*
Volume 4	**Project development and Implementation Plan**
Volume 5	**Capacity Building and Training Plan**

Demonstration Projects

Volume 6A	*Flood Risk Assessment in the Nam Mae Kok Basin, Thailand;*
Volume 6B	*Integrated Flood Risk Management Plan for the Lower Xe Bang Fai Basin, Lao PDR;*
Volume 6C	*Integrated Flood Risk Management Plan for the West Bassac Area, Cambodia;*
Volume 6D	*Flood Protection Criteria for the Mekong Delta, Viet Nam;*
Volume 6E	*Flood Risk Management in the Border Zone between Cambodia and Viet Nam.*

The underlying report is **Volume 3D** of the above series.

[1] Developed by the Delft Cluster

The FMMP Component 2, Structural Measures and Flood Proofing, was developed in three steps: the Inception Phase and Stages 1 and 2 of the Implementation Phase. The Inception Phase began at the end of September 2007 and concluded in accordance with the Terms of Reference with a Regional Workshop in Ho Chi Minh City at the end of January 2008, only 4 months after project initiation. The original TOR envisaged the Stage 1 Implementation Phase to be carried out in a period of 6 months, leaving 12 months for the Stage 2 Implementation Phase. See for reference *Final Report*, Volume 1.

1.2 Best Practice Guidelines for Integrated Flood Risk Management (IFRM) for Basin Development Planning

A framework for the development of Best Practice Guidelines for Basin Development Planning (BDP)[2] was prepared for the FMMP-C2. The general objective and specific purpose of the IFRM Guidelines for BDP are to:

1. reduce, overall, the socio-economic costs of flooding in the Lower Mekong River Basin, while preserving the environmental and other benefits of floods, through a better understanding of the management of flood risk and flood behaviour by the MRC and by national line agencies via national programs; and
2. improve, specifically, upon the Basin Development planning process by identifying and addressing flood-related impacts and benefits of investment projects at all levels in a consistent approach that is technically, socially, environmentally and financially responsible and effective.

As presented in the above mentioned framework, the MRC's vision for the role of these BDP guidelines and the IFRM in Basin Development Planning is illustrated in Figure 1-1. The MRC hopes that the IFRM guidelines for BDP will serve as a "screen" for or check on all type of water related investment plans and projects before they become part of the Integrated Water Resources Management (IWRM) based Basin Development Plan.

The MRC envisions this screening process as a means of standardising the measures of impact that different development plans and projects have, negative or positive, on flood risks in the LMB for each water-related investment sector. The IFRM guidelines offer a screening checklist that introduces flood risk related issues into the impact evaluations of these investment sector strategies, development plans and projects.

The BPG for IFRM planning and impact evaluation (Volume 3B) focuses on assessing the impacts of flood risk management measures on the environment, including socio-economic impacts on communities, ethnic groups and individuals with different characteristics. The focus of these IFRM guidelines in BDP is, by contrast, on the impact that socio-economic developments and on-going trends (e.g., population growth and consumption trends that may reflect current policies or lack of policies) may have on flood risk.

This BPG has been developed to provide methodologies for the evaluation of the impacts of sector developments in the LMB on flood risk, both inside specific areas of the developments as well as outside of those areas, with special emphasis on trans-boundary impacts.

The BPG is supplemental to existing EIA guidelines. The BPG does not provide the specific tools for flood risk assessments, that are presented elsewhere, but notes different potential causes of risk. The objectives of the BPG are to:

[2] MRC, March 2007, Volume 1, Chapter 6, Best Practise Guidelines.

1. Provide an overview of different developments from various sectors that may affect flood risks;
2. Identify the flood risk related elements that must be included in an impact assessment of investment policies, investment plans and investment projects in various sectors; and
3. Provide methodologies and samples of flood risk assessments on investment policies, investment plans and investment projects.

1.3 How to use the Best Practice Guidelines

These guidelines are intended for use in connection with existing MRC and country guidelines in the LMB for environmental impact assessments in other publicly defined sectors beyond flood control. Transport infrastructure, forestry, urban and industrial sectors can all have impacts on flooding.

As such the guidelines are intended to be used by the MRC, the National Mekong Committees (NMC's) and line agencies in the MRC Member Countries that are involved in policy, planning and project preparation in these sectors. In applying the Best Practice Guidelines, the MRC, the NMC's and the line agencies should be better able to take flood-related considerations into account in their day-to-day technical activities.

1.4 Background on the development of the Best Practice Guidelines

These guidelines are developed in connection with the BPG Guidelines for Flood risk assessment and the BPG for IFRM planning and impact evaluation.

Some of the concepts and tools presented in this BPG are drawn from the "Roads and Floods" guidelines (Delft Cluster)[3] and the conclusions of the Regional Consultative Committee (RCC) program on Mainstreaming Disaster Risk Reduction into Development Policy, Planning and Implementation in Asia (MDRD)[4].

Practices as presented have been tested and further elaborated in the Stage 2 Implementation Phase of the FMMP-C2 demonstration projects.

1.5 The Best Practice Guidelines and project phases/stages

In order to facilitate management of an engineering project, managers normally divide projects into phases such as the following five phases:

1. Initiation
2. Planning/Development/Design
3. Production/Implementation
4. Monitoring/Control
5. Closure

The Best Practice Guidelines are almost exclusively applicable to Phase 2: Planning/ Development/Design. This phase, its stages and the associated symbols used in the guidelines are elaborated in Appendix 1 and are presented briefly above in the report introduction.

[3] Recommendations for the Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong Floodplains of Cambodia and Vietnam, Delft Cluster 2008.
[4] RCC MDRD Program, RCC Guideline 3.1, ADPC 2008

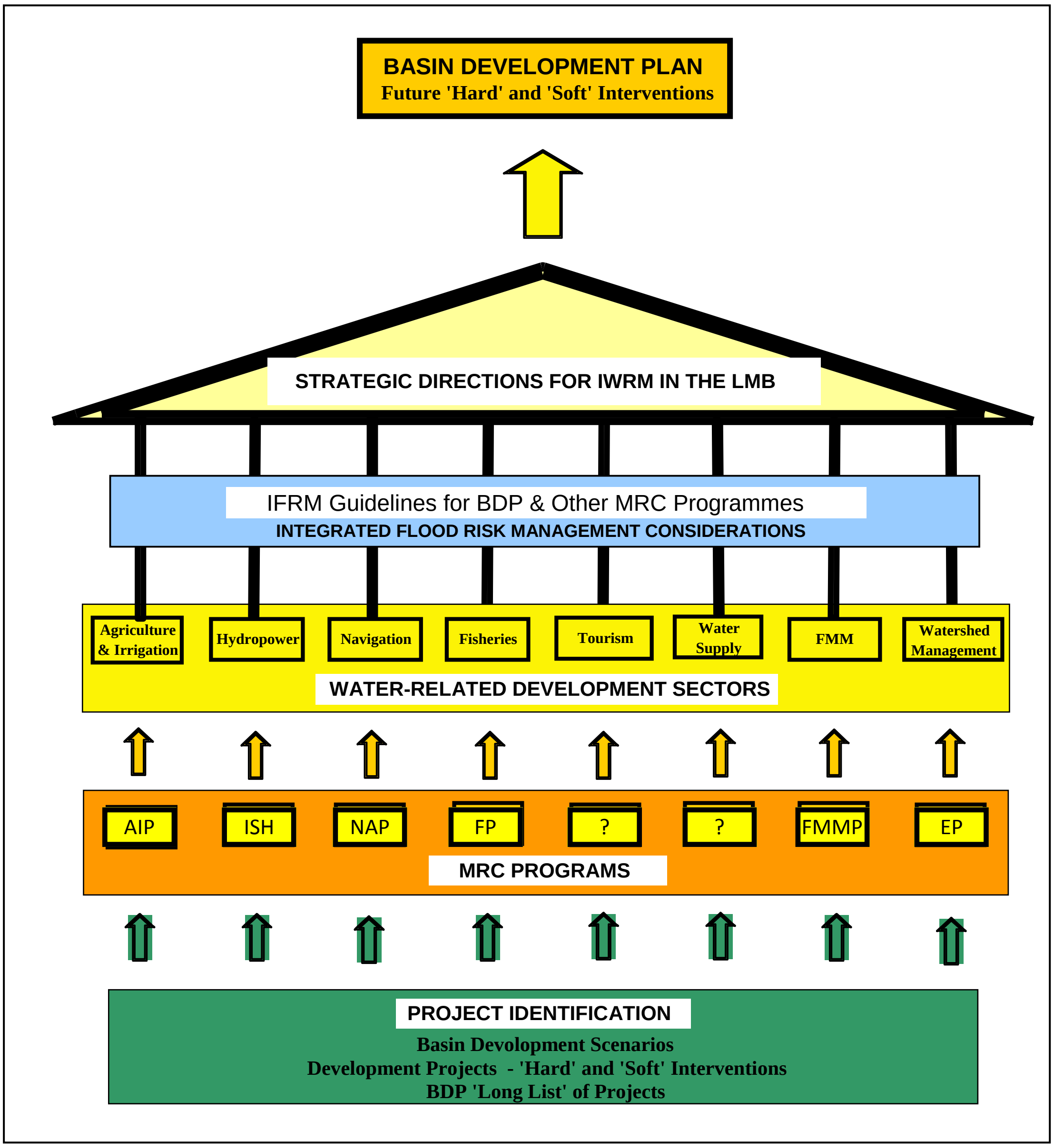


Figure 1-1 The envisioned role of the basin development guidelines in the steps towards improvement of a basin development plan.

CHAPTER 2

THE BASIN DEVELOPMENT PLAN AND FLOOD RISK

2 THE BASIN DEVELOPMENT PLAN AND FLOOD RISK

2.1 The Basin Development Plan

The Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin of 1995 empowers the Mekong River Commission Joint Committee with the authority and obligation to formulate a Basin Development Plan (BDP) "to promote, support, cooperate and coordinate in the development of the full potential of sustainable benefits to all riparian States and the prevention of wasteful use of the Mekong River Basin waters, with emphasis and preference on joint and/or basin-wide development projects and basin programmes".

In applying the principles of Integrated Water Resources Management (IWRM), the BDP process helps to coordinate developments affecting the management of water and related resources without compromising the sustainability of vital ecosystems (Global Water Partnership, 2000). To achieve this requires quality research and clear presentations on how to achieve an acceptable balance between economic exploitation of the basin and maintenance of its ability to sustain livelihoods, diverse cultures and environments.

The IWRM-based BDP comprises three elements:

- **Development Scenarios**, which assess the potential and constraints for the further development of some of the water resources in the various parts of the Mekong Basin. The results will guide the formulation of the IWRM-based Basin Strategy and the project portfolio;
- An **IWRM-based Basin Strategy**, which provides a long-term view of how the Mekong Basin may be developed in a sustainable manner for poverty reduction. The strategy will also guide the implementation of the IWRM at basin, national and sub-basin levels, and assist line agencies with preparation of plans and projects that are sensitive to resource protection issues;
- A **Project Portfolio** of structural (investment) projects and supporting non-structural projects, as envisioned in the 1995 Agreement, to develop some of the Mekong Basin's water and related resources and minimise harmful effects that might result from natural occurrences and man-made activities.

<u>Development Scenarios</u>: Scenarios are used to compare various "what if" situations using a combination of facts and conjecture on possible changes, situations or series of events. Investment scenarios for BDP purposes are based on assumptions of:

- Future hydrological conditions;
- Future water demands; and
- Interventions that have already been approved.

Analyses project how water availability and demand will change and suggest the resulting positive and negative economic, environmental and social impacts.

The MRC Joint Committee has approved nine test scenarios for different levels of investment activities and has organised them into four categories based on their time horizons. They are presented in Table 2.1, below with descriptions following the table. The four categories are: the baseline situation, the 'definite future' situation, the 'foreseeable future' situation and the 'longer-term future'. The scenarios are generated for the entire basin and represent various levels of resource exploitation in the various sub-basins during either the next two decades (for the 'foreseeable future' scenarios) and the next five decades (for the 'longer-term future' scenarios). These scenarios are based on national plans for water and related resource exploitation of the Mekong River countries, and assumptions regarding population and economic growth, other investments and trade, 'poverty reduction' plans, and other national policies and socio-economic plans.

Table 2-1 Mekong BDP development scenarios.

Baseline situation	**'Definite future' situation**	**'Foreseeable future' situation**	**'Long-term future'**
1. Baseline scenario	2. Upper Mekong River dams scenario 3. Definite future scenario	4. LMB 20-year plan scenario 5. LMB 20-year plan scenario, without mainstream dams 6. LMB 20-year plan scenario, without mainstream dams in the middle and lower basin 7. Mekong Delta flood management scenario	8. LMB long-term development scenario 9. LMB very high development scenario

The Baseline situation, Scenario 1, is based on the conditions (physical, socio-economic and management characteristics) that existed in the year 2000 and the hydro-meteorological conditions of the period from 1985 to the year 2000.

The 'Definite future' situation includes water resources developments in the Mekong River system that are currently being implemented or in an advanced stage of preparation.

- Scenario 2 projects the conditions of the hydropower infrastructure cascade; a series of reservoirs that is presently being constructed in the Lancang River in the Upper Mekong River Basin.
- Scenario 3 includes these dams plus all other water resources developments that are being constructed or soon to be built in the LMB.

The 'Foreseeable future' situation is based on foreseeable developments over the next 20 years. Four scenarios are considered possible within this 20-year period.

- Scenario 4, the LMB 20-year plan scenario, starts with the 'definite future' scenario 3 and adds the current development plans of the LMB countries for the next 20 years, including the 11 dams under consideration on the Mekong River mainstream and major planned increases in irrigation in Lao PDR and Cambodia, along with planned floodwater diversions from the Mekong River mainstream to north-eastern Thailand and other plans for flood management and mitigation.
- Scenario 5, the LMB 20-year plan scenario, without including mainstream dams is based on the current water resources development plans for the LMB countries, but does not include the 11 planned dams in the Mekong River mainstream.
- Scenario 6 is similar to Scenario 5, but includes some of the planned dams in the Mekong River mainstream; those downstream of Vientiane/Nong Khai.
- Scenario 7, the Mekong Delta flood management scenario is similar to Scenario 4, but includes additional flood risk reduction and drainage measurements in the Mekong Delta.

The 'Longer-term future' situation projects plausible developments that over the next 50 years.

- Scenario 8, the LMB long-term development scenario, projects present trends in hydropower development, irrigation, and changes in other water demands as well as population growth and economic activities over 50 years.
- Scenario 9, the LMB very high development scenario, is based on the 20-year plan scenario but adds assumptions for the full exploitation of the water supply, irrigated agriculture, hydropower and flood management sectors in the LMB countries.

The positive and negative impacts and the likely benefits and costs of each formulated scenario are assessed in the BDP. There is also an analysis on the possible contribution of different scenarios for achieving the United Nations Millennium Development Goals.

IRWM-based Basin Strategy: The IWRM-based Basin Strategy consists of a few strategic basin development options for meeting the water needs of all sectors. Table 2-2 lists the development sectors that are taken into account in the strategy, as well as the main development objectives that are specified for each sector.

Table 2-2 Development sectors and their main development objectives in the LMB.

Sector	**Main objectives**
Agriculture and irrigation	To promote safe food production, high income and high employment through agricultural water use.
Hydropower	To balance the increasing demand for affordable electric energy in the MRC member countries with minimal negative impacts on the environment and residents, with the goal of promoting productivity growth for the countries' mutual benefit.
Navigation	To increase international trade opportunities for the MRC member countries' mutual benefit, and to assist in co-ordination and co-operation in developing effective and safe waterborne transport in a sustainable and protective manner for the waterway environment.
Fisheries	To coordinate sustainable developments, use, management and conservation of fisheries.
Tourism	To expand regional water-related tourism with due regard to social and environmental impacts.
Domestic and industrial water supply	To assure that water is available for public and industrial use in sufficient quality and quality.
Flood management and mitigation	To prevent, reduce, or mitigate suffering and economic losses from floods while preserving the environmental benefits of floods.
Watershed management	To promote effective public management of watersheds in accordance with relevant ecological, economic and social watershed functions.

Chapter 3 presents detailed information on how these balances are to be achieved in the first six of these eight sectors (not including the seventh which is treated in Volume 3B). Watershed management covers many themes and needs to be examined at a higher level. It is therefore treated separately in Section 3.8.

Project Portfolio of Development Projects: The Basin Development Plan presents a combination of three categories of projects -- structural (investment) measures/projects, non-structural projects, and enabling projects -- to develop the Mekong River Basin's water and related resources while minimising harmful effects that might result from natural occurrences and human activities.

There are hundreds of water resources development projects within the LMB countries. Individual governments with or through endorsements of the private sector are planning hundreds more. Over 300 of these projects are included in de BDP 'long-list'. The three categories of projects as noted above are:

- Infrastructural projects: engineering projects such as river diversions, dams and hydropower projects, water supply and irrigation schemes;
- Non-structural projects: investments in facilities that contribute directly to improved water management like flood warning systems, monitoring systems; and
- Enabling projects: improvements to resource management practices and behavioural changes, like research programmes, institutional development, and capacity building.

Another grouping of the projects in the BDP classified them by the level at which they are undertaken. These categories include:

- National projects without trans-boundary implications developed and implemented by one country. They can be either infrastructural, non-structural or enabling projects;
- National projects with 'acceptable' trans-boundary implications developed and implemented by one country. This category mainly comprises infrastructure projects, that incorporate cross border co-operation under the Mekong River agreement and projects that have (significant) harmful trans-boundary impacts but that are still acceptable to the riparian countries;
- Joint-country projects developed by the four LMB countries and that create basin-wide benefits. Most joint-country projects are non-structural or enabling projects;
- Trans-boundary investment projects, developed between two or three MRC Member Countries. This category includes non-structural and enabling projects; and
- 'Controversial' projects, which are mostly structural projects.

Of the projects on the long-list considered by the BDP as of the time of this report, 69 were provisionally labelled as 'joint projects'. They were grouped under seven provisional joint development areas that are of relevance to all Member Countries:

1. Mekong River Bank Protection Management;
2. Capacity Building in Integrated River Basin Planning and Management;
3. Cooperation for Sustainable Tourism Development and Promotion;
4. Improved Water Use Efficiency in Irrigated Agriculture Development;
5. Integrated Watershed Management Programme;
6. Water Supply and Sanitation in Selected Areas; and
7. Flood and Drought Management and Mitigation.

Controversial projects will not be included in the project portfolio of the Basin Development Plan, but offered the MRC the opportunity to start a dialogue on these development projects in their very early stages of planning.

2.2 Flooding in the Mekong River Basin

As background to the scope and purpose of this guideline, the following sections provide a short overview of the characteristics of floods and flooding in the LMB, as well as the costs, environmental impacts and benefits related to the flooding.

2.2.1 Flood characteristics

Seasonal flooding is an annually recurring phenomenon in the Lower Mekong Basin. It a phenomenon which is of vital importance to maintain inland fishery and agricultural production in the basin, as well as a variety of flood related ecosystem services. At the same time, annual

floods inflict damages on households, agriculture and infrastructure and result in loss of life and property. With growing population and consumption, the need for protection of people and their socio-economic activities against flooding has increased.
There are two different sets of classifications for flooding that are being considered in the LMB and that have implications for future reporting in the BDP.

The Annual Flood Report 2005 (MRC, 2006) distinguishes the following types of floods:

1. Flash floods or tributary floods;
2. Mainstream floods on the Mekong River;
3. Combined floods affected by backwater from the Mekong River mainstream;
4. Floods in the Cambodian Floodplain; and
5. Floods in the Mekong Delta.

The (draft) document "Framework for the Development of Best Practice Guidelines for BDP", Volume 2: "Background Information" provides an alternate classification as follows:

1. Mainstream floods;
2. Tributary floods;
3. Local floods;
4. Dam release floods;
5. Dam-break floods;
6. Storm surge floods; and
7. Tsunami floods.

On the two lists, only the mainstream and tributary floods are common to both lists. Local floods, the third category, are not very different from tributary floods. Both result from heavy rainfall resulting in flows exceeding the area's drainage capacity. The other types of floods are based on infrastructure (two categories related to dams) and particular types of hydrological phenomena, in order to closely link them to flood protection interventions.

- Dam release floods do not require structural measures, but need an appropriate flow release procedure, with advance warning in case of excessive discharges to avoid calamities as with Yali dam releases.
- Dam-break floods computations are standard procedures in dam design. If measures are required, the potential for dam-breaks is included in the design.
- Storm surge floods are caused by typhoons and influence water levels near the coast. The category of Mekong Delta floods already pays attention to these.
- Tsunami floods require advance warning, which is not part of structural measures as envisaged to be developed under the Flood Management and Mitigation Programme.

The FMMP-Component 2 project adopted the first of the two classifications, as presented in the Annual Flood Report 2005 (MRC, 2006). These are described in more detail, below.

Tributary floods

Tributary floods are generally flash floods. They occur in the steep sloped upper reaches of the flood basins as a result of intense rainfall after a long rainy period, forcing the catchment to respond quickly to the rainfall. Flash floods are short-lived, rise and fall rapidly and the flow velocities are very high. Tributary floods affect far fewer people and cause significantly less damage than mainstream floods in Cambodia and Viet Nam. In upper and middle reaches, tributary flooding is limited to generally narrow floodplains. However, in lower tributary reaches, tributary flooding can be extensive, especially where significant floodplains have developed around confluences with the Mekong River.

Combined floods

The simultaneous occurrence of a mainstream flood and a tributary flood increase both peak flood levels and the duration of flooding and impede the drainage along lower tributary reaches. This type of flooding is called combined flooding. Moreover, when the levels in the Mekong River are high, water may flow back into the tributaries. These floods are unlike flash floods; they may last for weeks. This type of flooding is very common in the lower reaches of a large number of tributaries along the Mekong River downstream of Vientiane.

When combined with landslides, the effect of tributary floods is equivalent to the effect of dam break waves. Landslides occur in steep upland areas and are caused by heavy extended rainfalls. Water infiltrates, weakens and moistens the soil, causing a significant area to fail and 'slip' down-slope.

Mainstream floods

Mainstream floods are caused by high water levels on the Mekong River, resulting in overflowing of the banks. In Cambodia and Viet Nam vast areas of generally slow moving floodwaters inundate the floodplains of the Cambodian Lowlands and the Cuu Long Delta for periods of up to 2-3 months or longer. Flood depths can reach 3 m or more. The 1998 Flood ('small') and the 2000 Flood ('large') covered land areas of some 25,000 km^2 and 45,000 km^2 respectively. Depending on the duration of the flooding, the damage and disruption caused by mainstream floods in the Delta can be enormous. Mainstream flooding in southern Lao PDR and Thailand, where inundation of the riverside floodplains lasts for only a couple of weeks, results in much less damage.

Floods in the Cambodian floodplain

The flooding in the Cambodian floodplain is a result of the storage of floodwater in the floodplains along the Mekong River between Kratie and Phnom Penh, including flooding around Tonle Sap Lake and the inflow to and outflow from the lake via the Tonle Sap River. Important aspects determining the extent of flooding are the bank levels of the rivers, the floodplain conveyance in relation to the road infrastructure and existence and dimensions of embankments.

Floods in the Mekong (River) Delta

Flooding in the Mekong Delta occurs when floodwaters from the Mekong and Bassac rivers and their floodplains reach the Delta. The use of colmatage canals to divert and control the flow from and to the River also influences the flooding. In the delta, water levels rise slowly due to water storage in Tonle Sap Lake and in the Cambodian Mekong floodplains. The flood levels in the Mekong Delta in its downstream are determined by the amount of upstream inflow of floodwaters and downstream water levels where the river reaches the sea.

2.2.2 Costs of flooding

The total damages caused by a flood in a certain area are the sum of the direct damages and the indirect damages, minus the total benefits that the flood may bring (see Section 2.2.4). For a discussion of the different ways of defining and categorising these damages, see Volume 3A, Section 3.2.

Direct damages (from physical contact with the flood) result primarily from:

- Loss of life and injuries: number of people killed, missing and injured by the flood and treatment costs for the injured persons;
- Damages to public and private property and infrastructure including homes, schools, offices, commercial and industrial buildings and installations, hydraulic works, power lines and energy stations, transportation networks and other infrastructure. The size of these damages is in relation to the magnitude and duration of the flood;
- Crop damages: to fields and standing crops are also proportional to the depth, timing and duration of a flood; and
- Losses to livestock and agricultural equipment, in proportion to the magnitude and duration of the flood.

Indirect damages (that are as a consequence of flooding) include:

- Costs of illness of humans and livestock related to poor environmental conditions and increased waterborne diseases;
- Income losses due to disruption of economic activities and/or services by the flood for (i) individuals, landless labourers, families and enterprises; and (ii) non-household commercial and industrial enterprises that have been partly or fully closed for some period during the flood;
- Higher costs of living due to temporary relocation, purchase of food that otherwise would have been available from the family farm, purchase of basic supplies such as safe water and electricity, and additional costs for transportation and daily activities;
- Costs of temporary relocation and rescue, during and after the flood;
- Cost of prevention measures taken by individuals, households, enterprises and institutions before and during the flood;
- Costs of cleaning and sanitation of houses and buildings after the flood; and
- Other economic losses and costs, including the negative impacts of flooding on tourism revenue, the loss of social stability, greater impacts on the poor and the rise in crime and social pathologies.

As an example, the magnitudes, the numbers of deaths and victims of harm and the total financial damages as a result of flooding in Cambodia and Viet Nam and flooding in Lao PDR and Thailand for the years 2000, 2001 and 2002 are presented in Table 2-3 and Table 2-4, below. These statistics are taken from the report 'Best Practice Guidelines for IFRM in Basin Development Planning, Volume 1: Framework for Development of Guidelines'. Overall, mainstream flooding in Cambodia and Viet Nam in the period 2000-2002 caused 1,300 deaths and resulted in some USD 600 mln in damages, with major impacts on lives and livelihoods. (Mainstream flooding also occurred in Lao PDR and Thailand over this period, but was much less severe.)

Table 2-3 Impacts of mainstream flooding in Cambodia and Viet Nam, 2000, 2001 and 2002.

	2000			**2001**			**2002**		
Flood Impact	**Cambodia**	**Viet Nam**	**Total**	**Cambodia**	**Viet Nam**	**Total**	**Cambodia**	**Viet Nam**	**Total**
Persons Killed	347	>500	850	62	256	320	29	71	100
Persons Suffering Harm (mln)	3.4	5.0	8.4	0.6	1.0	1.6	1.5	0.3	1.8
Estimated Damage (USD mln)	160	290	450	36	?	>100	12.5	8.0	22.5

Source: MRC 2003c, Country Reports, Press Releases, NGO Reports, and Web Reports.

Flood impacts in Lao PDR and Thailand for the period 2000-2002 were lower than the impacts in Cambodia and Viet Nam. Flash Floods are generally much more frequent and cause more damage than mainstream floods in these countries but they occur in areas of lower population in Lao PDR and Thailand. The Thai figures do not reflect the data for LMB flooding since only a small part of Thailand is located within the basin.

Table 2-4 Impacts of flooding in Lao PDR and Thailand, 2000, 2001 and 2002.

	2000			2001			2002		
Flood Impact	**Lao PDR**	**Thailand**	**Total**	**Lao PDR**	**Thailand**	**Total**	**Lao PDR**	**Thailand**	**Total**
Persons Killed	15	25	40	-	192[c]	-	-	128	-
Persons Affected (mln)	0.4	2.3	2.7	-	2.8	-	0.06	3.3	-
Estimated Damage (USD mln)	20	70	90	-	48	-	-	40	-

Source: MRC 2003c, Country Reports, Press Releases, NGO Reports.

2.2.3 Environmental impacts of floods

Flooding is part of the natural cycle of many ecosystems and plays an important role in maintaining ecosystem functioning and biodiversity. Society benefits from ecosystem products and services that flooding provides (See Section 2.2.4.). When human activities interfere with these natural systems and disturb their processes, flood events may result in long-term, undesirable impacts on the environment.

The optimum condition of an ecosystem is its long-term capacity to maintain biodiversity and its normal functioning. Because of the complexity of ecological systems, the assessment of an ecosystem's condition requires use of a number of indicators that can be checked over time. For a river ecosystem such indicators can be used to check eco-system health in terms of things like water quality or physical changes. Note that it is important to use indicators over a long time-frame rather than to focus on short-term changes to ecosystem diversity or functioning. In the short-term, the ecological impacts of a flood may seem quite negative or even destructive, with death or even local extinction of plants and animals. Yet, in the longer run, it sometimes turns out that this short-term damage actually works to rejuvenate and ecosystem and adds to its viability and biodiversity.

Floods have five main characteristics that determine its environmental impacts or risks. They are the same characteristics that cause other flood damages: the magnitude of the water discharge, the velocity of the floodwater flows, the duration of the flood, the timing or seasonality of the event and the flood frequency.

Ecological impacts

Flooding has an ecological impact on several different ecosystems; not only on floodplains but also on the river channel itself may be affected. Further, estuarine ecosystems and even coastal marine biota may be influenced by flooding. The mechanisms through which these ecosystems are affected may vary from one case to another but generally they are related to either changes in water quality or direct physical disturbance. The impact on these several different eco-systems can be grouped into two causes – those affecting water quality and those that are physical disturbances – and considered as a result of these causes rather than examining the ecosystems individually.

Water quality induced impacts

The quality of river water may change considerably during a flood. Turbidity levels of the river (amount of organic and inorganic matter in the water) generally rise sharply with flooding. High turbidity is primarily the result of the contribution of sediment-rich surface runoff and erosion of the river bed and banks. However, an increased growth of algae, induced by increased levels of nutrients, may also add to turbidity. High sediment levels may have a negative impact on aquatic organisms: fish gills may clog and decreased penetration of light in the water column results in decreased photosynthesis and lower water temperatures. As a consequence, oxygen levels in the water may drop. When exotic plants (often, non-native crops) that are intolerant of extended inundation are flooded, these plants will die and decay, extracting oxygen from the water.

Flooding of rural areas may result in increased levels of pesticides and herbicides and nutrients from fertilizers entering the water. This is certainly the case when storage facilities of these agro-chemicals are flooded. Animal and human wastes, either from open pit latrines or from flooded septic tanks, contaminate flood water with organic material and pathogens. High organic waste levels may also result in reduced oxygen levels affecting aquatic life. This pathogen contamination is a direct threat to human health. Flooding of open solid waste dumps is another source of pollution. Depending on the nature of the wastes, this may result in increased levels of organic matter, chemical pollutants or microbiological pollutants in the flood water. Esthetical impacts, such as floating debris, can also result from flooding of dump sites.

Flooding of urban areas entails much higher environmental risks. Sewage systems may overflow or break, resulting in contamination with organic matter and pathogens. Industrial plants may flood, possibly resulting in the spread of toxic materials. Gas/petrol stations, garages and workshops may pollute waters with hydro-carbons. Open solid waste dumps in or near urban areas are another source of organic, chemical and pathogen pollution, as well as a source of floating debris.

High levels of nitrogen and phosphorous fertilizers may reduce the growth of the native floodplain and riparian plants and may enhance the growth of invasive species. Poor water quality in general may result in fish mortality and impacts on other aquatic biota.

High concentrations of sediments, nutrients, phytoplankton and possibly pollutants, together with the consequent increased turbidity in the flood plume may affect coastal marine ecosystems. For example, sea grass communities are very sensitive to a decrease in light penetration. Since sea grass meadows are an important habitat for a variety of fauna, including fish, shellfish, turtles and dugongs, many species may be affected. On the other hand, nutrients washed into the sea and the consequent growth of algae may have a positive effect on commercially important fish stocks.

Physical disturbance induced impacts

Impacts related to physical disturbance are often related to forces of the floodwaters acting upon biota. For example, the destruction of riparian vegetation (stripping) from the force of floodwaters results in a decrease in size and inter-connectivity of habitats and thus in reduced structural complexity of the riparian zone. Loss of the indigenous vegetation has a negative impact on the stability of the river banks.

Another form of physical disturbance is the coverage of flora and sometimes fauna with a layer of sediment. This may result in mortality of floodplain plants and fauna. Mortality may also be the result of prolonged inundation.

Floodwaters can also introduce invasive organisms. Exotic species such as floating weeds can be flushed out of the river into the floodplains and harm floodplain ecosystems over large areas. Flood events may also release exotic fish species into the rivers and tributaries from aquaculture ponds.

Table 2-5 summarises various immediate risks of flooding for the environment and for human health. The final and highest order impact of induced changes (not presented in the table) is the loss of biodiversity and a reduced ecosystem functioning, including a reduction in fish stocks for human consumption.

Table 2-5 Summary of environmental risks of flooding showing the increasing severity of the impacts.

Impact cause	**1st order impacts**	**Higher order impacts of increasing severity (from left to right)**		
Water quality impacts				
Change in water quality: due to bank and channel erosion and contaminants from agricultural or urban and industrial areas	• high sediment concentrations; • elevated Nitrogen and Phosphorous levels and resulting high algae concentrations.	• high turbidity and reduced light penetration; • reduced dissolved oxygen levels.	• clogging of fish gills; • decreased photo synthesis.	• fish mortality; • decreased primary production.
	• elevated pesticide and herbicide levels; • elevated levels of organic and chemical pollutants including hydrocarbons.	• fish and other aquatic species suffer increased mortality; • reduced growth of native species; • invasion of exotic species.		
	• increased levels of pathogens.	• impacts on human health.		
	• floating debris.	• aesthetic impacts.		
Physical disturbances				
• High floodwater flow velocities	• loss of indigenous vegetation.	• loss of habitat area; • loss of habitat connectivity; • direct loss of species.	• reduced river bank stability.	
• Deposition of (coarse) sediments	• coverage of flora and fauna with sediment.	• loss of habitat area; • loss of habitat connectivity; • direct loss of species.		
• Prolonged inundation	• mortality of plants.	• reduced oxygen levels.	• mortality of fish and other aquatic organisms.	
• High water levels, water flow	• spread of exotic (invasive) plant species; • escape of exotic fish species from ponds and into rivers.			

2.2.4 Benefits of flooding

Floods in the Lower Mekong Basin can be destructive and cause enormous damage. Flash floods of tributaries and extreme mainstream flood events are responsible for the largest share of the damages. At the same time, moderate floods are clearly beneficial for residents of the rural areas of the Basin. The annual mainstream flooding in the lowlands of the lower Mekong River Basin is a natural phenomenon that supports a complex, rich, diverse and highly productive ecosystem, essential to food security and biodiversity, and for the sustenance and livelihood of most of the Basin's inhabitants.

The notion that floods bring benefits appears to be widely acknowledged, especially in the Mekong Delta in Viet Nam. Recently the Government of Viet Nam adopted a 'Living with Floods' Strategy for the Mekong Delta. The strategy is based on the idea of 'flood exploitation', suggesting that flooding is a natural resource to be researched and exploited, and that this approach to coping with floods is preferable to flood prevention (Viet Nam Department of Dyke Management and Flood and Storm Control (DDMFSC), Ministry of Agriculture and Rural Development (DDMFSC/MARD), not dated).

The benefits of annual (mainstream) flooding can be presented in a long list. These benefits are found partly in the floodplains and partly in the river channels and coastal waters of the Mekong Delta. They include:

1- Increased agricultural productivity due to:

- Deposition of sediment which improves the soil fertility. Mainstream floods deliver 79 mln ton sediment per year to the delta. Some 9 – 13 mln ton are deposited per year on the Mekong Delta floodplains (over a land area of 25 – 35.000 km^2).
- Leaching of acidity (acid sulphate soils), toxic materials (pesticide residues) and salts and flushing of crop residues.
- Cleansing of waste from agricultural land, including the control of pests/diseases. Harmful insects are wiped out by floods and rodents are forced to concentrate in small, dry areas where they are easy to catch.

The importance of flooding for agriculture is illustrated by the results of Focus Group discussions held in the West Bassac Demonstration project area, as part of FMMP-C2. In the year following a high flood, rice yields were about 1 ton/ha higher than in the years following normal floods. In some areas, farmers noted an increase in yields of 1.5 ton/ha. Production costs were estimated to be the same each year. Farmers noted an overall financial benefit due to flooding at some USD 155 to 230 per ha as a result of increased agricultural production.

In Viet Nam, Focus Groups also reported higher rice paddy yields after a year with a high flood than after a year with a normal flood. After a high flood the yield rose some 0.3 to 1.5 ton/ha (some 4 to 20%, on average, given average yields of 0.7 ton/ha). Not only were the yields are higher, but the related production costs were lower (15 to 20%), resulting in a net benefit of the flooding to agriculture of between USD 135 and 315 per ha.

2- Maintenance of freshwater ecosystems (wetlands). Wetlands are important for:

- Maintenance of aquatic and terrestrial resource productivity:
    - Fisheries: Roughly 1.5 mln ton of fish are caught each year in the Lower Mekong Basin. Another 0.5 mln ton are produced by aquaculture and reservoir fisheries. The direct economic value of these is about USD 2 bln per year (Johnston *et al.*, 2003). About 2/3 of the LMB population is involved in fish production in one way or another and it is a major part of the diet;
    - Annual flooding is very important in the life-cycle of most fish species: it triggers migration and spawning and provides migration paths and habitats to spawning and recruitment;
    - Collection of handicraft raw materials, fuels, construction materials, medicines and other raw materials by local residents.

- Conserving biodiversity: The Mekong River wetlands are very diverse and productive ecosystems, with over 1,200 recorded fish species and a diverse fauna including shrimps, crabs, molluscs, reptiles and insects (Sverdrup-Jensen 2002) as well as waterfowl and other birds and animals. Diversity of the flora is also very high.
- Water supply in the dry season: During flooding, water is stored in the floodplain in depressions and closed channels. Groundwater is also replenished. Wetlands thus act as reservoirs and sponges and 'even out' water releases over time. Moreover, flood recession agriculture is widely practiced in the LMB.
- Regulation of flows: By storing large amounts of water, that are gradually released, wetlands delay and 'even out' peak flows. This attenuates downstream flooding.
- Regulation of water quality, through wastewater purification and control of sedimentation/siltation: Wetlands absorb, filter, process and dilute nutrients, pollutants and wastes. They usually have a high nutrient retention capacity and are effective in removing bacteria and microbes.

3- Rejuvenation of vegetation on islands, sandbars and riverbanks: Stripping of riparian vegetation is sometimes considered a negative impact of flooding. However, natural disturbances maintain the structure of these complex ecosystems and the great variety of niches. The resultant rejuvenation of riparian and floodplain vegetation has a positive effect on the diversity of flora and fauna.

4- Maintenance of marine ecosystem productivity and sustenance of coastal fisheries: Sediments and nutrients discharged into the coastal waters by the flood pulse are important for the sustenance of the coastal ecology and coastal fisheries.

5- Maintenance of river morphology by scouring and cleaning sand and gravel beds and bedrock sections: High discharges are important for removal of sediments that accumulate in the riverbed during periods of average and low river flows.

6- Improved possibilities for inland water transport/navigation: This benefit of flooding is related to the maintenance of the river morphology mentioned directly above.

7- Flushing of stagnant water and pollutants: During the low flow period, water may become stagnant in low-lying parts of the floodplain. In the course of the dry season, these waters often become highly polluted. Floodwaters are important in flushing these isolated water bodies and in diluting the pollutant load.

8- Reduction of the saltwater intrusion: The length of the saltwater intrusion in the lower reaches of the Mekong River has a direct relationship with the floodwater discharge. High floodwater discharges are important in 'pushing back' the salt water tongue.

9- Delta growth: About 60 to 70 mln ton of sediment are discharged annually into the coastal waters in southern Viet Nam. This results in an expansion of the land of the delta of 150 m per year.

10- Cultural/religious values: Flooding often plays an important role in local culture and religion. An example is the 3-day celebration of the reversal of the flow of the Tonle Sap River in Phnom Penh.

11- Aesthetic values and recreational/leisure pursuits: Flood-dependent wetlands often have a high value for recreational and leisure activities. Their high biodiversity and unique landscapes are important factors.

The benefits listed above can be described as either direct benefits or values of flooding or indirect. Direct benefits include the generation of raw materials, which are used directly for consumption or sale, such as those providing energy, food (agricultural products, fish), timber, or medicines. Indirect benefits include flood-dependent services that maintain and protect natural and human systems, such as maintenance of water quality and flow, flood control, and nutrient retention.

In addition to direct and indirect benefits/values, there are two other value categories used by experts: 'option values' and 'existence values'.

- 'Option values' are defined as the speculative benefit of maintaining a pool of flood-based or flood-dependent species, genetic resources and landscapes for future possible uses. Some of these uses may not yet be known, including leisure, commercial, industrial, agricultural and pharmaceutical applications.
- 'Existence values' are defined as the intrinsic, non-commercial and non-tangible values of flood-related ecosystems. They cannot be valued in terms of current or future uses, but represent a cultural, aesthetic, heritage and future bequest significance.

The total benefits/values of flooding and flood related ecosystems in the Lower Mekong River Basin are summarized in the following table:

Table 2-6 Total benefits/values of flooding and of flood dependent ecosystems.

Commercial use benefits/values	**Non-commercial use benefits/ values**
<u>Direct values</u> Outputs that can be consumed or processed directly, such as agricultural products, fish, timber, fodder, fuel, non-timber wetland products, medicines, wild foods, etc.	<u>Existence values</u> Intrinsic value of resources and landscapes, irrespective of its use such as cultural, aesthetic, or future bequest significance.
<u>Indirect values</u> Ecological services, such as regulation of water flows and supplies, nutrient retention, flood control, salinity control.	
<u>Option values</u> Premium placed on maintaining resources and landscapes for future possible direct and indirect uses, some of which may not be known now.	

Source: Emerton *et al.*, 2004

2.3 Flood risk and its management

2.3.1 <u>Introduction</u>

In general, the word 'risk' refers to the probability or likelihood of loss or harm. In the context of flood risk management, the 'risk' of an event (the flood hazard) is the product of the probable likelihood of that event occurring (a probability) and its associated consequences (amount of damages). In other words, flood risk can be described as the impact of a particular flood event. The definition adopted by the European Commission is the following:

"'Flood risk' means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event."

In general terms, we can manage 'risk' either by reducing the likelihood of occurrence of the event or by reducing its potential harms.

(Integrated) Flood risk management is defined as an approach to identify, analyse, evaluate, control and manage flood risks in a given area or river system. Figure 2.1 presents a general scheme for flood risk management consisting of four components:

- Definition of the flood system, the hazards and the scale and scope of the analysis.
- Quantitative analysis of probabilities and adverse consequences combined into a risk measure, presented graphically or displayed on a flood risk map.
- Evaluation (assessment) of risks acceptable or unacceptable; and
- Identification of measures for risk reduction and control, including structural and non-structural measures as well as management and control options (e.g., monitoring, inspection or maintenance).

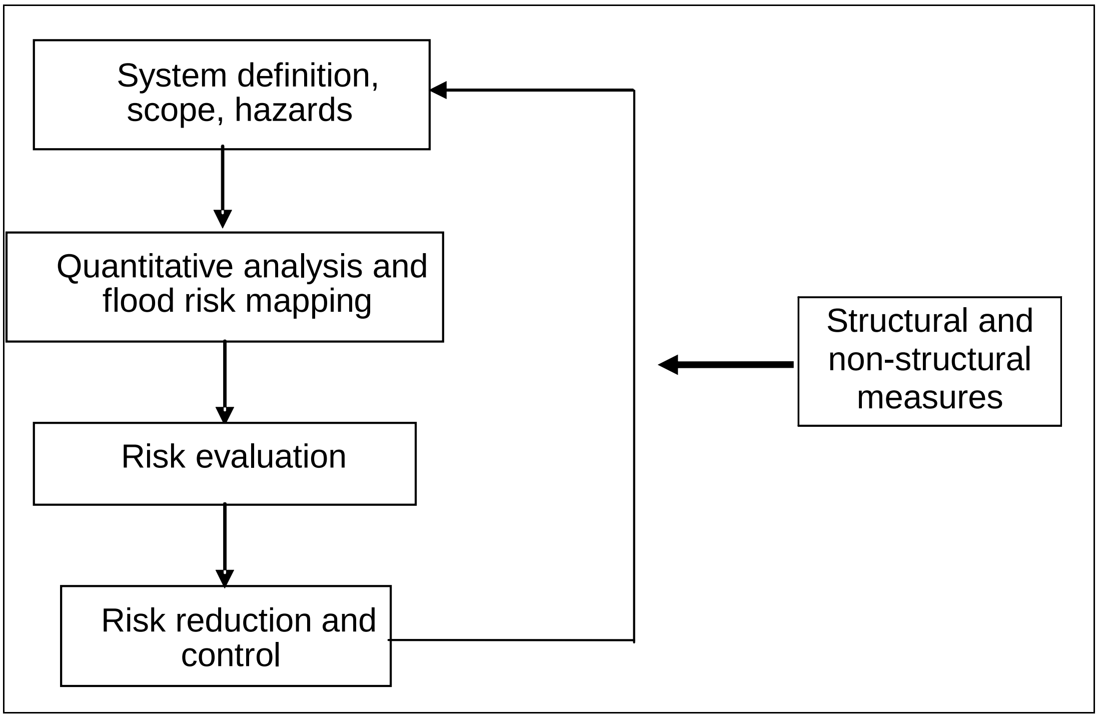


Figure 2-1 General scheme for flood risk management.

This general scheme focuses on minimization of flood risks to an acceptable level. In a broader application the approach could also be used to assess the overall hydrological performance of the system (e.g. minimization of drought, maximization of water quality and ecological quality). In such cases, the approach can focus on multiple objectives: not only to minimize the risk, but also to maximize the performance (e.g. drought minimization, water quality, or possibility of fishery) of the water system.

The concept of flood risk assessment generally refers to the second step in this general scheme; the quantitative analysis of the level of flood risk in an area or basin. This report focuses on that step. Other guidelines/reports offer insight into possible measures and approaches for the evaluation step. (See Section 1.2 in Volume 3A of this series).

2.3.2 Flood risk assessment

In this context, the terms ‘hazard’ and ‘vulnerability’ are often used. ‘Hazard’ refers to the source of danger; i.e., the (probability of) flooding. ‘Vulnerability’ describes the potential consequences (damages) of such an event.

The identification and mapping of flood risks requires several types of information collected in different steps. Figure 2-2 presents a general scheme for flood risk assessment, consisting of four components:

1. System definition and collection of basic data
   Definition of the system and area studied and the collection of relevant data for this area (e.g. data basic regarding elevation of the terrain and the hydraulic processes).

2. Flood hazard analysis
   Analysis of the occurrence of flooding. It includes an analysis of the occurrence of meteorological events (rainfall amount, duration, intensity etc.) that in combination with the characteristics of the respective watershed (runoff coefficients etc.) determine the hydrological hazard (peak discharges, volumes). Hydrological hazard combined with the characteristics of the river channel (e.g. discharge capacity) and floodplain (e.g. elevation, relief) gives the flood hazard in terms of inundation area, inundation depth etcetera. The results of this analysis can be presented in the form of flood (hazard) maps.

3. Vulnerability and damage assessment
   Potential damages in the areas prone to flooding are analyzed, based on socio-economic data and using a vulnerability/damage model. The damage of a flood event to a given community is a function of the location of the community in the floodplain, the nature of the flooding at that location (depth, duration etc.), the type of landuse and the nature of the flooded assets and infrastructure, and the socio-economic vulnerability of the affected community. The results of the damage assessment can be presented as e.g. flood damage maps.

4. Risk determination and flood risk mapping
   Flood risk is determined by combining the results of the flood hazard analysis, providing insight in the probability of a certain flood event, with the results of the damage assessment. The results of this analysis can be presented in different forms, e.g. as risk maps or in graphs or risk numbers that give insight in the average annual expected damage.

The scheme presented in Figure 2-3 shows a variation on this approach. The figure indicates how meteorological information is combined with watershed and river information to determine hydrological non-flood and flood hazards. Damages can be determined by combining data for the possibility of floods with data on the vulnerability to damage of the affected area. When the probability of exceedance for different flood events is included, the probability of a certain type of damage -- i.e., the risk – can be determined. The figure also indicates how crisis management can reduce the risk at the final stage.

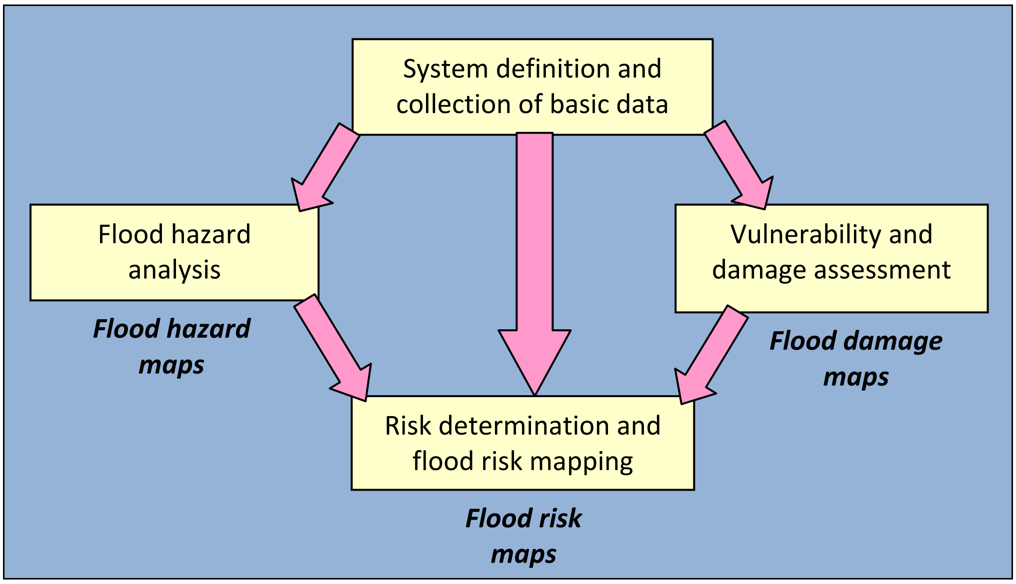


Figure 2-2 General scheme for flood risk assessment.

2.3.3 Flood risk in the Lower Mekong Basin

As part of the FMMP-C2, and presented in Volume 3A, Chapter 3, the MRC described a number of different possible damage categories and the various types of financial and other quantitative and qualitative measures that can be used to assess them.

One way to group some of these for risk assessment purposes is to place a number of types of damages into four damage categories such as the following:

1. **Loss of life and injuries**
   This category includes the number of people killed, missing after and injured by a flood along with treatment costs for injured persons and could also include other more hidden long-term effects.

2. **Infrastructure losses and relief costs**
   This combined category includes damage to everything ranging from public and private educational facilities and materials, medical facilities and materials and equipment, irrigation infrastructure, to riverbanks (in the form of erosion), fisheries infrastructure and equipment, transport infrastructure and equipment, communication infrastructure and equipment, industrial infrastructure and equipment, construction materials and equipment, and drinking water and sanitation infrastructure and equipment, along with the costs of rescue operations, support and relief.

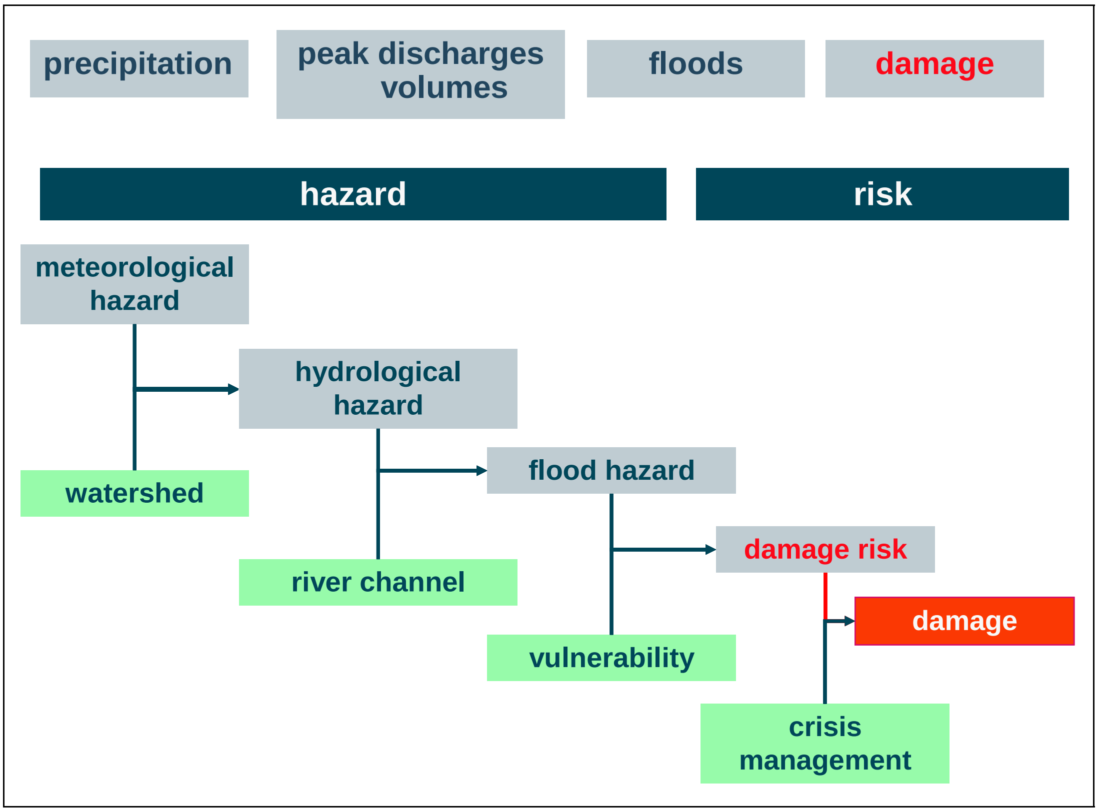


Figure 2-3 Schematic overview of flood risk assessment as applied in FMMP-C2.

3. **Housing damage**
   Housing damage includes completely damaged and destroyed homes, partly damaged or submerged houses, damaged roofs and other private property damage, losses to cultural and historical structures, offices, small industrial units, markets and commercial centres and warehouses; and

4. **Agricultural losses as an example of productive losses**
   Among economic losses to flooding are those to farming operations that are a result of flooding of rice growing fields and crops, flower and vegetable areas, other annual crops, perennial crops, large and small livestock and poultry, damaged agro-chemicals and erosion of farmland and homestead land.

For detailed descriptions of the separate procedures to be followed to assess meteorological hazards, hydrological hazards, flood hazards, flood damages and flood risks for tributary floods, mainstream floods, combined floods and floods in the Mekong River Delta, refer to the MRC Secretariat Designated Guidelines for Flood Risk Assessment in the Lower Mekong River Basin (Volume 3A).

2.3.4 Risk determining factors

The basic principle of flood risk that has been presented above is that flood risk is determined by both flood hazard and flood damage. This means that the assessment of the impact on flood risks of those investment plans, investment programmes or investment measures that are incorporated in the Basin Development Plan project portfolio (the focus of these IFRM guidelines for BDP, see Section 1.2) must also distinguish between impacts on the flood hazard and impacts on the potential damage.

An impact on a flood hazard results when either the meteorological hazard or the hydrological hazard changes as a result of an investment. The parameters that are important to measure are the distribution of the rainfall over a catchment and, over time, the total rainfall amount and the intensity. However, rainfall is not considered to be affected by those developments in the basin that are foreseen in the BDP. The only exception are the (unintentional) changes in rainfall patterns and amounts that result from large scale land cover/landuse changes and from climate changes that are a direct result of increases in human population and consumption.

Hydrological hazard is determined by peak floodwater flow and floodwater volume, taking into account their interrelationships. The timing, of the peak flows is also important in the measure of the hazard. Hydrological hazard is directly increased as a result of developments that have an influence on:

- Interception of flooding by foliage: Foliage retains some water and releases it through the process of evapotranspiration;
- Evaporation and evapotranspiration, either from ponds, lakes, and other water surfaces, from the soil surface and from the basin's vegetation;
- Surface water storage capacity, either in small surface irregularities or larger depressions and wetland areas, but also manmade ponds, embanked areas; and
- Soil infiltration (water absorption) rates/water run-off coefficients: These are influenced by the sealing of the soil which changes the rate of water infiltration, direct overland flow of floodwaters and the delays to this overland flow.

To measure the flood hazard, peak floodwater flow statistics have to be translated into water levels. Usually a hydraulic model of the relationship between floodwater flows and water levels is used for this purpose. The factors that influence how a hydrological hazard translates into a flood hazard are those of the physical characteristics of the river channel and the adjacent floodplain. Among the key measures used by hydraulic engineers are:

- The hydraulic radius, which serves as a measure of a river channel flow efficiency. Flow speed of floodwater along a channel depends on its cross-sectional shape (among other factors). The hydraulic radius is a characterisation of the channel that intends to measure its efficiency in carrying away flood water. The hydraulic radius is determined by measuring a river cross section area and dividing it by the wet perimeter of the channel.
- The (hydraulic) gradient of the river. This is the slope or rate of change in vertical elevation per unit of horizontal distance of the bed or water surface.
- The sinuosity of the river. This is a measure of the curvature of the river, described technically as the deviation of a path length along the river channel from the shortest possible path direct down river.
- The hydraulic roughness of the channel and the floodplain.
- The presence of flow obstacles, either in the river channel or the floodplain; and
- The elevation/morphology of the floodplain. This factor affects the amount of water that can be stored on the floodplain at a given water level. Embankments are particularly important. Areas protected by embankment should be considered as having an elevation equal to the level of the lowest section of the embankment.

Basin developments that result in changes one of these above given characteristics of the river channel or floodplain have an impact on the flood hazard.

The potential flood damage, or vulnerability, at a given location or in a certain area depends on the following three factors:

- The characteristics of the flooding, or the flood hazard, as described above;
- The number and type of landuse functions affected and their value; and

- The susceptibility of these land uses to flooding.

Characteristics of the flood that have a significant influence on the resulting damage are:

- The area and depth of inundation;
- The time of occurrence of the flooding;
- The speed with which the water rises;
- The stream velocities of the floodwaters; and
- The duration of the flooding.

Given certain flood characteristics, the resulting damage is determined by the kind and nature of the affected land uses, their values and their susceptibility or the inability of a system or community/society to cope with the damaging effect of a flood. In short, any basin development that results in a change in land use, land use value or susceptibility to flooding will have an impact on the overall flood risk.

CHAPTER 3

SECTOR DEVELOPMENTS AND FLOOD RISK

3 SECTOR DEVELOPMENTS AND FLOOD RISK

3.1 A first screening

The overall development objective of the Basin Development Plan is to achieve development initiatives generated and/or promoted under the BDP in the following sectors as already listed in Section 2.1:

1. Agriculture development and irrigation;
2. Hydropower;
3. Navigation;
4. Fisheries;
5. Tourism;
6. Domestic and Industrial water supply;
7. Flood management and mitigation; and
8. Watershed management.

Not all of these developments will have an impact on both flood hazard and vulnerability. Table 3-1 shows the impact of developments in each of these sectors on flood hazard, potential flood damage or on both.

Table 3-1 Overview of sector development impact on hydrological hazard, flood hazard or vulnerability.

Sector	Impact on		
	Hydrological hazard	**Flood hazard**	**Potential damage**
Agricultural development and irrigation	yes	no	yes
Hydropower	yes	yes	no
Navigation	no	yes	yes
Fisheries	no	no	yes
Tourism	no	no	yes
Domestic and industrial water supply	no	no	yes
Flood management and mitigation	yes	yes	yes
Watershed management	yes	no	no

Sector developments can first be screened on their impact on the flood risk by applying simple screening criteria that apply the risk determining factors presented in Section 2.3.4. The table distinguishes between changes to the catchments, the river channel and floodplains and offers three levels of impact to differentiate the magnitude of the change. Minor impacts are not thought to have a significant impact on flood risk. Moderate changes may have significant impacts at the level of sub-basins and major changes may have an impact on flood risk over the entire Mekong River Basin.

Table 3-2 Screening table to identify possible impacts on flood risk of basin developments.

Is there a change in:	**Magnitude of change**			
	No	**Minor**	**Moderate**	**Major**
1- Catchment Characteristics and impact on the hydrological hazard				
- Rainfall interception				
- Evapotranspiration				
- Surface water storage capacity				
- Runoff coefficients of land surfaces				
2- River channel characteristics and impact on the flood hazard				
- Hydraulic radius				
- Hydraulic gradient				
- Sinuosity				
- Roughness				
- Presence of flow obstacles				
3- Floodplain characteristics and impact on potential damages				
- Flood characteristics (derived using data from 2, above)				
- Area and depth of inundation				
-Time of occurrence of the flooding				
- Speed with which the water rises				
- Stream velocities of the flood water				
- Duration of the flooding				
- Elevation/morphology				
- Landuse type				
- Value of landuse type				
- Susceptibility of the landuse type				
- Floodplain area				
- Presence of flow obstacles				

In the following sections the impact of developments in various BDP sectors are presented in more detail. As noted in Chapter 2, the Flood Management and Mitigation (FMM) sector is not detailed in this chapter since it is the subject of the FMMP Component 2 and detailed in the other Volumes in this series (see Section 1.1).

3.2 Agriculture development

3.2.1 Introduction

This section makes a distinction between agricultural development in the catchments and agricultural development (mainly irrigation) in the floodplains. Agricultural developments in the catchments have an impact on the hydrological and flood hazard. Irrigation developments in the floodplains influence both the flood hazard and potential damages.

3.2.2 Agricultural development in the catchments

Agricultural development in (upper) catchments often involves deforestation or conversion of shrub or grassland areas to agricultural uses. This usually has two important consequences: the hydrological response of the catchment to rainfall changes and the soil erosion rate, and thus the sediment delivery to the river channel, increases. Chapter 3.8 on Watershed management presents a detailed explanation of these changes. Here, only the final hydrological hazard related aspects are discussed.

It is easy to understand how the conversion of forests to agricultural use reduces the ability of land to hold water and increases the hazards of flooding. Forest cover intercepts 15 to 25% of rainfall and releases it back directly into the atmosphere through evaporation from the leaves. The deep root structure of trees gives them a much larger leaf area index than most agricultural crops. As a result, evapotranspiration losses of agricultural lands are lower than those of forested areas and the total annual stream flow from agricultural lands is higher than that of forested areas. Not only does the amount of stream flow change after forest conversion, but the timing and distribution of the flow over the wet and dry season also change.

Forest soils have high organic matter contents and consequently a high infiltration (absorption) rate given that they are more porous. Once these soils are used for agriculture, they quickly lose organic matter and the soil structure deteriorates. Infiltration rates decrease and a larger part of the rainfall becomes surface runoff, leaving the catchment in a quick flow. As a consequence of this, peak water flows from agricultural lands are steeper and higher than peak flows from forested catchments (assuming that other conditions like rainfall characteristics, soil types, and slope steepness remain constant). Conversely, though not relevant to the hydrological hazard, dry season flows from agricultural lands are lower than from forested areas. The effects of these landuse changes depend on the original vegetation cover and the type of land use along a spectrum of low to high flood hazard, as follows: natural forests more than (<) artificial forests < ungrazed pastures < controlled grazing < mixed cropping and crop rotation < monoculture cropping < excessive and uncontrolled grazing.

Table 3-3 summarizes the impact of agricultural development/landuse changes on the hydrological hazard.

Table 3-3 Impacts of agricultural development on the hydrological hazard.

Measure	**Functioning/mechanism**	**Impact on hydrological hazard**
Landuse change/ deforestation	- Decreased interception/ absorption of rainwater. - Decreased evapotranspiration. - Decreased infiltration/ absorption into the soils. - Increased surface runoff.	- Increase in total annual runoff. - Higher peak flows in the wet season, lower discharges in the dry season.

Agricultural development and conversion of forests also leads to higher soil erosion rates. Soil erosion is lowest in natural forests and usually highest on crop lands and areas with uncontrolled grazing, along the same spectrum presented above. For more details see, Chapter 3.8, Watershed management.

Higher soil erosion results in a higher sediment delivery to the river channel and the equilibrium between sediment supply and sediment transport capacity of the river is likely to be disturbed. As a consequence, the river starts to silt up. This results in changes to a number of the river channel characteristics (e.g., hydraulic radius, hydraulic gradient, roughness) that are linked to the flood hazard.

Table 3-4 Summary of impacts of agricultural development in the catchments on flood risk.

Is there a change in:	**Yes**	**No**
1- Catchment Characteristics that would increase the hydrological hazard:		
- Rainfall interception/absorption?	X	
- Evapotranspiration?	X	
- Surface water storage capacity?		X
- Runoff coefficients?	X	
2- River channel characteristics that would increase the flood hazard:		
- Hydraulic radius?	X	
- Hydraulic gradients?	X	
- Sinuosity?		X
- Roughness?	X	
- Presence of flow obstacles?		X

3.2.3 Irrigation development in floodplains

Agriculture is a very important contributor to and driver of the economic growth in the LMB. At present, there is significant development in irrigation in the basin and the potential for new developments is still large, particularly in Cambodia. According to the 20-year development scenario, irrigation can be extended to more than 5 mln ha of land. In Cambodia, tributary basins as well as the floodplains of the Mekong and Bassac rivers have potential for new and improved irrigation schemes. In Lao PDR, tributary floodplains can benefit from the hydropower developments. In Thailand, there is potential for improvement of existing schemes. Although the Viet Nam Mekong River Delta already has extensive irrigation infrastructure, there is still room for some expansion.

Irrigation developments in the floodplains will have impacts on the flood hazard and on the potential flood damage. Of major concern is the progressive loss of floodplain storage and conveyance capacity that results from the construction of agricultural embankments, built to protect the agricultural area against flooding.

These embankments not only decrease the available flood storage area, but also block or redirect flood flows. This affects the water conveyance capacity of the floodplain and its ability to convey floodwaters downstream. As with many impacts, it is not so much the impact of each separate development but the cumulative impact that a series of developments may have that are critical factors in increasing the hazard.

In the Cambodian floodplain, there are three types of agricultural embankment structures that have different impacts on flood hazards. Rainfed embankments are constructed to pool rainwater for rainfed crops and are usually between 0.6 and 1 m high. They are generally located in the shallow-flooded areas along the fringes of the floodplain and, therefore, do not have a significant impact on the flood hazard. Irrigation embankments are either storage embankments or embankments along irrigation canals. Storage embankments may be up to 6 m high. They store floodwater in the wet season for use in the dry season. As such, they do not decrease the floodplain storage and have no impact on the flood hazard. Embankments along irrigation canals are usually about 4 m high, though along main canals they may reach heights of 6 m. They can seriously impede the passage of floodwaters.

The third type of embankments is called 'colmatage' embankments. They inhibit the downstream floodwater flow over the floodplain and have a significant impact on floodwater conveyance in ways that can reduce the flood hazard.

The Water Utilisation Programme – Tonle Sap Lake and Vicinity study simulated the impact of embankments along the banks of the Mekong River between Kampong Cham and Phnom Penh. Embankment construction along the left bank turned out to increase the floodwater spillage over the right bank by about 15%, leading to the rise in water levels near Phnom Penh by about 0.35 m. Embankment of the right bank increase water levels near Phnom Penh by about 0.20 m. Embankments on both sides of the river would increase water levels near Phnom Penh by 0.50 m.

Clearly, embankments have consequences for flood levels and flood durations downstream or on the other side of the river. The reduced storage area and floodwater flow impediments may have impacts on the flood hazard: the depth of flooding may change and so may the speed with which the flood rises, the flow velocity of the floodwater and the duration of the flood.

Table 3-5 Summary of impacts of irrigated agriculture development on flood risk.

Is there a change in:	**Yes**	**No**
1- Catchment characteristics that would increase the hydrological hazard:		X
- Rainfall interception?		
- Evapotranspiration?		X
- Surface water storage capacity?	X	
- Runoff coefficients?		X
2- River channel characteristics that would increase the flood hazard:		
- Hydraulic radius?		X
- Hydraulic gradients?		X
- Sinuosity?		X
- Roughness?		X
- Presence of flow obstacles?	X	
3- Floodplain characteristics that would increase potential damages:		
- Flood characteristics (derived using data from 2, above)?		
- Area and depth of inundation?	X	
-Time of occurrence of the flooding?	X	
- Speed with which the water rises?	X	
- Stream velocities of the flood water?	X	
- Duration of the flooding?	X	
- Elevation/morphology?	X	
- Landuse type?	X	
- Value of landuse type?	X	
- Susceptibility of the landuse type?	X	
- Floodplain area?	X	
- Presence of flow obstacles?	X	

Improved drainage may also be part of agricultural development. Faster drainage of the flooded area after the passage of the flood peak may have consequences for the water levels downstream, causing the levels to rise. There are two other impacts that may be significant. First, groundwater levels in irrigated areas tend to rise. This means that intensive rainfall will more easily lead to floods than in areas without irrigation. Second, structures built for irrigation or drainage may form obstacles to flows and result in increased floodwater levels.

Potential damage in an area vastly increases as agricultural use increases. Not only is the potential crop damage higher, but so are the potential damage to irrigation and drainage infrastructure, access roads, and other structures. A detailed methodology for the assessment of potential damages in agricultural areas is presented in the Best Practice Guidelines for Flood Risk Assessment, Volume 3A in this series.

3.3 Hydropower

3.3.1 Introduction

Hydropower can be produced by using the artificially created downstream head of a storage reservoir or by low 'run-of-the-river' hydropower plants. Although run-of-the-river plants are being considered in the Mekong River Basin, they are not discussed here, since they would not affect the hydrological hazard or the flood hazard.

Construction of storage reservoirs for hydropower production is an on-going activity in the Mekong River Basin. The LMB has an estimated 'potential for hydropower development of about 30,000 MW. Only about 2, 000 MW, or 7% of this potential is presently exploited. The Mekong River Basin as a whole has a hydropower potential of 53,000 MW of which 9.4% is already exploited. Population and consumption growth and changes to traditional cultures are expected to sharply increase the demand for electricity, in line with the goals of elites in the region.

In the Upper Mekong River Basin, China is completing a hydropower cascade of 8 reservoirs on the Lancang River. The largest of these are the Xiaowan and the Nuozhadu reservoirs, with active storage capacities of 9,800 and 12,400 mln m^3 respectively. Total active water storage capacity of the China dams, after completion of the cascade, is estimated at over 30,000 mln m^3.

Not only in China but also in Lao PDR new storage reservoirs are being planned. Total active storage could be well on the order of 10,000 mln m^3.

Hydropower reservoirs do not have a direct measurable effect on the meteorological hazard, nor on vulnerability. They do have an impact on both the hydrological hazard and on the flood hazard.

3.3.2 Hydrological hazard

Storage reservoirs built for the purpose of hydropower production usually have a significant impact on the hydrological hazard, by storing flood waters in the period of high river flows. Reservoir operation is based on rule curves, which are predominantly guided by economic benefits. In other words, water is released to produce electricity, only when there is a demand. Demand is year-round, but usually fluctuates during the day or week, depending on the demands of the most important electricity consumers.

If industrial use dominates, demand during the daytime and on weekdays may be higher than during the night-time and weekends. When domestic use predominates, the demand is usually higher in the daytime and evening than during the night-time.

As a consequence, hydropower reservoirs have an impact on the flow regime over two types of time intervals as follows. They:

- Reduce seasonal variability of flows, increasing what were previously low flows and decreasing what were previously high flows; and
- Increase flow fluctuations during the day and throughout the week.

The impact reducing high water flows depends on the magnitude of the stored water volume compared to the flow volume in the downstream river. The impact of on increasing the low flows is very much determined by the volume of the releases compared to the low flow discharge in the receiving part of the river. Clearly, large reservoirs in small basins have a much higher impact than large reservoirs, and small reservoirs, in a large catchment. Moreover, the impact is largest directly downstream of the dam and decreases in proportion to the distance downstream.

In this respect, the impact of a tributary on tributary flooding is expected to be much more significant than the impact of mainstream dams on mainstream flooding.

As part of the WUP studies for the BDP programme the impact of storage reservoirs on peak water levels had been investigated with hydrologic and hydraulic simulation models and an accompanying Decision Support Framework to test four different scenarios. Total active water storage capacity in these scenarios varied between 22.3 (low development scenario) and 47.6 km^3 (high development) as compared to an active storage volume in the Base Case (the situation in the year 2000) water storage capacity of 5.7 km^3. Impact on annual peak floodwater levels (for the lowest, the average and the highest peak flow level in the period 1986-2000) was calculated for five water level monitoring stations along the main river.

As expected, the impacts on flood levels of the China dams (total active storage volume of 28.5 km^3) are greatest in the upstream reaches. Downstream, where waters from undimmed tributaries enter the river, the impacts are smaller. The reduction in average annual floodwater peak levels of 1.81 m predicted for Luang Prabang is smaller downstream; 0.22 m at Pakse and to less than 0.1 m in Tan Chau.

For the maximum storage scenario (47.6 km^3) an additional reduction of average annual peak levels (over the impact of the Chinese dams) of 0.2 m at Pakse and 0.05 m or less at Tan Chau is estimated in the simulations. Table 3-6 presents the data.

As noted above, the impact of large storage reservoirs in smaller catchment may have a more significant impact on peak flows. For example, after completion of the Nam Theun-2 hydropower station, daytime releases to the Xe Bang Fai were estimated at about 300 m^3/s, which is significant compared to a peak flow maximum of around 2,000 m^3/s.

3.3.3 Flood hazard

Storage reservoirs disrupt the natural flow of sediments, with different potential impacts on flood hazards in different areas. With decreasing stream velocity in the reservoir the sediment transport capacity of the flow decreases and suspended sediments are released from the water. Sediments from a river entering a reservoir are usually deposited at the reservoir inflow area, where a delta may develop. Sediment trapping efficiencies of reservoirs are commonly between 60 and 95%, depending of the size of the reservoir and the grain size distribution of the sediment.

Table 3-6 Simulated impact of hydropower development on flood levels using historic flood levels for reference.

Station/reference water level	Base Case gauge height (m)	Change compared to Base Case gauge height (m)	
		Chinese dams	High development
Luang Prabang			
- Lowest (1992)	9.40	-0.99	-1.18
- Mean (1986-2000)	15.59	-1.81	- 1.93
- Highest (1995)	19.06	- 2.68	- 2.78
Pakse			
- Lowest (1992)	8.86	- 0.10	- 0.24
- Mean (1986-2000)	11.01	- 0.22	- 0.40
- Highest (1991)	13.70	- 0.34	- 0.56
Tan Chau			
- Lowest (1998)	3.59	-0.21	- 0.29
- Mean (1986-2000)	4.65	- 0.11	- 0.17
- Highest (2000)	5.30	- 0.05	- 0.05

Sediment depleted water released from a reservoir has a high sediment transport capacity (erosive power) and will start to erode the receiving channel, thereby scouring the downstream streambed and banks until the equilibrium sediment load is re-established. Bars and islands may erode and disappear, as may riffles and pools. Indeed, a number of the channel characteristics as identified as having an impact on the flood hazard may change: the hydraulic radius, the hydraulic gradient, the sinuosity and even the roughness of the riverbed (coarsening, fine sediment wash away). The changes are greatest close to the dam and reduce in scale moving downstream.

Overall the discharge capacity of the channel downstream of the reservoir will increase, and floodwaters will be routed faster downstream, thus reducing flood hazards downstream of the reservoir. On the other hand, the faster downstream routing of flood water may increase flood levels further downstream where the riverbed has not increased its capacity.

Sediment trapping of existing mainstream reservoirs is considerable. The Manwan Dam, the first dam in the Lancang Cascade, which was completed and put in operation in 1993, had a very significant impact on the sediment flux downstream along the Lower Mekong River. It had a sediment trapping efficiency of 68%. As a result of the dam construction, the sediment flux at Chiang Saen, 660 km downstream was more than halved; from 70 mln ton per year to 31 mln ton per year. Impacts were noticeable as far downstream as Pakse, where post Manwan Dam average annual sediment loads are 20% lower than pre-Manwan Dam loads.

Sediment trapping efficiency of the whole cascade is estimated at 94%, and a further reduction in sediment flux has to be expected.

Impacts of tributary dams may be significant as well but probably only affect the flood hazard along the tributary itself, not so much along the main stream.

Table 3-7 Summary of impacts of hydropower development on flood risk.

Is there a change in:	**Yes**	**No**
1- Catchment characteristics that would increase the hydrological hazard:		
- Rainfall interception?		X
- Evapotranspiration?		X
- Surface water storage capacity?	X	
- Runoff coefficients?		X
2- River channel characteristics that would increase the flood hazard:		
- Hydraulic radius?	X	
- Hydraulic gradient?	X	
- Sinuosity?	X	
- Roughness?	X	
- Presence of flow obstacles?		X

3.4 Navigation

River transportation provides an efficient means for residents of the basin to access different areas of the basin and to move good from producers to consumers and link with regional and global markets. It also helps to connect isolated areas and improve livelihood opportunities in such places.

Trade has risen sharply in the region in the last 10 years and river navigation is thought to play an important role in further transport development.

The MRC navigation strategy (MRCS, March 2003) puts emphasis on the improvement of the legal and operational environment, the provision of navigation aids, and the implementation of structural projects to reduce travel times and open up the Mekong River from the East Sea to China. Such interventions could promote the construction of weirs and storage capacity and the improvement of the channel, including deepening the river by dredging, re-alignment of parts of the river or removal of obstructions.

Improvement of the channel would have an impact on the flood hazard, since the hydraulic radius and gradient, as well as the river sinuosity would likely to change as a result of channel improvement. The overall effect of these changes would be to route floodwaters more quickly downstream, resulting in higher water levels downstream of the improved river reach.

Weirs will obstruct the river flow and would tend to increase floodwater levels upstream of the weir. Downstream of the weir, water levels would decrease and the river may begin to erode its bed.

Potential damage would also increase as a result of developments in navigation. Floods may damage port infrastructure and navigation aids.

Table 3-8 Summary of impacts of navigation development on flood risk.

Is there a change in:	**Yes**	**No**
River channel characteristics that would increase the flood hazard:		
- Hydraulic radius?	X	
- Hydraulic gradient?	X	
- Sinuosity?	X	
- Roughness?		X
- Presence of flow obstacles?	X	

3.5 Fisheries

The Mekong River has one of the largest fish stocks among rivers in the world. About 40 mln people are engaged in catching or raising fish in the basin. The value of the annual catch is estimated to be about 3 billion USD. Fish production is very important for the livelihood and diet of the population of the basin and is also of enormous economic importance.

Previously, fish capture has been so productive that there was little incentive for investment in aquaculture. Moreover, until recently, poor infrastructure limited the distribution of fish feed, fingerlings and the produce of the industry. Nevertheless, aquaculture is now steadily increasing. Cambodia is considered to have huge aquaculture investment potential. Pond culture and fish farming in rice fields are also steadily increasing in importance.

Developments in the sector will not affect the hydrological and flood hazard. Flooding, however, may cause damage to aquaculture ponds. When floodwater levels exceed the level of embankments around fish ponds or rice fields, fish may escape into the wild and result in losses to aquaculture. In other words, developments in aquaculture increase the damage potential in the floodplains.

Procedures on how to assess these kinds of potential damages are provided in the Best Practice Guidelines for Flood Risk Assessment, Volume 3A in this series.

3.6 Tourism

Very little is known about the expected developments in the tourism sector. However, whatever these developments may be, impacts on the hydrological and flood hazard are not anticipated.

Potential damage, however, will increase as developments rise. Indeed, developments in tourist facilities in flood prone areas will increase the potential damage and may put more people at risk during flood events.

Procedures on how to assess these kinds of potential damages are provided in the Best Practice Guidelines for Flood Risk Assessment, Volume 3A in this series.

3.7 Domestic and Industrial water supply

Less than 40% of the population in Cambodia and Lao PDR has access to safe water. In rural areas this is even less than 30%. In urban areas the presence of piped water supply systems increases the availability of safe water. In Cambodia however, during the dry season the number of households with access to safe water declines in both urban and rural areas, compared with the rainy season. In Thailand and Viet Nam, access to safe water is generally more widespread, both in urban and rural areas. The situation in the Mekong River Delta is worse; there only about half the households have access to safe drinking water. The United Nations Millennium Development Goals targets a reduction of 50% of the proportion of the population not having access to safe drinking water by 2015.

Very limited is known about the expected changes in industrial water demand, but demand increases will probably be limited and local.

Impacts of developments in the domestic and industrial water supply sector on the hydrological and flood hazard are not anticipated.

Potential damage, however, will increase as development increases. Infrastructure for domestic and industrial water supply may be damaged by flooding and result in significant indirect damages such as the spread of diseases as a result of shortage of safe drinking water and production losses of industries that are forced to close due to the unavailability of processed water.

Procedures on how to assess these kinds of direct and indirect potential damages are provided in the Best Practice Guidelines for Flood Risk Assessment, Volume 3A in this series.

3.8 Watershed management

3.8.1 Introduction

Watershed management is defined as the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plants, animals, and human communities within a watershed boundary.

Usually watershed management programs target degraded watersheds, characterised by high soil erosion rates, high sediment yields in the rivers and high surface runoff rates. Watershed management aims to reduce soil erosion rates and restore the hydrological conditions in a basin.

Watershed management measures influence the hydrological hazard, but have no impact on the conditions in the river channel and on the floodplain. Hence, they have no impact on flood hazard and vulnerability.

3.8.2 Soil erosion control

There are two different approaches to soil erosion control: prevention and management. Prevention of erosion -- i.e., keeping the erosion rates at tolerable levels, involves appropriate landuse planning and farming practices. Erosion control, on the other hand, relies on engineering approaches such as water run-off management.

Rational landuse planning is the first line intervention for keeping soil erosion rates at tolerable levels. Every landuse type has its own magnitude of erosion risk. This risk can become a problem if the land is used for purposes which cannot sustain it. The ability land of land to maintain its integrity depends mainly on the soil characteristics, the slope angle, the vegetation and the climate. On steep slopes with a thin or highly erodible soil, for example, the natural vegetation cover should be maintained because this generally provides the best protection against raindrop impacts. Less steep slopes with less erodible soils do not need such strict protections. With other factors held constant, erosion risk follows a spectrum from low risk to high risk along the following types of land: natural forests < artificial forests < ungrazed pastures < controlled grazing < mixed cropping and crop rotation < monoculture cropping < excessive and uncontrolled grazing.

Since upland erosion is caused mainly by the impact of raindrops and the shear forces of water flowing over the soil surface, an effective prevention and erosion control strategies are to reduce the impact of the raindrops, increase the shear resistance of the soil or decrease the shear force of flowing water in order to reduce both the soil detachment and the transport capacity of the eroding agents. Figure 3-1 illustrates these principles of erosion prevention and control.

The best way to reduce the impact of raindrops is to maintain ground cover. Vegetation cover reduces the fall height and thereby reduces the kinetic energy and erosive power of the raindrops. The effectiveness of vegetation cover in protecting the soil against raindrop impact depends on the height, density, structure and continuity (over time) of the canopy.

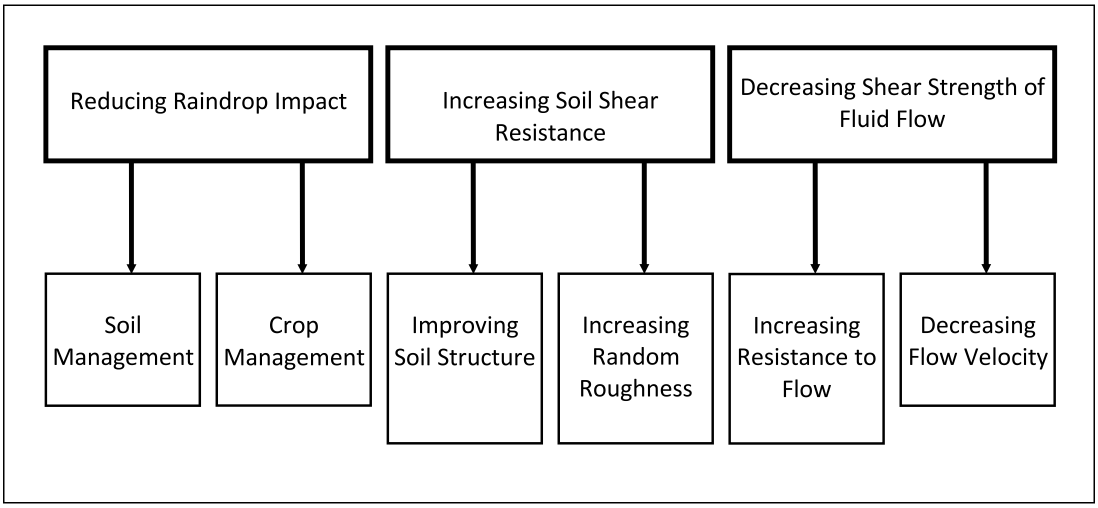


Figure 3-1 Strategies and tactics of erosion prevention and control.

Soil structure is the critical factor in resistance of the soil to shear forces. Organic matter content is very important for improving soil structure and overall soil stability. Good soil structure improves the water infiltration/absorption capacity of the soil and thereby reduces the amount and erosive power of the surface runoff. Various methods exist to improve the aggregate stability of soil. Most commonly applied are mulching (to improve the organic matter content) and the use of soil conditioners. Forest soils usually have a higher organic matter content than soils used for agriculture or grazing.

Agronomic or engineering practices can decrease the shear strength of the surface runoff and channel flow. These practices seek to reduce the amount and/or the velocity of the overland water and channel flow. Agronomic measures change the way in which the soil is ploughed (contour ploughing) and the seedbed is prepared. The application of buffer strips or contour cropping is effective in reducing overland flow velocities and in arresting sediment erosion, as well. Examples of engineering or mechanical measures are terracing and the construction of gully plugs, water retention basins and run-off disposal systems to remove excess water.

3.8.3 <u>Restoration of hydrological conditions</u>

The hydrologic pathways of water from the upper watershed to the lower parts of a drainage basin depend on the difference between precipitation and evapotranspiration and on the infiltration- and water-holding capacity of the soils. The evapotranspiration is, itself, largely dependent on the vegetation or landuse. The infiltration and water-holding capacities of soils depend on depth, organic matter content and particle size and distribution of the soil; parameters which are influenced heavily by soil erosion processes. Landuse changes, catchment degradation and increasing erosion rates affect the amounts of water entering the lower reaches of a river, as well as the timing and distribution of the stream flow.

One of the most common watershed management measures is reforestation, and it is worth describing its impact on the hydrological response of drainage basins.

Reforestation has many consequences for the hydrological behaviour of a watershed. The processes involved are very complex and interrelated. Generally, both the magnitude and distribution of stream flow are affected. A number of soil properties also change in such a way that the infiltration capacity of the soil increases, whereas the soil erodibility decreases. Furthermore, the increase in transpiration and interception of rainfall, evaporating directly from the leaf surfaces, increases the total evapotranspiration. Clearly, the catchment response largely depends on the kind of conversion that takes place; a change from grassland to forest will have different consequences than a change from cropland to forest.

It is generally believed that reforestation increases the stream flow quantity and the amount of water available for human use. However, other than for cloud-forest areas, where mist interception by tree canopies may increase the total amount of water reaching the forest floor, research has shown that total water yield always decreases as a result of reforestation. Reasons for this decrease are the increase in evapotranspiration (forests have higher evapotranspiration rates than grasslands or croplands) and interception losses (15 to 25% of the rainfall may be intercepted by a forest vegetation). As a rule of thumb, reforestation increases stream flow at a rate that is generally proportional to the reduction of forest cover over the catchment. In humid areas, reduced soil compaction results in higher infiltration rates and lower surface runoff amount and with more groundwater replenishment wet season storm-flows decrease and dry season flows increase.

The effects of reforestation on peak and storm flow are variable, but most studies report smaller storm-flow volumes, a marked decrease in peak-flows, and also a marked delay in time to floodwater peaking. On very shallow soils the effect of reforestation on storm flow peaks and floodwaters is often very limited.

Most watershed management projects or programmes consist of a combination of landuse changes, including reforestation and construction of structures to reduce the erosive power of the eroding agents or to store surface run-off. The efficiency of watershed management is not always directly noticeable. Usually, on-site erosion rates decrease quickly after project implementation while effects on sediment yields and catchment hydrology may only become apparent in the long run, after several decades when trees mature and vegetation returns.

Table 3-9 summarizes the most common watershed management measures, and their impacts on hydrological hazard while Table 3-1 summarises the impacts of watershed management on overall flood risk.

Table 3-9 Common watershed measures and their effect on hydrological hazard.

Measure	Functioning/mechanism	Impact on hydrological hazard
Landuse change/ reforestation	- Increased interception/absorption; - Increased evapotranspiration; - Improved infiltration/ absorption; - Reduced surface runoff.	- Decrease in total annual runoff; - Lower peak flows in wet season, higher discharges in dry season.
Agronomic measures - Mulching - Contour ploughing - Contour cropping	- Reduced soil erosion; - Improved infiltration/absorption; - Reduced surface runoff.	- Lower peak flows in wet season, higher discharges in dry season.
Engineering measures - Gully plugging - Terracing - Retention basins	- Reduced soil erosion; - Improved infiltration/absorption; - Reduced surface runoff.	- Lower peak flows in wet season, higher discharges in dry season.

Table 3-10 Summary of impacts of watershed management on flood risk.

Is there a change in:	**Yes**	**No**
1- Catchment characteristics that would increase the hydrological hazard:		
- Rainfall interception/absorption?	X	
- Evapo(trans)piration?	X	
- Surface water storage capacity?	X	
- Runoff coefficients?	X	

CHAPTER 4

METHODOLOGIES

4 APPLICATION OF FLOOD IMPACT ASSESSMENT: REFERENCE AND SUPPORT

4.1 Use of the Best Practice Guidelines for IFRM

The identification and assessment of potential impacts of sector developments on hydrological and flood hazard and on vulnerability to flooding as described in Chapter 3 do not provide in detail the methodologies that should be applied in carrying out the impact assessment of such developments. These methodologies are presented in the **Best Practice Guidelines for Flood Risk Assessment** (see Volume 3A). That volume details procedures for undertaking hydrological and flood hazard assessment, flood damage assessment and flood risk assessment in the Lower Mekong River Basin. Each sector development that would have an impact on the hydrological and flood hazard and/or the flood vulnerability should incorporate those methods into in its development plan or project preparation phase.

The **Best Practice Guidelines for Integrated Flood Risk Management Planning and Impact Evaluation** (see Volume 3B) describes the methodologies for planning of structural flood risk reduction measures and the evaluation of the environmental, and socio-economic impacts. It also offers guidelines on the process of stakeholder consultation and public participation in project preparation. These guidelines, though geared towards IFRM, can, in many cases, also be applied in the assessment of impacts of sector developments, given that these are either public developments or public and private developments with public impacts. The impacts on floods and flooding of the development plan or project are certainly matters of direct public concern that can be subject to public decision-making.

The **Best Practice Guidelines for Structural Measures and Flood Proofing** (see Volume 3C), and the **Best Practice Guidelines for the Integrated Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong River Floodplains of Cambodia and Viet Nam** (see Volume 3E) should also be used by planners and engineers in cases where other sector developments contain elements of civil engineering works within rivers sections and floodplains.

4.2 Use of Analytic Tools

Measuring or estimating the impact of sector developments on flood hazard often requires the use of a hydrodynamic model. Such models already exist for parts of the LMB: i) for the Nam Mae Kok Basin in Thailand, ii) for the Xe Bang Fai River basin in Lao PDR, and iii) for the Lower Mekong River Basin in Cambodia and Viet Nam. The first model is available from the Thai National Mekong Committee (TNMC,) while the other two models have been developed by the MRCS and are being maintained by the Information and Knowledge Management Programme (IKMP) of the MRCS. The models and the associated database and Geographic Information System (GIS) are also available at the Regional Flood Management and Mitigation Centre (RFMMC) at Phnom Penh.

Developers of plans or projects that would have an effect on the hydrological and/or flood hazard should contact the RFMMC in Phnom Penh in order to make arrangements with that Centre for the use of the models. The software and the models are highly sophisticated tools, normally requiring that experts of the RFMMC refine and update them for each potential application. The RFMMC role is that of a service provider. Data on the impacts of those projects that are implemented would be added to the model as part of the process of updating and improving the models.

4.3 Who should use the Guidelines?

This Best Practice Guideline as well as the other guidelines are intended for use by those who are preparing development plans or specific projects, whether they are from the public or private sector. Potential users include Line Agencies of various public ministries, private investors and consultants who assist line agencies, and investors. In general, given the complexities in flood risk assessment, users would normally be professionals trained in hydrology and hydraulic engineering.

4.4 Need for information sharing

Impacts of developments on flood risk can be minimal (e.g., in the case of small local irrigation projects) or considerable, such as in the case of construction of a series of large hydropower dams. All impacts on flood risk, beneficial or harmful, should be brought to the attention of the relevant Line Agencies in the country or countries concerned and to the MRCS BDP, FMMP and other relevant programmes. In case of harmful impacts, mitigating measures should be investigated by the plan or project promoter, including the demonstration of the effectiveness of the mitigating measures proposed.

CHAPTER 5

REFERENCES

5 REFERENCES

[1} ADPC. 2008. Incorporating Disaster Risk Assessments as part of Planning Process before construction of new Roads: Mainstreaming DRR into Urban Planning and Infrastructure. RCC Guideline 3.1. Guideline prepared for the Regional Consultative Committee on Disaster Management (RCC) Program on Mainstreaming Disaster Risk Reduction (DRR) into Development.

[2] Delft Cluster (2008), Recommendations for the Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong Floodplains of Cambodia and Vietnam.

[3] Emerton, L. and Bos, E. (2005). Value: Counting Ecosystems as an Economic Part of Water Infrastructure. IUCN, Gland, Switzerland and Cambridge, UK.

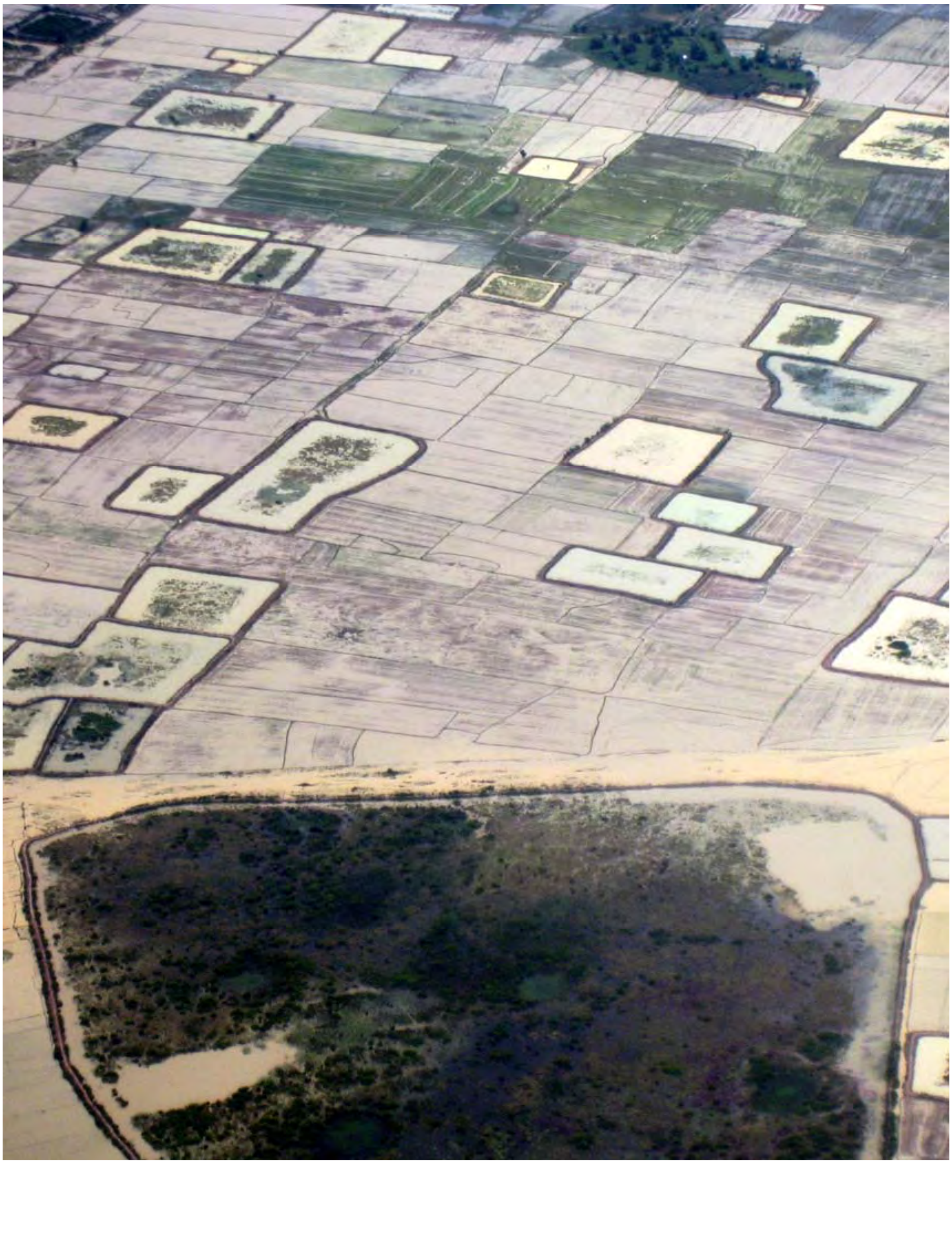
[4] Johnston *et al*., 2003.

[5] MRC (2006), Annual Flood Report 2005.

[6] MRC (March 2007), Best Practice Guidelines IFRM Guidelines for the BDP, Volume 1 Framework for Development of Guidelines.

[7] Additional sources include:
MRC Country Reports.

APPENDIX



Appendix 1 The Best Practice Guidelines and Project Phases/Stages

In order to facilitate management of an engineering project, project managers normally divide projects into phases such as the following five phases:

1. Initiation
2. Planning/Development/Design
3. Production/Implementation
4. Monitoring/Control
5. Closure

A project starts with an idea to solve or mitigate a problem, create a product or structure, or some other objective. In the initiation phase, finances are mobilised, a project team is formed, equipment and tools are purchased, and the idea begins to take shape. The second phase is the planning/development/design phase. The feasibility of the idea is tested, and, if successful, a project plan is produced and the design is prepared. In Phase 3, the plans and designs are implemented; the production takes place and the project is underway. Monitoring during project implementation may reveal the need to correct the planning and/or design, and make adjustments. After completion, the project will be closed; the project team disbands, accounts are closed, and the product or result may be handed over to a client.

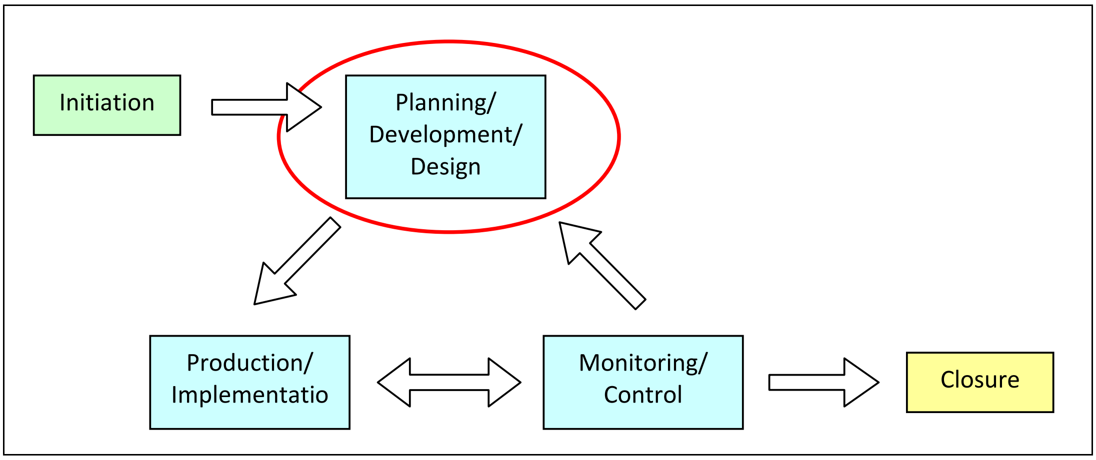


Figure 1 The phases of an engineering project.

The Best Practice Guidelines are almost exclusively applicable to Phase 2: Planning/ Development/Design. This phase can be subdivided in various stages, listed below.

a) Preliminary/pre-feasibility study
b) Feasibility study and overall planning
c) Preliminary design
d) Detailed design and detailed planning
e) Construction/bid documents

The number and content of the stages may differ, depending mainly on project type or country-specific preferences. The preliminary design stage, for example, is often included in the feasibility study for engineering projects.

Each section of the guidelines applies to one or more of the above stages. In the guidelines this will be indicated by displaying symbols that represent each stage (shown below) in the page margins.

Phase 2 contains all of the following five stages:

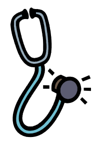
a) Preliminary/pre-feasibility study

A pre-feasibility study is the precursor to a feasibility and design study. Its main purpose is to decide whether it is worthwhile to proceed to the feasibility study stage and to ensure there is a sound basis for undertaking a feasibility study.

A pre-feasibility study generally includes:

- Definition of achievable project outcomes;
- Analysis of the development situation and constraints the project is to address based on collected data;
- Identification of related (government and other stakeholder) policies, programs and activities;
- Preliminary assessment of the viability of alternative approaches; and
- Preliminary identification of likely risks to feasibility and benefits (including risks to sustainability).

b) Feasibility study and overall planning



If a project is considered to be feasible based on the pre-feasibility study, a more thorough feasibility study can begin. A feasibility study defines the project and its objectives in detail, and looks at these various forms of feasibility:

- Technical feasibility: Can the measures technically be realised in the local context?
- Operational feasibility: Are the measures to be implemented manageable by the local people?
- Economic feasibility: Is the cost-benefit analysis favourable?
- Social feasibility: Are the objectives and measures socially acceptable?
- Environmental feasibility: Are the environmental impacts acceptable?
- Political feasibility: Will the measures be supported by those with power?
- Overall feasibility: Will implementation of the envisaged measures result in accomplishment of the project objectives?

Field surveys, hydrological and hydraulic analyses (in flood mitigation projects), social and environmental assessments, stakeholder meetings, and costs estimates are among the basis for answering the above questions. If the answers are positive, the operations/management structure and management method can be defined, and any initial planning can be detailed.

c) Preliminary design

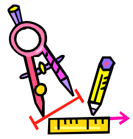
If a project is deemed feasible, the preliminary design stage can start. This stage focuses on the technical measures, as follows:

- Site surveys and investigations and computer modelling provide the data for preliminary design criteria;
- The design criteria can be translated into the preliminary design of structures and measures in an integrated and balanced system in which the envisaged management activities are linked to one another;

- The cost-benefit analysis (construction and operation) and analysis of environmental, social and political factors demonstrate whether the project is still viable.

If necessary, project planning can be adjusted based on new insights gained in this stage.

d) Detailed design and detailed planning



During the final design stage, the detailed architectural and engineering drawings (the blueprints) of all physical components of the project are produced. Virtually all design problems must have been resolved before the end of the final design stage. Sufficient detail must be provided by the drawings and the report to allow reasonably accurate estimates of construction and operating costs, as well as the construction scheduling.

e) Construction documents/bid documents

The detailed designs and construction scheduling are incorporated in construction documents and bid specifications, giving the contractors the information they need for construction.

Where sections of the guidelines refer to other than the above-described phases (e.g. the construction or monitoring phase), the following symbol is used.

Mekong River Commission

www.mrcmekong.org

Office of the Secretariat in Phnom Penh (OSP)
576 National Road, #2, Chak Angre Krom,
P.O. Box 623, Phnom Penh, Cambodia
Tel: (855-23) 425 353.
Fax: (855-23) 425 363

Office of the Secretariat in Vientiane (OSV)
Office of the Chief Executive Officer
184 Fa Ngoum Road,
P.O. Box 6101, Vientiane, Lao PDR
Tel: (856-21) 263 263.
Fax: (856-21) 263 264

May 2010