THE MEKONG RIVER COMMISSION SECRETARIAT

Best Practise Guidelines for Integrated Flood Risk Management for Basin Development Planning

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

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Draft Final Report

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UNESCO IHE

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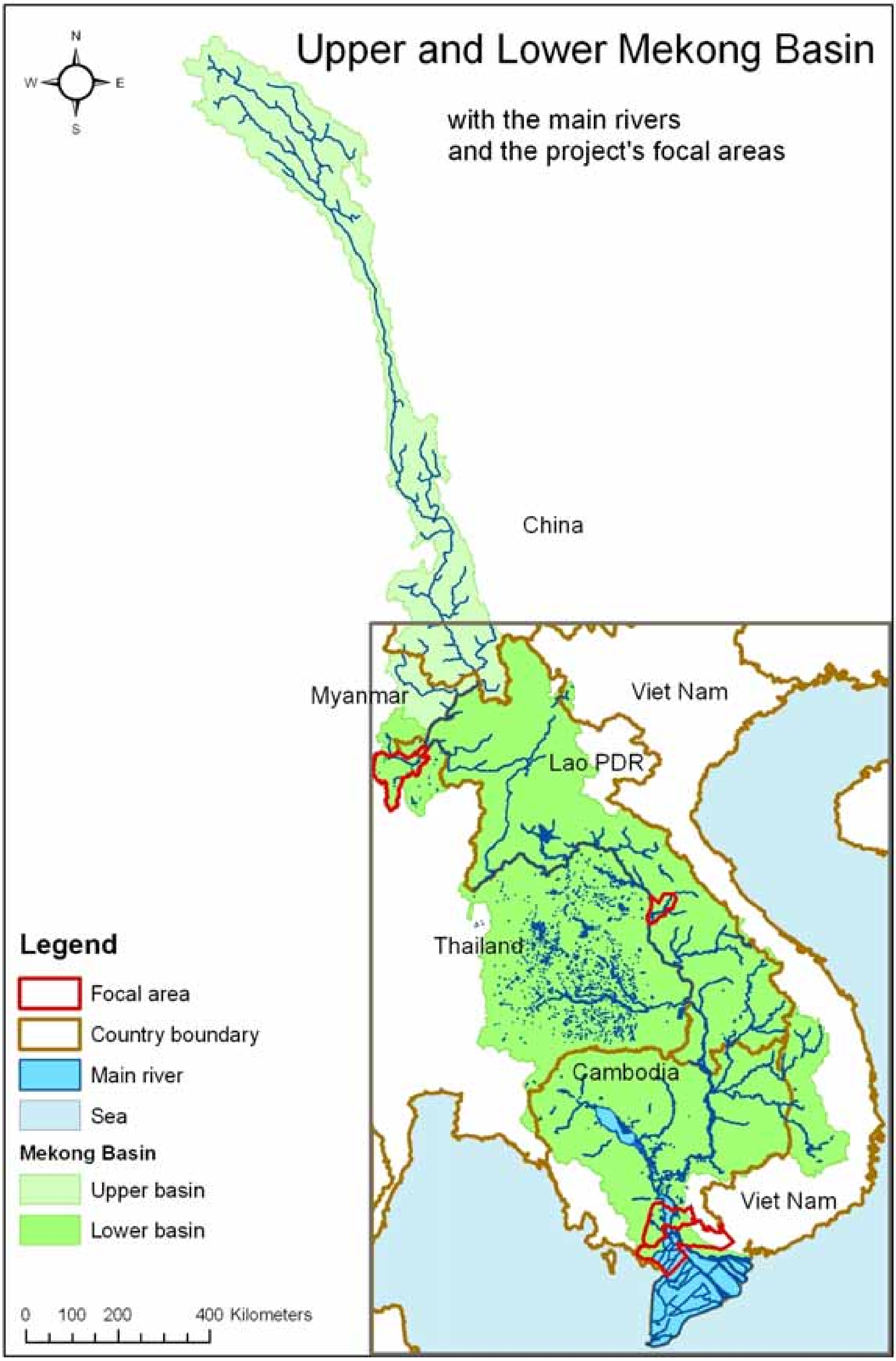
Appendix 1 The Best Practice Guidelines and project phases/ stages


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

GLOSSARY

Damage curve	The functional relation between inundation characteristics (depth, duration, flow velocity) and damage for a certain category of elements at 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, economic assets, loss of standing crops and livestock, loss of human life, immediate health impacts and loss of ecological goods.
Exposure	The people, assets and activities that are threatened by a flood hazard.
Flood control	A structural intervention to reduce the flood hazard.
Flood damage	Damage to people, property and the environment caused by a flood. This damage refers to direct as well as indirect damage.
Flood damage risk (= Flood risk)	The combination or 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*.
Flood hazard	A flood that *potentially may* result in damage. A hazard does not necessarily lead to damage.
Flood hazard map	Map with 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 infrastructural works, buildings and/or the contents of buildings located in flood hazard areas.
Flood risk management	Comprehensive activity involving risk analysis, and identification and implementation of risk mitigation measures.
Flood risk management measures	Actions that are taken to reduce the probability of flooding or the possible damages due to flooding or both.
Flood risk map	Map with the predicted extent of different levels / classes of *average annual possible damage.*
Hydrological hazard	A hydrological event (discharge) that may result in flooding.
Indirect damage	All damage which relate to the disruption of economic activity and services due to flooding.
Integrated flood risk management	The approach to Flood Risk Management that embraces 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
Resilience	The ability of a system / community / society to cope with the damaging effect of floods
Susceptibility	The opposite of resilience, that is to say the inability of a system / community / society to cope with the damaging effect of floods
Vulnerability	The potential damage that flooding may cause to people, property and the environment

ABBREVIATIONS

N.B. Abbreviations that occur only once and that are explained in the text are not included in the table below.

ADCP	Acoustic Doppler Current Profiler (Acoustic Doppler Profiler); instrument to measure how fast water is moving across an entire water column
ARF	Area Reduction Factor (hydrology)
BCM	Billion Cubic Meters
BDP	Basin Development Planning
BPG	Best Practise Guidelines
CBA	Cost Benefit Analysis
d/s	downstream
DACA	Damage and Casualties Assessment project for the Lower Mekong Basin based on HIS-SSM
DEM	Digital Elevation Model (see also DTM)
DSF	Decision Support Framework
DTM	Digital Terrain Model (see also DEM)
EC	European Commission
EU	European Union
EV1	Extreme Value type 1 distribution (hydrology)
EXCIMAP	European Exchange Circle on Flood Mapping
FEMA	Federal Emergency Management Agency
FHA	Flood Hazard Assessment
FMM	Flood Management and Mitigation
FMMP-C2	Flood Management and Mitigation Programme, Component 2
FN curve	Curves relating the probability per year of causing N or more fatalities (F) to N
FRA	Flood Risk Assessment
FV	Future Value (economic analysis)
GEV	Generalised Extreme Value distribution (hydrology)
GIS	Geographic Information System
HAZUS	Software for risk assessment analysis of potential losses from floods, hurricane winds and earthquakes (by FEMA)
HH	Household(s)
HIS-SSM	Hydrological Information System - damages and casualties assessment module
HYMOS	Information system for water resources management
IFRM	Integrated Flood Risk Management
ISIS	Hydrodynamic simulator for modelling flows and levels in open

	channels and estuaries
IUH	Instantaneous Unit Hydrograph (hydrology)
JICA	Japan International Cooperation Agency
LMB	Lower Mekong Basin
LMD	Lower Mekong Delta
LXQ	Long Xuyen Quadrangle (Vietnam)
MCM	Million Cubic Meters
MRC(S)	Mekong River Commission (Secretariat)
MSL	Mean sea level, the average (mean) height of the sea, with reference to a suitable reference surface
NPV	Net Present Value (economic analysis)
PDR (Lao)	(Lao) People’s Democratic Republic
PoR	Plain of Reeds (Vietnam)
PV	Present Value (economic analysis)
RFMMP	Regional Flood Management and Mitigation Programme
RID	Royal Department of Irrigation
RR	Rainfall Ratio (hydrology)
SBF	Se Bang Fai (Lao PDR)
SCS-CN	Soil Conservation Service (USA) Curve Number method (hydrology)
SWAT	River basin scale model quantifying the impact of land management practices in large, complex watersheds
TCEV	Two Component Extreme Value (hydrology)
u/s	upstream
UH	Unit Hydrograph (hydrology)
UK	United Kingdom
UNESCO-IHE	Institute for Water Education (IHE) of the United Nations Educational, Scientific and Cultural Organization
USA	United States of America
WUP	Water Utilisation Programme

USED SYMBOLS

The FMMP-C2 guidelines contain in the left margins symbols for quick reference. The symbols indicate:

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

A) The report texts have been categorised into four groups. These groups are as follows:

I) Project background / Report info

Text on the FMMP-project and its background,
or explanation on the report structure or content.

II) Theory

Theory behind the proposed/ applied methods and guidelines.

III) Example

Example of the proposed/ applied methods and guidelines.

The fourth group comprises the remainder of texts and concern methodology and theory adapted/ applied to the Lower Mekong Basin, i.e. the guidelines. These guidelines are to be applied in one of the five project stages described below (B).

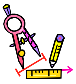
B) A project consists in general of five phases (see Section 1.6). Project FMMP-C2 encompasses only Phase 2: Planning/ Development/ Design. This phase can be subdivided in the following five stages:

a) Preliminary/ prefeasibility study

b) Feasibility study & overall planning

c) Preliminary design

d) Detailed design & detailed planning



e) Construction/ bid documents

Any part of a guideline falling outside the
scope of the five phases above will be marked with: ✚

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 Mekong Floodplains of Cambodia and Vietnam*[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 Bangfai 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, Vietnam;*
Volume 6E	*Flood Risk Management in the Border Zone between Cambodia and Vietnam.*

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

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[1] Developed by the Delft Cluster

1.2 Best Practice IFRM Guidelines for Basin Development Planning

A framework for the development of Best Practice IFRM Guidelines for Basin Development Planning (BDP)[2] was prepared for the FMMP-C2. The objective and purpose of the IFRM Guidelines for BDP were stated as follows:

1. The objective of the BDP Guidelines is ‘to reduce the socio-economic costs of flooding in the Lower Mekong Basin, whilst preserving the environmental and other benefits of floods, through a better understanding of the management of flood risk and flood behaviour by MRC via the BDP and by national line agencies via national programs’; and
2. The purpose of the BDP Guidelines ‘is to ensure that the BD planning process identifies and addresses flood-related impacts and opportunities of potential development scenarios and development projects in a consistent fashion that is technically, socially, environmentally and financially responsible and effective’.

The role of these BDP guidelines and IFRM in Basin Development Planning was illustrated as in Figure 1.1. This illustration suggests that the IFRM guidelines for BDP serve as a "screen" for all type of water related plans and projects emerging from the MRC programs to pass before being taken up in the (IWRM based) Basin Development Plan.

From the strict perspective of flood risk management, the function of the "screen" would be to assess to what extent mentioned plans and projects have an impact, negative or positive, on flood risks in the LMB. In this context, the IFRM guidelines for BDP are meant to guide the process of impact (on flood risk) assessment for each water related development sector. Consequently the IFRM guidelines will essentially consist of a checklist for each of these sectors of flood risk related issues that need to be addressed in the impact evaluation of sectoral strategies, plans and projects.

The BPG for IFRM planning and impact evaluation focuses on the evaluation of the impacts of flood risk management measures on the environment, including existing and planned socio-economic conditions and developments. The focus of these IFRM guidelines for BDP is, on the contrary, on the impact that socio-economic developments may have on flood risk.

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

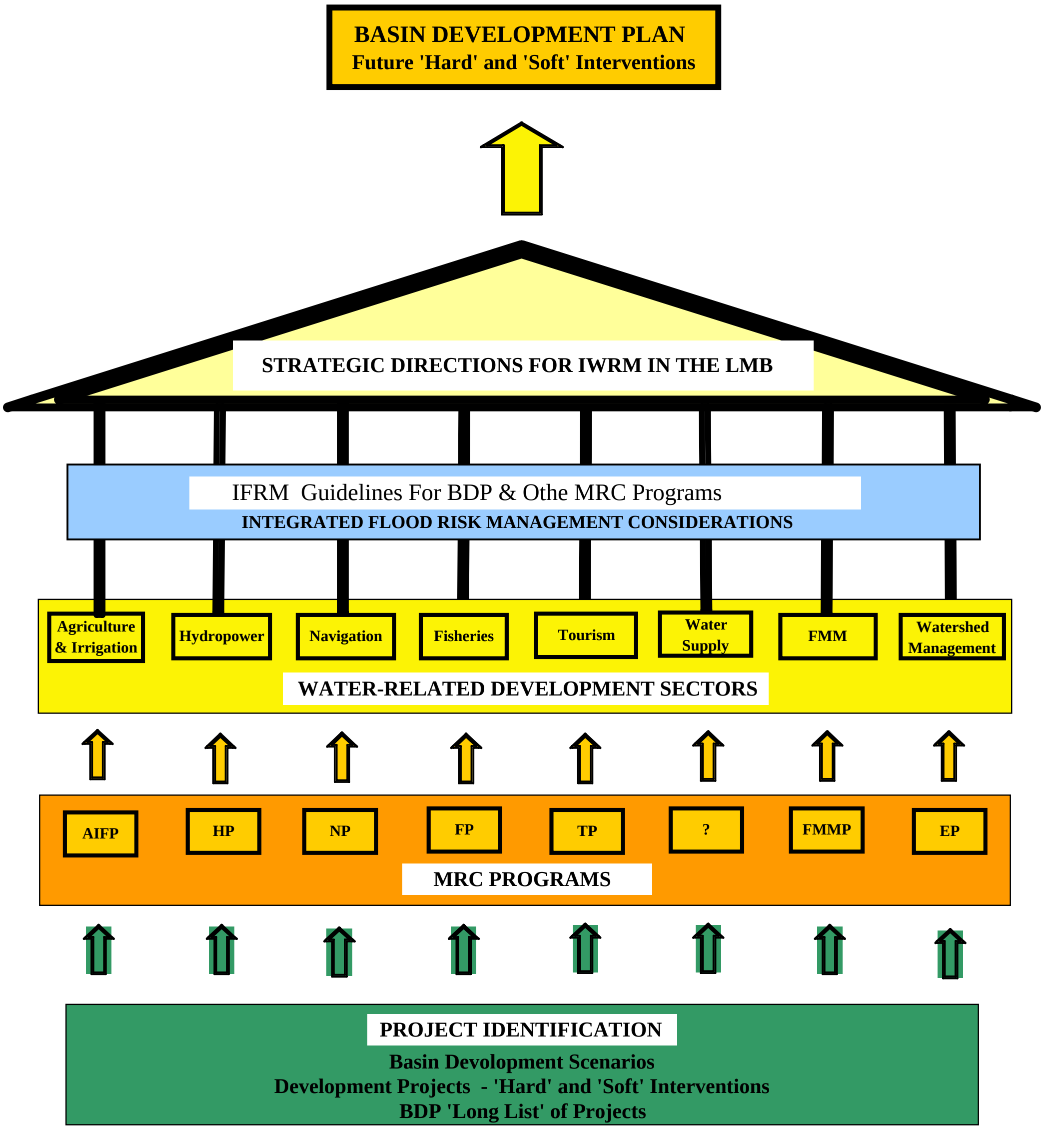

Figure 1.1 The role of the basin development guidelines in the steps towards a basin development plan.

1.3 How to use the Best Practice Guidelines

These guidelines are intended to be used in connection with existing guidelines in the MRC and the different countries in the LMB for environmental impact assessments in other sectors. Not only water related but also transport infrastructure, forestry, urban and industrial development related sectors.

As such the guidelines are intended to be used by MRC, NMC's and line agencies in the riparian countries that are involved in policy, planning and project preparation in these sectors. By applying the Guidelines MRC, NMC’s and the line agencies should be able to better take into account flood-related considerations in their day-to-day technical activities.

1.4 Background on the development of the Best Practise Guidelines

This BPG has been developed in connection with the Best Practice Guidelines for Flood risk assessment and the BPG for IFRM planning and impact evaluation.

In the formulation of the BPG also use was made of the results of the "Roads and Floods" guidelines (Delft Cluster)[3] and builds on the conclusions of the RCC (Regional Consultative Committee) 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 FMMP-C2 demonstration projects during the Stage 2 Implementation Phase.

1.5 Purpose and scope

This BPG has been developed to provide methodologies for the evaluation of the impacts of sectoral developments in the LMB on the flood risk, both inside the development area as well as outside these areas, with special emphasis on transboundary impacts.

The BPG is intended to form an appendix to existing EIA guidelines. The BPG will not provide the specific tools for flood risk assessments. The objectives of the BPG are to:

1. Provide an overview of sectoral developments that may affect flood risks;
2. Identify the flood risk related elements that must be included in an impact assessment of sectoral development policies, plans and projects; and
3. Provide methodologies and samples of flood risk evaluation of development policies, plans and projects.

1.6 The Best Practice Guidelines and project phases/ stages

In order to manage an engineering project properly, it is normally divided in project phases. Common is a division in the following five phases:

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

The Best Practise 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.

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[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

CHAPTER 2

THE BASIN DEVELOPMENT PLAN AND FLOOD RISK

2 THE BASIN DEVELOPMENT PLAN AND FLOOD RISK

2.1 The Basin Development Plan

The 1995 Agreement charges the Mekong River Commission Joint Committee with the formulation of 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 Basin waters, with emphasis and preference on joint and/or basin-wide development projects and basin programmes". The purpose of the BDP is therefore to identify, categorise and prioritise projects and programmes at basin level.

Using the principles of Integrated Watershed Resource Management (IWRM), the BDP process promotes the coordinated development and management of water and related resources, in order to maximise economic and social welfare in a balanced way without compromising the sustainability of vital ecosystems (Global Water Partnership, 2000). This requires the preparation of information that informs discussion and decisions on achieving an acceptable balance between development of the basin and maintenance of its ability to sustain livelihoods and environmental values.

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.

Scenarios are used to compare various "what if" situations and are usually built from a combination of facts and possible changes, situations or future series of events. Development scenarios for BDP purposes are defined based on assumptions of:

- Future hydrological conditions;
- Future water demands; and
- Interventions assumed to be in place.

Analysis of these assumptions shows how water availability and demand will alter, along with the resulting positive and negative economic, environmental and social implications.

The MRC Joint Committee has approved of nine scenarios in four groups: the baseline situation, the definite future situation, the foreseeable future situation and the longer-term future. The scenarios are formulated for the entire basin and represent various levels of resource development in the various sub-basins during the next two decades. They are based national plans for water and related resource development of the Mekong countries, and assumptions regarding population and economic growth, investments and trade, poverty reduction, and other issues in national policies and socio-economic plans. They are presented in the table below and described briefly in the following.

Table 2.1 Mekong BDP development scenarios.

Baseline situation	Definite future situation	Foreseeable future situation	Long-term future
1. Baseline scenario	2. Upper Mekong 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, represents the development conditions (physical, socio-economic and management characteristics) that existed in the year 2000 and the hydro-meteorological conditions of the period 1985 – 2000.

The Definite future situation includes water resources developments in the Mekong system that are presently being implemented or in an advanced stage of preparation. Scenario 2 relates to the hydropower cascade that is presently being constructed in the Lancang in the Upper Mekong Basin, Scenario 3 relates to these dams plus all other definite water resources developments that are constructed or prepared for construction in the LMB.

The Foreseeable future situation represents the development conditions that could become reality in the next 20 years. Four scenarios are thought to be possible within this 20-year period. Scenario 4, the LMB 20-year plan scenario, comprises the definite future scenario 3 plus the current development plans of the LMB countries in the next 20 years, including the 11 presently studied dams on the mainstream and considerable increase in irrigation in Lao PDR and Cambodia, diversions from the mainstream to northeast Thailand and plans for flood management and mitigation. Scenario 5, LMB 20-year plan scenario, without mainstream dams comprises the current water resources development plans for the LMB countries, without the dams in the mainstream. Scenario 6 is similar to Scenario 5, but including the presently studied dams in the mainstream, downstream of Vientiane/ Nong Khai. Scenario 7, Mekong Delta flood management scenario equals Scenario 4, but includes additional flood risk reduction and drainage measurements in the Mekong Delta.

The Longer-term future situation represents developments that are plausible in 50 years from now. Scenario 8, the LMB long-term development scenario represents a continuation of present trends in hydropower development, irrigation, development of other water demands and population growth and economic activities. Scenario 9, the LMB very high development scenario, comprises the 20-year plan scenario, plus full potential development 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 will be assessed, as well as its contribution to achieving the Millennium Development Goals for sustainable development and poverty alleviation. Based on these assessments an IWRM-based Basin Strategy, consisting of a few strategic basin development options for meeting the water needs of all sectors, will be prepared. Table 2.2 gives the development sectors that are taken into account in the strategy development, as well as the main development objectives formulated for each sector.

Table 2.2 Development sectors and their main development objectives in the LMB.

Sector	Main objectives
Agriculture and irrigation	Safe food production, high value and high employment generated by agricultural water use
Hydropower	The increasing demand for affordable electric energy in the MRC member countries is met with minimal negative impacts on the environment and local people, thereby promoting economic growth for the countries' mutual benefit
Navigation	To increase the 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	Coordinated and sustainable development, utilization, management and conservation of the fisheries
Tourism	Regional water-related tourism further developed, with due regard to social and environmental impacts
Domestic and industrial water supply	Water available to people and industries in sufficient quality and quality
Flood management and mitigation	People's suffering and economic losses due to floods are prevented, minimized, or mitigated, while preserving the environmental benefits of floods
Watershed management	Effective management of watersheds by relevant institutions in accordance with the maintenance of relevant ecological, economic and social watershed functions

The first six sectors in the above table are elaborated in Chapter 3. Flood management and mitigation are discussed below (in this chapter). Watershed management covers many themes and has to be looked at from a higher level; this is therefore treated separately in Chapter 4.

The actual 'rolling' Basin Development Plan will consist of a combination of structural (investment) measures/ projects, supporting non-structural projects, and enabling projects, to develop the Mekong Basin's water and related resources and at the same time minimise harmful effects that might result from natural occurrences and human activities.

There are hundreds of water resources development projects existing within the LMB countries and many hundreds more are planned by the individual governments and the private sector. Over 300 of these projects have been included in de BDP 'long-list'. As already mentioned three different types of projects can be distinguished:

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

Another grouping of the projects applied in the BDP is the following:

- National projects without transboundary implications developed and implemented by one country. They can be either infrastructural, non structural or enabling projects;
- National projects with acceptable transboundary implications developed and implemented by one country. This category mainly comprises infrastructural projects, that benefit from cross border corporation under the Mekong agreement and projects that have (significant) adverse transboundary impacts that are acceptable to the riparian countries;
- Joint projects that are developed by the four LMB countries and that create basin-wide values and mutual benefits for the riparian countries. Most joint projects are non-structural or enabling projects, few are structural projects;
- Transboundary projects, developed between two or thee riparian countries. This category comprises non structural and enabling projects; and
- Controversial projects, mostly structural projects.

Of the projects on the long-list, 69 have been provisionally labelled ‘joint projects’. They have been grouped under seven provisional joint development areas, that are of relevance to all member states. The joint development areas identified are:

1. Mekong 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 Program;
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 offer the MRC the opportunity to start a dialogue on projects in a very early stage of planning.

2.2 Flooding in the Mekong basin

2.2.1 Flood characteristics

Seasonal flooding is an annually recurring phenomenon in the Lower Mekong Basin (LMB), a phenomenon which is of vital importance to maintain the inland fishery and agricultural production in the basin, as well as a variety of flood related ecosystem services. On the other hand, the yearly floods inflict damages on households, agriculture and infrastructure and result in loss of live and property. With growing population and economic development, the need for protection of people and their socio-economic activities against flooding has increased and flood management and mitigation projects are widely implemented.

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

1. Flash floods or tributary floods;
2. Main stream floods;
3. Combined floods affected by backwater from the main stream;
4. Floods in the Cambodian Flood Plain; and
5. Floods in the Mekong Delta.

In the (draft) document “Framework for the Development of Best Practice Guidelines for BDP”, Volume 2: “Background Information” another classification is given, which reads:

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.

It is noted that only the mainstream and tributary floods are equivalent to the above typology. Local floods and tributary floods do not differ much. Both result from heavy rainfall resulting in flows exceeding the drainage capacity and do not require extra attention. 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. Dambreak floods computations are standard procedures in dam design and if measures are required this will be part of the design. Storm surge floods are caused by typhoons and set up the water levels near the coast. These are implicitly included in the boundary conditions for defining floods in the Mekong Delta, and do not require special attention. Tsunami Floods require advance warning, which is not part of structural measures as envisaged to be developed under this Project. The first classification as presented in the Annual Flood Report 2005 (MRC, 2006) has been adopted by the FMMP-C2 project.

Tributary floods

Tributary floods are generally flash floods which occur in the steep sloped upper reaches of the basins due to 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 Vietnam. 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.

The simultaneous occurrence of a mainstream flood and a tributary flood will 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 are high, backwater flowing into the tributaries may occur. The character of these floods is not flashy; 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 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 infiltrating, weakening and lubricating the soil and 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 Vietnam vast areas of generally slow moving floodwaters inundate the floodplains of the Cambodian Lowlands and Cuu Long Delta for periods of up to 2-3 months or longer. Flood depths are up to 3 m or more. The 1998 Flood (‘small’) and the 2000 Flood (‘large’) covered some 25,000 km2 and 45,000 km2 respectively.

Depending on the duration of the flooding, the damage and disruption caused by mainstream floods in the Delta can be in enormous. Mainstream flooding in southern Lao PDR and Thailand, where inundation of the riverside floodplains lasts for only a couple of weeks, result in a much lower damage.

Floods in the Cambodian floodplain

The flooding in the Cambodian flood plain is related to the conveyance and storage of floodwater in the flood plains along the river stretch between Kratie and Phnom Penh, inclusive of the flooding around Tonle Sap Lake and the inflow to and outflow from the lake via the Tonle Sap River. Important aspects here are the spill levels of the rivers, the flood plain conveyance in relation with the road infrastructure and existence and dimensions of embankments.

Floods in the Mekong delta

The flood in the Mekong delta deals with the conveyance of flood water via the Mekong and Bassac Rivers and via their flood plains, including the use of colmatage canals to divert and control the flow from and to the River. In the delta the water levels rise slowly due to the storage in Tonle Sap Lake and in the Cambodian Mekong flood plains. The flood levels in the Mekong Delta in its downstream part are essentially the result of upstream inflow and downstream water levels at 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). Direct damages 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 properties and infrastructure such as houses, schools, offices, commercial and industrial buildings and installations, hydraulic works, energy, transportation and other infrastructures. These damages depend on the magnitude and duration of the flood;
- Crop damages: these depend on the depth, timing and duration of a flood; and
- Damage to livestock and agricultural equipment. This damage depends on the magnitude and duration of the flood.

Indirect damages, among others, are from:

- Costs of illness of humans and livestock related to poor environmental conditions and increased water-born diseases;
- Income losses due to disruption of economic activities and/or services by the flood for (i) individuals, landless labourers, families and enterprises; (ii) large commercial and industry enterprises that have been partly or fully closed down for some period during the flood;
- Higher costs of living due to temporary relocation, purchase food that otherwise would be available from the family farm, lack of basic supply as save water and electricity, additional cost for transportation and daily activities;
- Costs of temporary relocation and rescue, during and after the flood, to support affected people;
- 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;
- Other costs, including the negative impacts of flooding on tourism revenue, loss of social stability, problems in income distribution and confidence of people in the Government.

Numbers of persons killed and affected and total financial damages as a result of mainstream flooding in Cambodia and Vietnam as well as flooding in Lao PDR and Thailand for the years 2000, 2001 and 2002 are given in the report 'Best Practice IFRM Guidelines for the BDP, Volume 1: Framework for Development of Guidelines'. The figures are reproduced here in Table 2.3 and Table 2.4. Mainstream flooding in Cambodia and Vietnam in the period 2000-2002 caused some 1,300 fatalities and resulted in some $ 600 M in damage. The lives and livelihoods of a large number of people were affected. 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 Vietnam, 2000, 201 and 2002.

	2000			2001			2002		
Flood Impact	Cambodia	Vietnam	Total	Cambodia	Vietnam	Total	Cambodia	Vietnam	Total
Persons Killed	347	>500	850	62	256	320	29	71	100
Persons Affected (M)	3.4	5.0	8.4	0.6	1.0	1.6	1.5	0.3	1.8
Estimated Damage ($M)	160	290	450	36	?	>100	12.5	8.0	22.5

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

Flood impacts in Lao PDR and Thailand over the period 2000-2002 are lower than the impacts in Cambodia and Vietnam. Flash Floods are generally much more frequent and cause more damage than mainstream floods in Lao PDR and Thailand. Thai figures are not representative of 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, 201 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 (M)	0.4	2.3	2.7	-	2.8	-	0.06	3.3	-
Estimated Damage ($M)	20	70	90	-	48	-	-	40	-

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

2.2.3 Environmental impacts of floods

Under natural conditions flooding is part of the natural cycle of many ecosystems and plays an important role in maintaining ecosystem functioning and biodiversity. Society benefits from flooding because of the provision of a number of ecosystem products and services. This is described in 2.2.4. However, when human interference with the natural system disturbs the natural processes, flood events may result in long-term, undesirable impacts on the environment.

The desired condition of an ecosystem is long-term capacity to maintain biodiversity and ecosystem functioning. Because of the complexity of ecological systems, the assessment of ecosystem condition requires identification of a number of general indicators that can be measured or monitored over time. In the following a number impacts of flooding on ecosystem condition will be discussed. Impacts of floods that cause changes in ecosystem condition that contribute to degradation in the long term of either diversity or function are considered negative. It is important to take the time scale (long term) into account: in the short term, ecological impacts of a flood may seem very negative or even destructive, with death and injury or even local extinction of plants and animals, in the longer run it may turn out that this rejuvenation of the ecosystem works out positive and adds to ecosystem viability and biodiversity.

There are five main characteristics of a flood that together make up for the environmental impacts or risks of flooding. They are: the magnitude of the discharge, the velocity of the flow, the duration of the flood, the timing or seasonality of the event and the flood frequency.

Ecological impacts

Flooding not only has an impact on floodplain ecology, also the ecology of the river channel itself and the riparian zone may be affected. Besides, estuarine ecosystems and even coastal marine biota may be influenced. 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.

Water quality induced impacts

The quality of river water may change considerably during a flood. Turbidity levels of the river generally raise sharply as compared to the turbidity in low flow periods. High turbidity is primarily the result of the contribution of sediment rich surface runoff to the flood and erosion of the river bed and banks. However, also an increased growth of algae, induced by increased levels of nutrients, may add to turbidity. High sediment contents 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, a phenomenon that may be more serious when exotic plants that are intolerant of extended inundation are flooded, since decay of the organic matter extracts oxygen from the water.

Flooding of rural areas may result in increased levels of pesticides and herbicides and nutrients from fertilizers. This may certainly be the case when storage facilities of these agro-chemicals flood. Animal and human waste, either from open pit latrines or flooded septic tanks, contaminates the flood water with organic material and pathogens. High organic waste levels may result in reduced oxygen levels affecting aquatic life. Pathogen contamination is a 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, floating debris, may 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 filling stations, garages/ workshops etc. may form a source of pollution with hydro-carbons. Open solid waste dumps in or near urban areas are another source of organic, chemical and pathogen pollution, as well as of floating debris.

High nutrient contents, nitrogen and phosphorous, may be limiting to 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 kills and impact 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, e.g. 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 effected. 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 acting upon biota, for example, destruction of riparian vegetation (stripping) results in a decrease in size and connectivity of habitats and thus in reduced structural complexity of the riparian zone. Loss of the riparian 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.

Yet another form of physical processes inducing impacts is the spread of organisms with the flood water. Exotic species, e.g. floating weeds, can be flushed out of the river into the floodplains and become invasive in floodplain ecosystems over large areas. Flood events also may be important in the release of exotic fish species from outside aquaculture ponds.

Table 2.5 summarises risks of flooding for the environment and human health. Ultimately the final highest order impact (not given in the table) of the induced changes will be a loss of biodiversity and a reduced ecosystem functioning, including a reduction in stocks of fish for human consumption.

Table 2.5 Summary of environmental risks of flooding.

Impact cause	1st order impacts	Higher order impacts		
Change in water quality: due to e.g. bank and channel erosion, contaminants from agricultural or urban and industrial areas	• high sediment concentrations • elevated N and P 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 incl. hydrocarbons	• fish and other aquatic species mortality • reduced growth of native species • invasion of exotic species		
	• increased levels of pathogens	• impacts on human health		
	• floating debris	• esthetical impacts		
Physical disturbances				
• High flow velocities	• loss of riparian vegetation	• loss of habitat area • loss of habitat connectivity • direct loss of species	• reduced river bank stability	

Impact cause	1st order impacts	Higher order impacts		
• Deposition of (coarse) sediments	• coverage of flora and fauna	• 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 from ponds			

2.2.4 Benefits of flooding

Floods in the Lower Mekong River Basin can be destructive and cause enormous damages, this is especially the case for flash floods of tributaries and extreme mainstream flood events. On the other hand, moderate floods are clearly beneficial for the people living in 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 so 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 Delta in Vietnam. Recently the Government of Vietnam adopted a ‘Living with Floods’ Strategy for the Mekong River Delta. The strategy is based on the idea that ‘flood exploitation’, meaning that flooding is considered a natural resource that needs to be researched and exploited for local socio-economic development, seems to be a better approach in coping with floods than flood prevention (DDMFSC/ MARD, not dated).

The following benefits/ values of the annual (mainstream) flooding can be distinguished. Partly these benefits manifest themselves in the floodplains, partly they are related to conditions and phenomena in the river channels and the receiving coastal waters.

1- Increased agricultural productivity due to:

- Deposition of sediment, which improves the soil fertility. Mainstream floods deliver 79 M tonnes sediment per year to the delta, 9 – 13 M tonnes are deposited per year on the delta floodplains (25 – 35.000 km^2).
- Leaching of acidity (acid sulphate soils), toxic materials (pesticide residues) and salts and flushing of crop residues.
- Sanitation of agricultural land, the control of pests/ diseases. Harmful insects get killed and rodents concentrate in small, not inundated areas where they can easily be caught.

The importance of flooding for agriculture is illustrated by the results of Focal Group discussions held in the West Bassac Demonstration project area, as part of FMMP-C-2. It turned out that in the year after a year with a good flood, rice yields are about 1 kg/ha higher than after a year with a bad flood. In some areas an increase of 1.5 kg/ha was mentioned. Production cost was estimated to be the same after a year with a good flood as after a year with a normal flood. Overall benefit of the flood for agricultural production is estimated at 155 to 230 USD/ha.

Also in Vietnam Focal Groups reported higher paddy yields after a year with a high flood than after a year with a normal flood. After a high flood the yield is 0.3 to 1.5 ton/ha (4 to 20%, on average 0.7 ton/ha) higher. Not only the yields are higher, but also the related production costs are lower (15 to 20%), resulting in a net benefit of the flooding for agriculture of between 135 and 315 USD/ha.

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

- Maintenance of aquatic and terrestrial resource productivity:
  - Fisheries, roughly 1.5 M tonnes fish is caught each year in the Lower Mekong Basin. Another 0.5 M ton is produced by aquaculture and reservoir fisheries. The direct economic value of these are about 2 B US$/year (Johnston *et al*., 2003). About 2/3 of the LMB population is involved in fisheries one way or another: consequently fish is very important to the diet of the majority of he basin's population;
  - The annual flooding is very important in the life-cycle of most fish species: it triggers migration and spawning runs and provides migration paths and habitats to spawning and recruitment;
  - Collection of craft materials, fuels, construction material, medicines and raw materials by local population.
- Conserving biodiversity: the Mekong 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, closed channels etc. Groundwater is replenished. As such, wetlands act as reservoirs and sponges and even out water releases over time. 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 and so attenuate downstream flooding.
- Regulation of water quality, e.g. 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. As such 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 flow.

6- Improved possibilities for inland water transport/ navigation. This benefit of flooding is related to the maintenance of the river morphology mentioned under 5-.

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 waterbodies 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 discharge. High discharges are important in 'pushing back' the salt water tongue.

9- Delta growth. About 60 to 70 M tonnes of sediment are discharged into the coastal waters in Southern Vietnam. This results in a delta growth of 150 m per year.

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

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

Above given benefits are either direct benefits or values of flooding or indirect benefits/ values. The direct benefits include the flood based of flood depending production of raw materials, which are used directly for consumption or sale, such as those providing energy, food, (agricultural products, fish), timber, medicines, etc. Indirect values are flood related services that maintain and protect natural and human systems, such as maintenance of water quality and flow, flood control, nutrient retention etc.

Next to direct and indirect benefits/ values, two other value categories can be considered: option values and existence values. Option values can be defined as the premium placed on maintaining a pool of flood-based or flood-dependent species, genetic resources and landscapes for future possible uses. Some of these uses may not be known yet, such as leisure, commercial, industrial, agricultural and pharmaceutical applications. Existence values are intrinsic values of flood-related ecosystems. They can not be related to current or future uses, but represent a cultural, aesthetic, heritage and bequest significance.

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

Table 2.6 Total benefits/ values of flooding and flood related ecosystems.

Use benefits/ values	**Non use benefits/ values**
Direct values Outputs that can be consumed or processed directly, such as agricultural products, fish, timber, fodder, fuel, non-timber wetland products, medicines, wild foods, etc.	Existence values Intrinsic value of resources and landscapes, irrespective of its use such as cultural, aesthetic, bequest significance, etc.
Indirect values Ecological services, such as regulation of water flows and supplies, nutrient retention, flood control, salinity control etc.	
Option values 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 Introduction

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 is the product of the likelihood of that event occurring and its associated consequences. In other words, flood risk can be describes as the impact of a nominated 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 broad terms, we can manage 'risk' by either reducing the likelihood of occurrence of the event or by ameliorating its potential consequences.

(Integrated) Flood risk management is defined as an approach to identify, analyse, evaluate, control and manage the flood risks in a given area or system. A general scheme for flood risk management is presented in Figure 2.1. The following steps are identified:

- Definition of the system, the analysed hazards and the scale and scope of the analysis;
- A quantitative analysis to assess the probabilities and consequences of flooding, followed by calculation of the risk by combining probabilities and consequences en display of the results in a risk number, a graph or a flood risk map;
- Risk evaluation: with the results of the analyses described under the second bullet, the risk is evaluated and a decision is made whether the risk is acceptable or not.
- Risk reduction and control: dependent on the outcome of the risk evaluation, measures have to be identified and implemented to reduce the risk. Either structural or non-structural measures or a combination of the two can be applied.

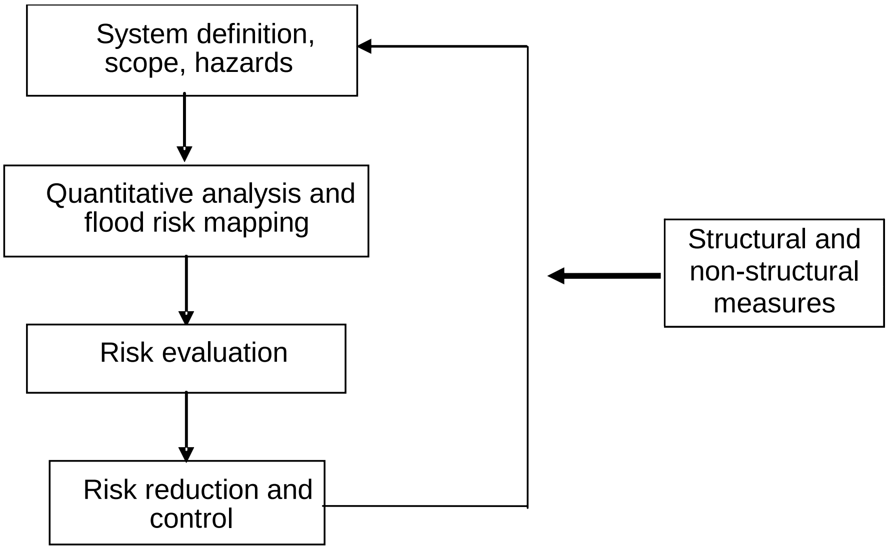

Figure 2.1 General scheme for flood risk management.

The 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).

Then the approach will focus on multiple objectives: not only to minimize the risk, but also maximize the performance (e.g. drought minimization, water quality, or possibility of fishery).

The concept of flood risk assessment generally refers to the second step, i.e. the quantitative analysis of the level of flood risk in an area or basin, and this report focuses on that step. Other guidelines/ reports give insight in possible measures and approaches for evaluation (see Section **Error! Reference source not found.** for an overview of other guidelines).

2.3.2 Flood risk assessment

In this context also the terms hazard and vulnerability are often used. Hazard refers to the source of danger, i.e. the (probability of) flooding. Vulnerability relates to potential consequences in case of an event.

For the identification and mapping of flood risks a procedure as shown in Figure 2.2 and explained below has to be followed:

- System definition and collection of basic data
  The first step is the 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).
- Flood hazard analysis
  The second step is the 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.
- Vulnerability and damage assessment
  In the third step potential damages in the areas prone to flooding are analysed, 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 on the flood plain, 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.
- Risk determination and flood risk mapping
  In the final step the flood risk is determined by combining the results of the flood hazard analysis, that gives 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.

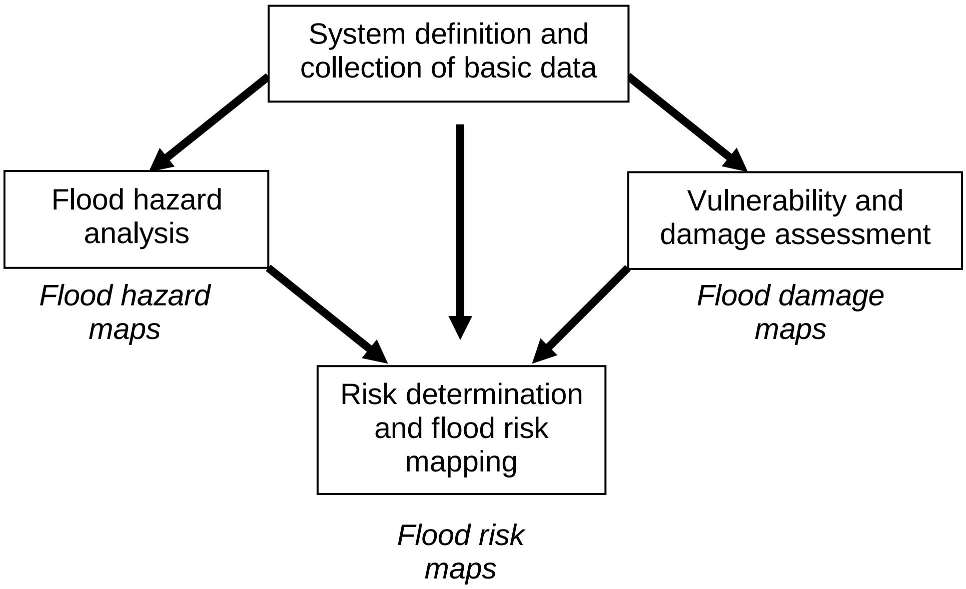

Figure 2.2 General scheme for flood risk assessment.

The scheme presented in Figure 2.3 basically covers the same steps. It schematically shows how meteorological information in combination with watershed and river information is used to determine the hydrological and flood hazards. By relating the flood probability to the vulnerability of the affected area the damage is determined. When the return periods of different flood events are included, the probability of a certain damage, i.e. the risk, results. Finally, it can also be evaluated how different structural or non structural measures, can reduce the risk.

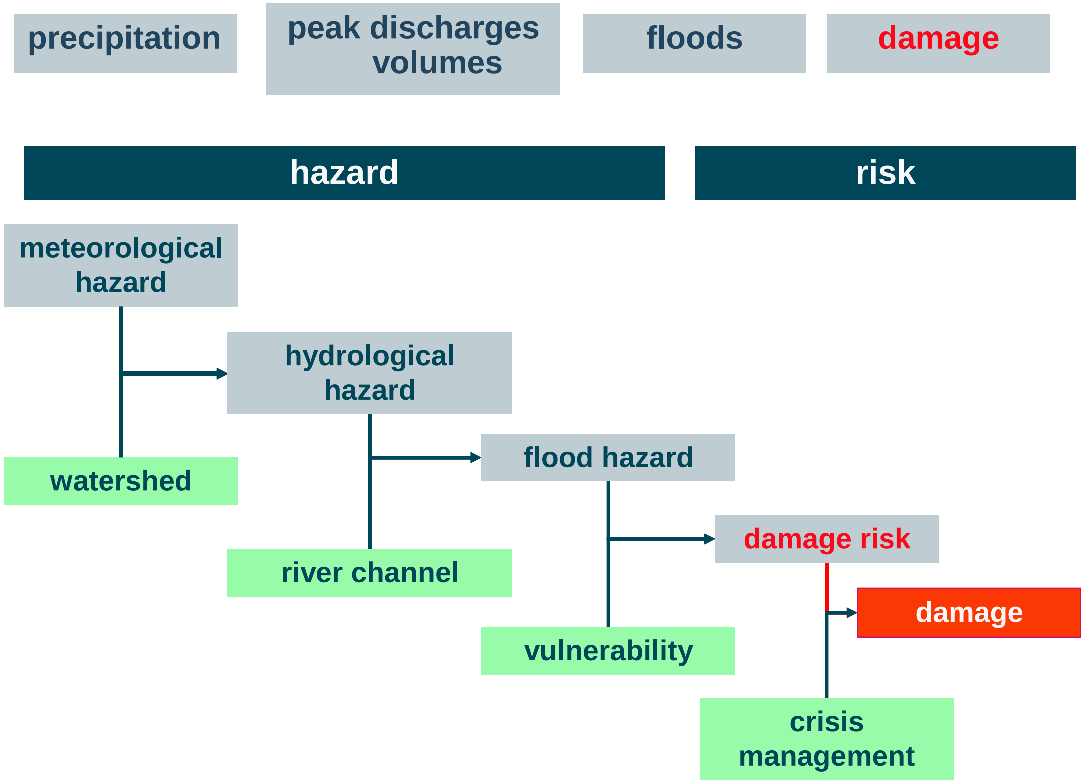

Figure 2.3 Schematic overview of flood risk assessment as applied in FMMP-C2

2.3.3 Flood risk in the Lower Mekong Basin

In FMMP-C2 four main damage categories have been distinguished for risk assessment purposes:

1. **Loss of life and injuries,** includes number of people killed, missing and injured by the flood; treatment costs for the injured persons;
2. **Damage to infrastructure and Relief,** including educational facilities and materials, medical facilities, materials and equipment, irrigation infrastructure, bank erosion, fisheries infrastructure and equipment, transport infrastructure and equipment, communication infrastructure and equipment, industrial infrastructure and equipment, construction materials and equipment, drinking water and sanitation infrastructure and equipment, rescue operations, support and relief;
3. **Damage to houses,** including collapsed and swept away houses, partly damaged or submerged houses, damaged roofs and other private property damage, cultural & historical structures, offices, small industrial units, markets and commercial centres and warehouses; and
4. **Agricultural damage,** including damage to rice crops, flower and vegetable crops, other annual crops, perennial crops, large and small livestock and poultry, damaged agro-chemicals and erosion of farm land and housing 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 Delta, reference is made to the Best Practice Guidelines for Flood Risk Assessment in the Lower Mekong Basin, developed under FMMP-C2.

2.3.4 Risk determining factors

Above has been described that flood risk is determined by both flood hazard and flood damage. This implies that to be able to assess the impact on flood risks of socio-economic development plans, programmes or measures, as incorporated in the Basin Development Plan project portfolio (the focus of these IFRM guidelines for BDP, see Section 1.2) a distinction has to be made between impacts on the flood hazard and impacts on the potential damage.

An impact on the flood hazard results when either the meteorological hazard or the hydrological hazard changes as a result of a development. The rainfall parameters that are of importance are the distribution of de rainfall over the catchment and over time, the total rainfall amount and the rainfall intensity. However, rainfall is considered not to be affected by developments in the basin, as foreseen in the BDP. The only exception could be the (unintentional) changes in rainfall patterns and amounts that could result from large scale land cover/ land use changes. Changes in rainfall patterns and amounts that have an origin unrelated to developments in the basin, like global warming or the El Nino effect, are also not taken into consideration.

Hydrological hazard is determined by peak flow and flood volume, taking into account their interrelationships. Of importance for the final risk related to the flood hazard is also the timing, of the peak flows. In other words hydrological hazard is by those developments that have an influence on:

- Interception by foliage, which retains some water, subsequently transformed into evapotranspiration;
- Evaporation and evapotranspiration either from ponds, lakes, free water surfaces, from the soil surface and from the basin's vegetation;
- Surface water storage capacity, either in small surface irregularities or larger depressions, wetland areas, but also manmade ponds, embanked areas etc.; and
- Soil infiltration rate/ runoff coefficient, influenced by e.g. the sealing of the soil and determining the ratio between infiltration, direct overland flow and delayed overland flow.

To determine the flood hazard peak flow statistics have to be translated in water levels. Usually a hydraulic model is used for this purpose. How the hydrological hazard translates into a flood hazard depends on the physical characteristics of the river channel and the adjacent floodplain. Important in this respect are:

- The hydraulic radius as a measure of a river channel flow efficiency. Flow speed along the channel depends on its cross-sectional shape (among other factors), and the hydraulic radius is a characterisation of the channel that intends to capture such efficiency. It is defined as river cross section area divided by the wetted perimeter;
- The (hydraulic) gradient of the river, 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, a measure for 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 parameter determines the amount of water that will be stored on the flood plain at a given water level. Of special importance are embankments. 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 discussed above;
- The number and type of land use functions affected and their value; and
- The susceptibility of land use functions against 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 flood water; and
- The duration of the flooding.

These characteristics of the flooding follow from the flood hazard assessment.

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 summary, any basin development that results in a change in land use, land use value or susceptibility to flooding will have en impact on the final flood risk.

CHAPTER 3

DEVELOPMENT SECTORS AND FLOOD RISK

3 DEVELOPMENT SECTORS AND FLOOD RISK

3.1 A first screening

The overall development objective of the Basin Development Plan will be achieved via development initiatives generated and/or promoted under the BDP in the following sectors as already described in 2.1:

1. Agricultural 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 sector developments will have an impact on both hazard and vulnerability. Table 3.1 shows whether developments in each of the sectors affect hazard, potential damage or both.

Sector developments can be screened on their impact on the flood risk by applying Table 3.2. In this table a distinction is made between no change, minor, moderate and major changes in either the catchments, the river channel or the floodplains. Minor impacts are not thought to have a significant impact on flood risks, moderate changes may have significant impacts at the level of sub-basins, major changes may have an impact on the flood risk at the level of the whole basin.

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

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/ Hydrological hazard				
- Rainfall interception				
- Evapotranspiration				
- Surface water storage capacity				
- Runoff coefficient				

Is there a change in:	Magnitude of change			
	No	Minor	Moderate	Major
2- River channel characteristics/ Flood hazard				
- Hydraulic radius				
- Hydraulic gradient				
- Sinuosity				
- Roughness				
- Presence of flow obstacles				
3- Floodplain characteristics/ Potential damage				
- Flood characteristics (result from 2)				
- 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				
- Land use type				
- Value of land use type				
- Susceptibility of the land use type				
- Floodplain area				
- Presence of flow obstacles				

In the following chapters the impact of developments in the various BDP sectors will be elaborated in more detail.

3.2 Agricultural and irrigation

3.2.1 Introduction

In the following a distinction will be made between agriculture development in the catchments and agricultural development (mainly irrigation) in the floodplains. Agricultural development in the catchments has an impact on the hydrological and flood hazard, irrigation development in the floodplains influences both the flood hazard and the potential damage of the area under development.

3.2.2 Agricultural development in the catchments

Agricultural development in (upper) catchments quite often involves deforestation or taking into cultivation shrub or grassland areas. 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. In Chapter 4, Watershed management, a detailed explanation of these changes is given, here only the final hydrological hazard related aspects are discussed.

A forest cover intercepts 15 to 25% of the rainfall that evaporates from the leaves. Furthermore trees root deeper and have 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. As a result the total annual streamflow from agricultural lands is higher than that of forested areas. Not only the amount of streamflow changes after forest conversion, also the timing and distribution of the flow over wet and dry season flow commonly changes.

Forest soils have high organic matter contents and consequently a high infiltration rate. When taken into agricultural production these soils quickly lose organic matter and the soil structure deteriorates. Infiltration rates decease and a larger part of the rainfall will not infiltrate, but transforms to surface runoff and leaves the catchment as quick flow. As a consequence peak-flows from agricultural lands are steeper and higher than peak flows from forested catchments (other conditions like rainfall characteristics, soil types, slpe steepness etc being the same). Reversely, but not of interest from a point of view of hydrological hazard, dry season flows from agricultural lands are lower than from forested areas. The effects of land use change described above increase with the type of land use as follows natural forests < man-made 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/ land use change on the hydrological hazard.

Table 3.3 Impacts of agricultural development on the hydrological hazard.

Measure	Functioning/ mechanism	Impact in hydrological hazard
Landuse change/ deforestation	- Decreased interception - Decreased evapotranspiration - Decreased infiltration - 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 being lowest in natural forests and usually highest on crop lands and areas with uncontrolled grazing according to the sequence given above. For details see Chapter 4, Watershed management.

Higher soil erosion rated result in a higher sediment delivery to the river channel, at the equilibrium between sediment supply and sediment transport capacity of the river is likely to be disturbed. As a consequence the river start to silt up which results in changes of a number of the river channel characteristics (e.g. hydraulic radius, hydraulic gradient, roughness) that are determining 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/ Hydrological hazard		
- Rainfall interception	X	
- Evapo(trans)piration	X	
- Surface water storage capacity		X
- Runoff coefficient	X	
2- River channel characteristics/ Flood hazard		
- Hydraulic radius	X	
- Hydraulic gradient	X	
- Sinuosity		X
- Roughness	X	
- Presence of flow obstacles		X

3.2.3 Irrigation development in the floodplains

Agriculture is a very important contributor to and driver of the economic growth in the riparian countries. Presently there is significant development of irrigation in the basin, and potential for new developments is still large, particularly in Cambodia. According to the 20 year development scenario irrigation on more than 5 million ha land can be supported. In Cambodia tributary basins as well as the floodplains of the lower Mekong and Bassac rivers have potential for new and improved schemes, in Lao tributary floodplains can benefit from the hydropower developments, in Thailand there is scope for improvement of existing schemes and although the Vietnam delta is already heavily developed, there is still room for some expansion.

Irrigation development 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, so affecting the conveyance capacity of the floodplain, the ability to convey flood water 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.

In the Cambodian floodplain three types of agricultural embankments can be distinguished. Rain-fed embankments are constructed to pond rainwater for rainfed crops; they are usually between 0.6 and 1 m high. They are usually 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 are to store floodwater in the wet season for use in the dry season. As such they do not decrease the floodplain storage and so the flood hazard. Embankments along irrigation canals are usually about 4 m high; along main canals they may reach heights of 6 m. They may seriously impede the passage of flood flows.

The third type of embankments is called colmatage embankments, which are in fact polder dikes that inhibit the downstream flood flow over the floodplain and have a significant impact on the flood conveyance.

The WUP-TLSV study simulated the impact of embankment along the banks of the Mekong River between Kampong Cham and Phnom Penh. Embankment construction along the left bank turned out to increase the flood spill over the right bank with about 15%, whereas water levels near Phnom Penh would rise with about 0.35 m. Embankment of the right bank increase water levels near Phnom Penh with about 0.20 m. Embankments on both sides of the river would increase water levels near Phnom Penh with 0.5 m.

It will be clear that embankment has consequences for flood levels and duration downstream or on the other side of the river. Also on site the reduced storage area and flood flow impediment may have impacts on the flood hazard: the depth of flooding may change, as may the speed with which the flood rises and flow velocity of the water 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/ Hydrological hazard		X
- Rainfall interception		
- Evapo(trans)piration		X
- Surface water storage capacity	X	
- Runoff coefficient		X
2- River channel characteristics/ Flood hazard		
- Hydraulic radius		X
- Hydraulic gradient		X
- Sinuosity		X
- Roughness		X
- Presence of flow obstacles	X	
3- Floodplain characteristics/ Potential damage		
- Flood characteristics (result from 2)		
- 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	
- Land use type	X	
- Value of land use type	X	
- Susceptibility of the land use 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: these may go up. Two final impact have to be mentioned: firstly groundwater levels in irrigated areas tend to rise. This means that intensive rainfall will easier result in flooded conditions than in areas without irrigation. Secondly, structures build for irrigation/ drainage may form obstacles to flows and result in increased water levels.

Potential damage in an area vastly increases, once it becomes more developed for agriculture. Not only the potential crop damage is higher, but also the potential damage to all kinds of irrigation and drainage infrastructure, access roads etc. A detailed methodology for the assessment of potential damages in agricultural areas is given in the Best Practice Guideline for Flood Risk Assessment.

3.3 Hydropower

3.3.1 Introduction

Hydropower can be produced by using the artificially created head downstream of a storage reservoir or by low head-run-of-the-river hydropower plants. Although run-of-the- river plants are being considered in the Mekong basin, they will not be discussed here, since they will not affect the hydrological hazard, nor the flood hazard and consequently not the flood risk.

Construction of storage reservoirs for hydropower production is an ongoing activity in the Mekong Basin. The Lower Mekong basin has an estimated potential for hydropower development of about 30,000 MW. Only about 2, 000 MW, or 7% of the potential is presently developed. The Mekong Basin as a whole has a hydropower potential of 53,000 MW of which 9.4% is developed already. Economic growth will sharply increase the power demand in the years to come.

In the Upper Mekong basin China is completing a hydropower cascade of 8 reservoirs on the Lacang. Of prime importance are the Xiaowan and the Nuozhadu reservoirs, with active storages of 9,800 and 12,400 million m3 respectively. Total active storage is of the China dams, after completion of the cascade, will be over 30,000 million m3.

Not only in China but also in Lao PDR new storage reservoirs will very likely be constructed. Total active storage could be well in the order of 10,000 million m^3.

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

3.3.2 Hydrological hazard

Storage reservoirs build 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 will be released to produce power, only when there is a demand. This demand is year-round, but usually fluctuates over the day or week, depending on the nature of the most important power consumers.

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

As a consequence, hydropower reservoirs have an impact on the flow regime:

- Reduced seasonal variability of flow, i.e. low flows increase and high flows decrease; and
- Increased flow fluctuations at and hourly and daily time step.

The impact on high flows depends on the magnitude of the stored volume as compared to the flow volume in the downstream river. The impact of on the low flows is very much determined by the volume of the releases as compared to the low flow discharge in the receiving river. It will be clear that large reservoirs in small basins have a much higher impact than large reservoirs, and of course also small reservoirs, in a large catchment. Moreover, impact will be biggest directly downstream of the dam side and will decrease with distance downstream.

In this respect the impact of 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 has been investigated with hydrologic and hydraulic simulation models and an accompanying Decision Support Framework for four scenarios. Total active storage capacity in these scenarios varied between 22.3 (low development) and 47.6 km3 (high development) as compared to an active storage volume in the base case (situation in the year 2000) of 5.7 km3. Impact on annual peak levels (for the lowest, the average and the highest peak flow level in the period 1986-2000) was calculated for 5 water level monitoring stations along the main river.

As was to be expected, impacts on flood levels of the China dams scenario (total active storage volume of 28.5 km3) are greatest in the upstream reaches and decrease gradually downstream with increasing discharge from uncontrolled tributaries. The reduction in average annual peak level of 1.81 m predicted for Luang Prabang decreased to 0.22 m at Pakse and to less than 0.1 m in Tan Chau.

For the maximum storage scenario (47.6 km3) 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 simulated. Table 3.6 gives the details.

Table 3.6 Impact of hydropower development on flood levels.

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

As stated already, impact of large storage reservoirs in smaller catchment may have a more significant impact on peak flows. After completion of Nam Theun-2 daytime releases to the Se Bang Fai will be about 300 m^3/sec, which is significant compared to a peak flow maximum of around 2,000 m^3/sec.

3.3.3 Flood hazard

Storage reservoirs disrupt the natural flow of sediments. With decreasing stream velocity in the reservoir the sediment transport capacity of the flow decreases and suspended sediments drop out. Bed load of a river entering a reservoir is usually deposited at the reservoir inflow, 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.

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. In other words, 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 the reservoir will increase, and floodwaters will be routed faster downstream, so reducing flood hazard downstream of the reservoir. On the other hand, 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. Manwan Dam, the first dam in the Lancang Cascade was closed in 1993. It had a very significant impact on the sediment flux downstream along the Lower Mekong. It has a sediment trapping efficiency of 68% and as a result of the dam construction the sediment flux at Chiang Saen, 660 km downstream has more than halved from 70 million ton per year to 31 million ton per year. Impacts are noticeable as far downstream as Pakse, where post Manwan Dam sediment average annual sediment loads are 20% lower than pre-Manwan loads.

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

Impacts of tributary dams may be significant as well but will 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/ Hydrological hazard		
- Rainfall interception		X
- Evapo(trans)piration		X
- Surface water storage capacity	X	
- Runoff coefficient		X
2- River channel characteristics/ 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 the people of the basin to access different areas of the basin, to move goods 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. Low transportation cost are crucial in transport development, as such river navigation is though to play an important role in further transport development.

The MRC navigation strategy 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 South China Sea to China. Such interventions could be related to the construction of weirs and storage capacity and the improvement of the channel, e.g. deepening by dredging, re-alignment or removal of obstructions.

Improvement of the channel would have an effect on the flood hazard, since the hydraulic radius and gradient, as well as the river sinuosity are likely to change as a result of channel improvement. The overall effect of these kind of works is that the flood water is routed faster downstream, resulting in higher water levels downstream of the improved river reach.

Weirs will obstruct the flow and tend to increase flood water levels upstream of the weir. Downstream of the weir water levels will decrease and the river may tend to start eroding its bed.

The potential damage also increases as a result of developments in navigation. Floods may damage the 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/ 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 most abundant fisheries in he world. About 40 million people are engaged in fisheries in the basin. The value of the annual catch is estimated to be about 3 billion USD. Fisheries are very important for the livelihood and diet of the population of the basin, but is also of enormous economic importance.

A distinction has to be made between wild fish capture and aquaculture, the raising of fish in ponds, gages etc. Until now the capture fishery has been so productive that there has been little incentive for development of aquaculture. Moreover, until recently, poor infrastructure limited the distribution of fish feed, fingerlings and the produce of the industry. Nevertheless, aquaculture is a steadily increasing part of the economy and e.g. the delta in Cambodia is considered to have huge aquaculture development potential. Pond culture and fish farming in rice fields are steadily increasing in importance.

Developments in the Fisheries sector will not affect the hydrological and flood hazard, however, flooding may cause damage to the aquaculture ponds: when flood levels exceed the level of the embankments around the fish ponds or rice fields, the raises fish may escape into the wild. This implies an economic damage. In other words, developments in aquaculture increase the damage potential in the floodplains.

Procedures on how to assess these kind of potential damages are given in the Best Practice Guideline for Flood Risk Assessment.

3.6 Tourism

Very limited is known abut the expected developments in this sector. However, whatever the developments may be, impacts on the hydrological and flood hazard are not to be expected.

That only leaves an impact on the potential damage. Indeed, development of tourist facilities in flood prone areas will increase the potential damage and may pose more people at risk during flood events.

Procedures on how to assess these kinds of potential damages are given in the Best Practice Guideline for Flood Risk Assessment.

3.7 Domestic and Industrial water supply

Less than 40% of the population in Cambodia and Lao PDR has access to safe water, in the 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 Vietnam access to safe water is generally more widespread, both in urban and rural areas. The situation in the Mekong Delta is less good, there only about half the households have access to safe drinking water. The Millennium Development Goals target at a reduction with 50% of the proportion of people not having access to safe drinking water by 2015.

Very limited is known abut the expected developments 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 to be expected.

That only leaves an impact on the potential damage. Infrastructure for domestic and industrial water supply may be damaged by flooding and result in fairly significant indirect damages like diseases as a result of shortage of safe drinking water and production losses of industries that are forced to shut down due to unavailability of process water.

Procedures on how to assess these kinds of direct and indirect potential damages are given in the Best Practice Guideline for Flood Risk Assessment.

CHAPTER 4

WATERSHED MANAGEMENT

4 WATERSHED MANAGEMENT

4.1 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 plant, animal, and human communities within a watershed boundary.

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

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

4.2 Soil erosion control

As far as soil erosion is concerned, two different approaches can be followed: firstly, soil erosion can be prevented, secondly, it can be controlled. Prevention of erosion problems, i.e. keeping the erosion rates at tolerable levels, involves appropriate land use planning and the use of good farming practices. Erosion control, on the other hand, relates more to narrow based engineering approaches like runoff management.

Rational land use planning is the first consideration in keeping soil erosion rates at tolerable levels. Each land use type has its own magnitude of erosion risk, a risk which may turn into a problem if the land is used for purposes which it is not capable of sustaining. The land capability 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 gives the best protection against raindrop impact. Less steep slopes with less erodible soils can be used for a multitude of applications. Other factors being the same, the erosion risks increase with the type of land use as follows: natural forests < man-made forests < ungrazed pastures < controlled grazing < mixed cropping and crop rotation < monoculture cropping < excessive and uncontrolled grazing.

As upland erosion is caused mainly by the impact of raindrops and the shear forces of water flowing over the soil surface, effective prevention and control of erosion may be attained by reducing the impact of the raindrops, by increasing the shear resistance of the soil or by decreasing the shear force of the flowing water. In this way both the soil detachment and the transport capacity of the eroding agents are reduced. Figure 4.1 illustrates these principles of erosion prevention and control.

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

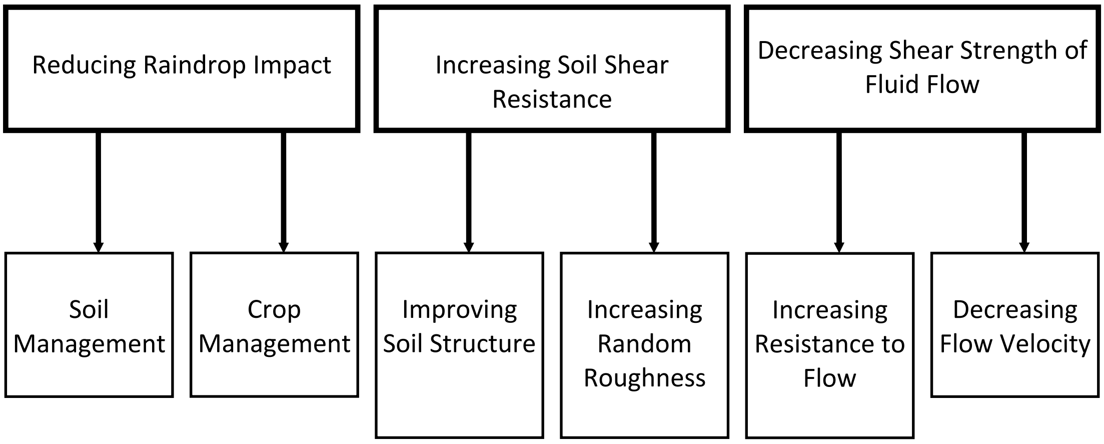

Figure 4.1 **Principles of erosion prevention and control.**

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

A decrease in the shear strength of the surface runoff and channel flow can be attained by either agronomic or engineering practices. These practices aim at reducing the amount and/or the velocity of the overland and channel flow. Agronomic measures that have to be mentioned are related to the way in which the soil is ploughed (contour ploughing) and the seedbed is prepared. The application of buffer strips, contour cropping etc. is effective in reducing overland flow velocities and in arresting sediment as well. Examples of engineering or mechanical measures are terracing, the construction of gully plugs, construction of retention basins and the construction of runoff disposal systems to remove excess water.

4.3 Restoration of hydrological conditions

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 on its turn to a large extent depending on the vegetation or land use. The infiltration and water-holding capacities of the soils depend on depth, organic matter content and aggregate distribution of the soil; parameters which are influenced heavily by soil erosion processes. Land use changes, catchment degradation and increasing erosion rates therefore affect the amounts of water entering the lower reaches of a river, as well as the timing and distribution of the streamflow.

Below some general information is presented on the hydrological response of drainage basins to reforestation, one of the most common watershed management measures.

Reforestation has many consequences for the hydrological behaviour of a watershed. The processes involved are very complex and interrelated and generally both the magnitude and distribution of streamflow are affected. A number of soil properties 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 losses. It will be clear that the catchment response depends strongly on the kind of conversion that takes place, a change from grassland to forest will have other consequences than a change from cropland to forest.

It is generally thought that reforestation increases the streamflow quantity and the amount of water available for human use. However, except for cloud-forest areas, where mist interception by tree canopies may increase the total amount of water reaching the forest floor, research proved 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 it can be stated that reforestation increases streamflow at a rate, generally proportional to the reduction of forest cover over the catchment. In humid areas reduced soil compaction, resulting in higher infiltration rates and lower surface runoff amounts, often compensate for the higher evapotranspiration losses. as a net result groundwater recharge increases, wet season storm-flows decease 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-flow, and also a marked delay in time to peaking. On very shallow soils the effect of reforestation on storm flow peaks and hydrograph form is often very limited.

Most watershed management projects or programmes consist of a combination of land use change, including reforestation, and construction of structures to reduce the erosive power of the eroding agents or to store surface runoff. The efficiency of watershed management is not always directly noticeable, usually on-site erosion rates decrease very fast after project implementation, effects on sediment yields and catchment hydrology may only become apparent on the long run, after several decades.

Table 4.1 summarizes the most common watershed management measures, and their effect on the hydrological hazard.

Table 4.1 Common watershed measures and their effect on the hydrological hazard.

Measure	Functioning/ mechanism	Impact in hydrological hazard
Landuse change/ reforestation	- Increased interception - Increased evapotranspiration - Improved infiltration - 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 - 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 - Reduced surface runoff	- Lower peak flows in wet season, higher discharges in dry season

Table 4.2 Summary of impacts of watershed management on flood risk.

Is there a change in:	Yes	No
1- Catchment Characteristics/ Hydrological hazard		
- Rainfall interception	X	
- Evapo(trans)piration	X	
- Surface water storage capacity	X	
- Runoff coefficient	X	

CHAPTER 5

REFERENCES

5 REFERENCES

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MRC Country Reports, Press Releases, NGO Reports, Web Reports.

APPENDIX

APPENDIX 1 THE BEST PRACTICE GUIDELINES AND PROJECT PHASES/ STAGES

In order to manage an engineering project properly, it is normally divided in project phases. Common is a division in the following five phases:

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

A project starts with an idea to solve or mitigate a problem, create a product or structure etc. In the initiation phase finances are mobilised, a project team is formed, the equipment and tools are acquired, and the idea is given its first shape. The second phase is the planning/ development/ design phase. The feasibility of the idea is tested, and, if successful, a project plan is elaborated and the design is made. In Phase 3 the plans and designs are implemented, i.e. the production takes place, the project is being executed. Monitoring during execution may reveal the necessity to correct the planning and/or design, and make adjustments in the execution. After completion of the works the project will be closed, i.e. the team will break up, the accounts will be closed, and the product or result may be handed over to a client.

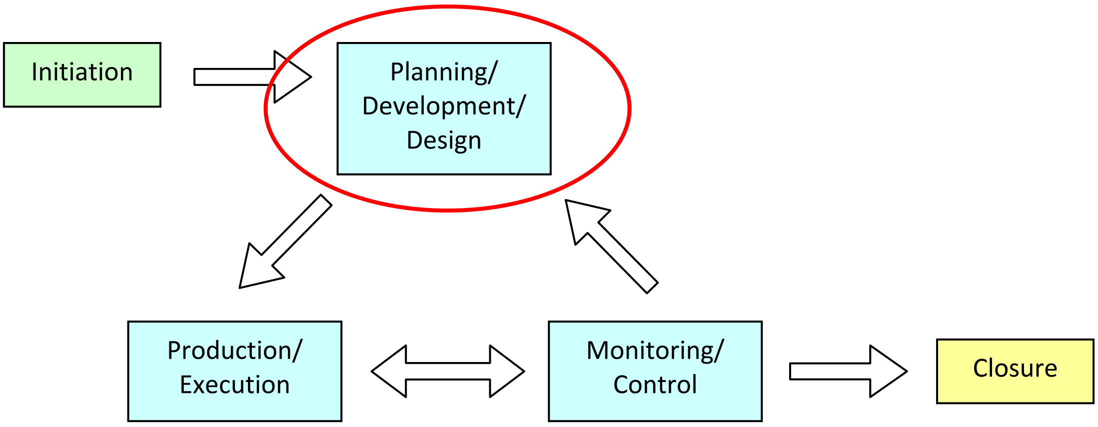


Figure 5.1 The phases of an engineering project.

The Best Practise Guidelines are almost exclusively applicable to Phase 2: Planning/ Development/ Design. This phase can be subdivided in various stages: see the list below. 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 in engineering projects often included in the feasibility study.

a) Preliminary/ prefeasibility study
b) Feasibility study & overall planning
c) Preliminary design
d) Detailed design & detailed planning
e) Construction/ bid documents

Each section of the guidelines applies to one or more of the above stages. In the guidelines this will be indicated by displaying the above symbols in the page margin.

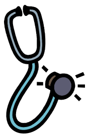
The five stages of Phase 2 contain the following:

a) Preliminary/ prefeasibility study

A prefeasibility 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 prefeasibility 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 stakeholders) policies, programs and activities;
- Preliminary assessment of the viability of alternative approaches;
- Preliminary identification of likely risks to feasibility and benefits (including risks to sustainability).

b) Feasibility study & overall planning



If a project is considered to be feasible based on the prefeasibility study, a more thorough feasibility study can start. A feasibility study defines the project and its objectives in detail, and look at various forms of feasibility:

• Technical feasibility:	Can the measures technically be realised in local context?
• Operational feasibility:	Will the implemented measures be manageable by the local people?
• Economic feasibility:	Is the cost-benefit analysis positive?
• Social feasibility:	Are the objectives and measures socially acceptable?
• Environmental feasibility:	Are the environmental impacts acceptable?
• Political feasibility:	Will the measures be supported by the politicians?
• 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, costs estimates etc. are the basis for answering the above questions. If the answers are positive, the operations/ management structure and management method will be defined, and any initial planning will be detailed.

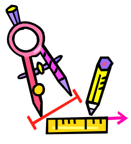
c) Preliminary design

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

- Site surveys and investigations and computer modeling provide the data for preliminary design criteria;
- The design criteria are translated into the preliminary design of structures and measures in an integrated and balanced system in which the envisaged management activities are geared to one another;
- A review of the cost-benefit analysis (construction and operation) and analysis of environmental, social and political factors still show the viability of the project.

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

d) Detailed design & 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.

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