THE MEKONG RIVER COMMISSION SECRETARIAT

Best Practise Guidelines for Flood Risk Assessment

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

December 2009

Draft Final Report

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UNESCO IHE

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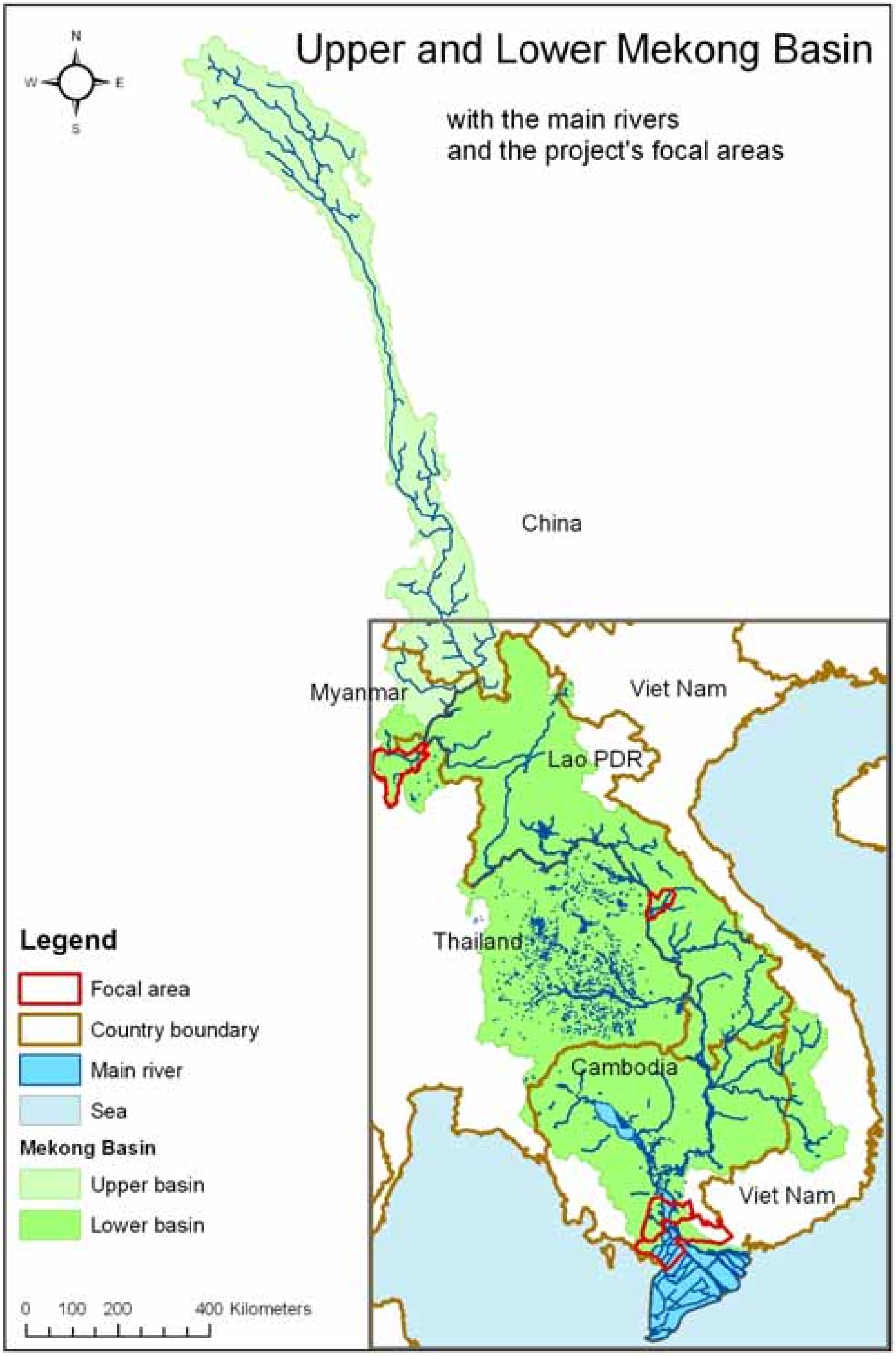
APPENDICES


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

IDW	Inverse Distance Weighting method: an interpolation method to obtain a continuous GIS-raster on the basis of data points (nodes), assigning most weight to nearby points by using their distance to the point to calculate(see also NN)
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
NN	Natural Neighbours method: an interpolation method to obtain a continuous GIS-raster on the basis of data points (nodes), assigning most weight to nearby points by calculating overlapping areas in Voronoi/ Thiessen polygons (see also IDW)
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).

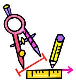
B) A project consists in general of five phases (see Section 1.6). Project FMMP-C2 encompasses only Phase 2: Planning/ Development/ Design. This phase can be subdivided in the following five stages:

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 3A** of the above series.

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[1] Developed by the Delft Cluster

1.2 Best Practice Guidelines for Integrated Flood Risk Management

The Best Practice Guidelines (BPG) for Integrated Flood Risk Management have been developed under FMMP-C2 to provide policy-makers, managers and FMM professionals in MRC and national line agencies with a common knowledge base to apply in:

- policy formulation,
- strategy and plan development, and
- project design and evaluation for flood risk management in the Lower Mekong Basin (LMB).

Each member country of the MRC has its own policy and legal frameworks that will guide or regulate the planning, evaluation and implementation of flood risk management plans and measures.

The BPGs do not attempt to summarize or replace these national guidelines, nor are they intended as a recipe for carrying out planning or project design for flood risk management in the LMB. Rather the BPGs will provide an information resource/ tool to be adapted according to each country and project context.

Basis for any attempt to manage flood risks in the LMB is a proper assessment of the actual risks to be managed. The best practice guidelines for flood risk assessment (BPG for FRA) in the LMB are therefore considered a key guideline.

1.3 Concepts in the Best Practice Guidelines for Flood Risk Assessment

1.3.1 Flood risk and flood risk management

In general the word risk refers to the probability of loss or harm. In the context of flood risk management it denotes the combination of the probability of a flood and its consequences. 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 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.

(Integrated) Flood risk management is an approach to identify, analyse, evaluate, control and manage the flood risks in a given system. A general scheme for flood risk management is presented in Figure 1.1. The following steps are identified:

- Definition of the system, the analysed hazards and the scale and scope of the analysis.
- A quantitative analysis where the probabilities and consequences are assessed and combined/ displayed into a risk number, a graph or a flood risk map.
- Risk evaluation: with the results of the former analyses the risk is evaluated. In this phase the decision is made whether the risk is acceptable or not.
- Risk reduction and control: dependent on the outcome of the risk evaluation, measures can be taken to reduce the risk. Measures could concern structural and non-structural measures. It should also be determined how the risks can be controlled and managed, for example by monitoring, inspection or maintenance.

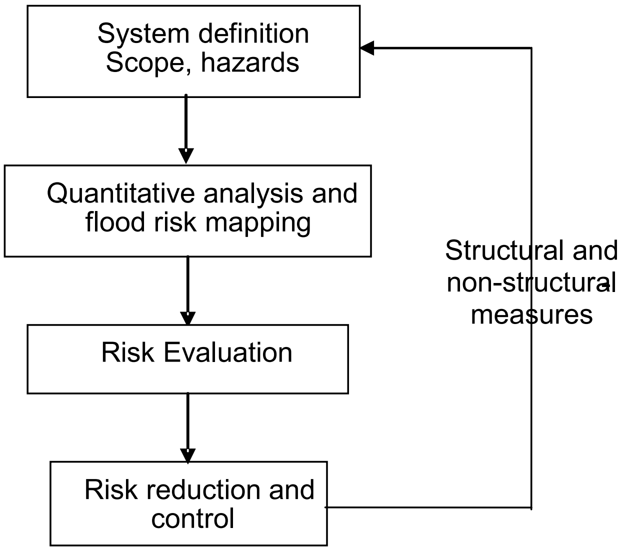


Figure 1.1 General scheme for flood risk management.

The scheme focuses on minimization of flood risks to an acceptable level. 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.

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 1.2 for an overview of other guidelines).

1.3.2 Flood risk assessment

The identification and mapping of flood risks requires information on several elements and steps. These are shown in Figure 1.2 and discussed in further detail below.

- **System definition and collection of basic data**
  The first step is the definition of the system and area studied and the collection of 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 meteorological events that may eventually lead to flooding. In connection with the characteristics of the respective watershed the hydrological hazard (peak discharges, volumes) is assessed that eventually may create the flooding. In connection with the characteristics of river channel and floodplain the flood hazard is assessed in terms of inundation area, depth etcetera. The results can be eventually displayed by means of flood (hazard) maps.
- **Vulnerability and damage assessment**
  The third step is the analysis of potential damages in the areas prone to flooding based on socio-economic data and a vulnerability / damage model.
- **Risk determination and flood risk mapping**
  In the final step the risk is determined by combining the results of the flood hazard analysis, that gives insight in the probability of a certain hazard, and the results of the damage assessment. These results can be displayed in different forms, e.g. by means of risk maps or graphs or risk numbers that give insight in the yearly expected damage.

These steps are separately elaborated in the sections in this report.

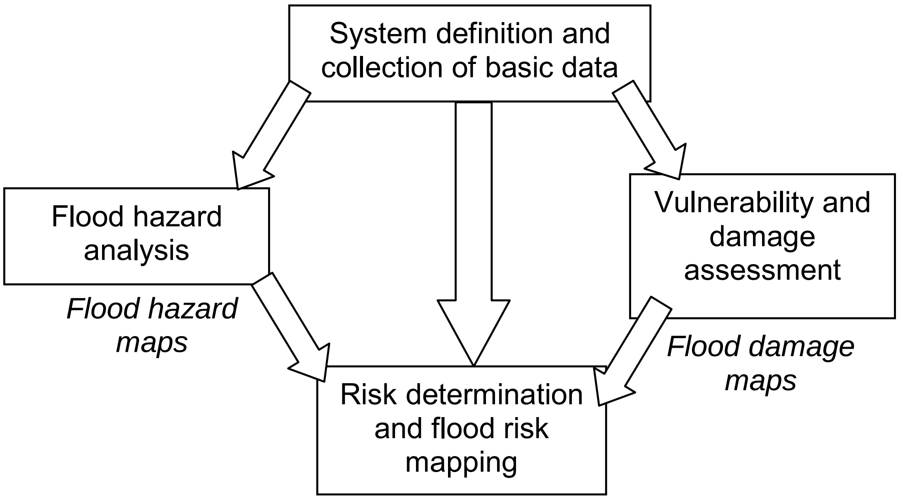


Figure 1.2 General scheme for flood risk assessment.

A related scheme is used throughout the FMMP-C2 project. It is shown in Figure 1.3 and basically covers the same steps as in Figure 1.2. 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 possible floods to the vulnerability of the affected area the damage can be determined. When the return periods of different flood events are included, the probability of a certain damage, i.e. the risk, is determined. Finally, it can also be evaluated how several measures, including crisis management can reduce the risk.

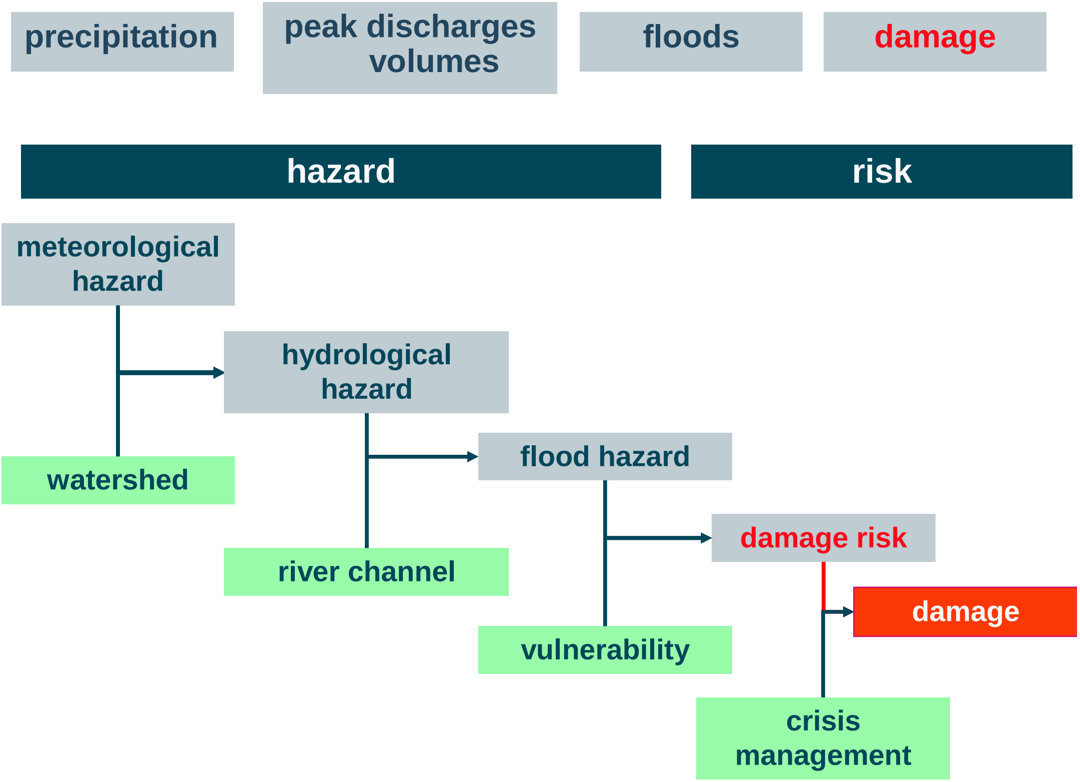


Figure 1.3 Scheme for flood risk assessment used in the FMMP-C2.

1.4 Basis of the Flood Risk Assessment Guidelines

The Best Practice Guidelines were prepared on the basis of:

1. a review of other guidelines or best practice documents in the field of flood risk assessments (see Appendix 1 of this BPG);
2. a review of existing guidelines in the LMB countries regarding damage assessments;
3. experience gained during the flood risk assessments made for the LMB focal areas during the Stage 1 of the FMMP-C2.

In Stage 1 of the FMMP-C2 a damage data collection and processing methodology was designed that could be expected to yield the required data for the LMB focal areas, given the availability of secondary data, time and budget constraints. The methodology was evaluated by the survey teams that did the secondary and primary data collection for workability and by the consultants as for providing the required information. Both concluded that the method was workable and suitable in the local context of the MRC-member countries and that the damage data could be used for processing into flood risks. For details on the FMMP-C2 damage data collection, see Annex 2 to the Stage 1 Evaluation Report.

Annex 1 to the Stage 1 Evaluation Report gives the details and results of the methodologies applied for the assessment of the flood hazards in the LMB focal areas; these are updated in Stage 2.

The guidelines for flood risk assessment will be further elaborated and tested during Stage 2 of FMMP-C2, especially through the demonstration projects and through feedback from the regional training courses.

1.5 Use of the Flood Risk Assessment Guidelines

Who should use the guidelines and what is the main use for which the BPG has been prepared?

1. The group of policy makers that will participate in the development of the flood risk management strategies at national and/or regional level.

2. The regional and/or basin planners that should be aware of the impact of development scenarios on flood risks and that should take flood risk management as an essential component of Integrated Water Resources Management. For this group also the IFRM BPG for Basin Development Planning (BDP) is of relevance.

3. The group that will participate in the preparation of flood risk management related projects, structural or non-structural. The guidelines can be used to generate field level flood benefits and costs that can be used as an input for project analysis. This project analysis itself is treated in the Best Practice Guidelines for IFRM Planning and Impact Assessment.

4. The group that will participate in multilateral dialogues regarding transboundary flood risk related impacts.

The BPG for FRA provide a set of methodologies for the assessment of:

1. flood hazards,
2. flood damages, and
3. flood risks.

These guidelines have the objective to combine theory and practice with specific emphasis on application to flooding in the Lower Mekong Basin. This document follows the general scheme for flood risk mapping (Figure 1.2). Section 2 describes the analysis of flood hazards and Section 3 focuses on flood damage and vulnerability assessment. Section 4 discusses how flood risk can be determined and displayed.
Within each section the following topics are discussed:

- The principles, concepts and terminology;
- Existing models to determine and quantify hazards, consequences or risk;
- The proposed approach for the Lower Mekong Basin;
- Examples of results from stage 1 of Mekong FMMP-C2.

These guidelines are intended to enable a consistent and uniform approach for flood risk assessment for several areas in the Lower Mekong Basin. The guidelines describe the theory and make the connection to the practice in the LMB by including examples of results of flood hazard, damage and risk assessments for a case study area. These guidelines do not prescribe all details of the methods and models in the risk assessment, but provide the principles and give an overview of the steps that need to be followed for a complete risk assessment.

The exact elaboration and application of the risk assessment depends on many factors, as objectives and scope of the assessment, available data and local situation (hydrology, land use). For example the type of flooding is crucial. Within the Lower Mekong Basin several types of flooding can occur, such as tributary floods, main stream floods, or floods in the floodplains (see Section 2.2). Each type of flooding is associated with particular flooding processes, like flood duration or flow speed, and these determine (among others) the details of the flood hazard analysis.

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 5.

CHAPTER 2

FLOOD HAZARD ASSESSMENT

2 FLOOD HAZARD ASSESSMENT

2.1 Introduction

There is a variety of measures available to prevent or reduce damaging effects of flood hazards. Whether or not these measures are effective strongly depends on the system under consideration. It is therefore vital to have a clear understanding of the processes involved. For each area of interest the following questions (among others) need to be addressed:

- What type of floods does occur?
- Where does the water come from and where does it flow to?
- Which quantities are involved?
- Which system characteristic influence the flow of water?
- How frequent do floods occur?

This type of analysis is referred to as “flood hazard assessment”. Chapter 2 presents the basic guidelines in flood hazard assessment for the Mekong river basin. Section 2.2 presents a classification of different types of flood events in the Mekong basin. This classification is relevant because the different types require different guidelines. Sections 2.3 - 2.6 each present the guidelines for a separate type of flood. The guidelines are clarified with a number of examples for selected “focal areas” in the Mekong basin.

2.2 Classification of type of flood

A classification of floods is used as applied by the MRC for the Lower Mekong Basin, including:

- Tributary floods,
- Main stream floods,
- Combined floods,
- Floods in Cambodian flood plain, and
- Floods in the Mekong delta.

The Mekong basin is divided in sub-basins numbered from 1 to 10: see Figure 2.1. An overview of the location where different flood types occur in the Mekong Basin is given in Figure 2.2. The flood types are described in more detail below.

Tributary floods that occur in the steep sloped upper reaches of the basins are generally flash floods, caused by 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. Effects of flash floods, when accompanied with landslides, are equivalent to dam break waves. Further downstream, in the middle sections of the tributaries the flashiness reduces, but the flood levels are not affected by backwater from the Mekong, like in the Nam Mae Kok at Chiang Rai.

Mainstream floods are floods along the Mekong caused by high water levels on the Mekong. The hydrological hazard is determined by the flood peaks responsible for the maximum water levels, whereas the flood volumes are of importance when flood duration is considered. Mainstream floods occur at a number of locations along the Lower Mekong between Chiang Saen and Kratie.

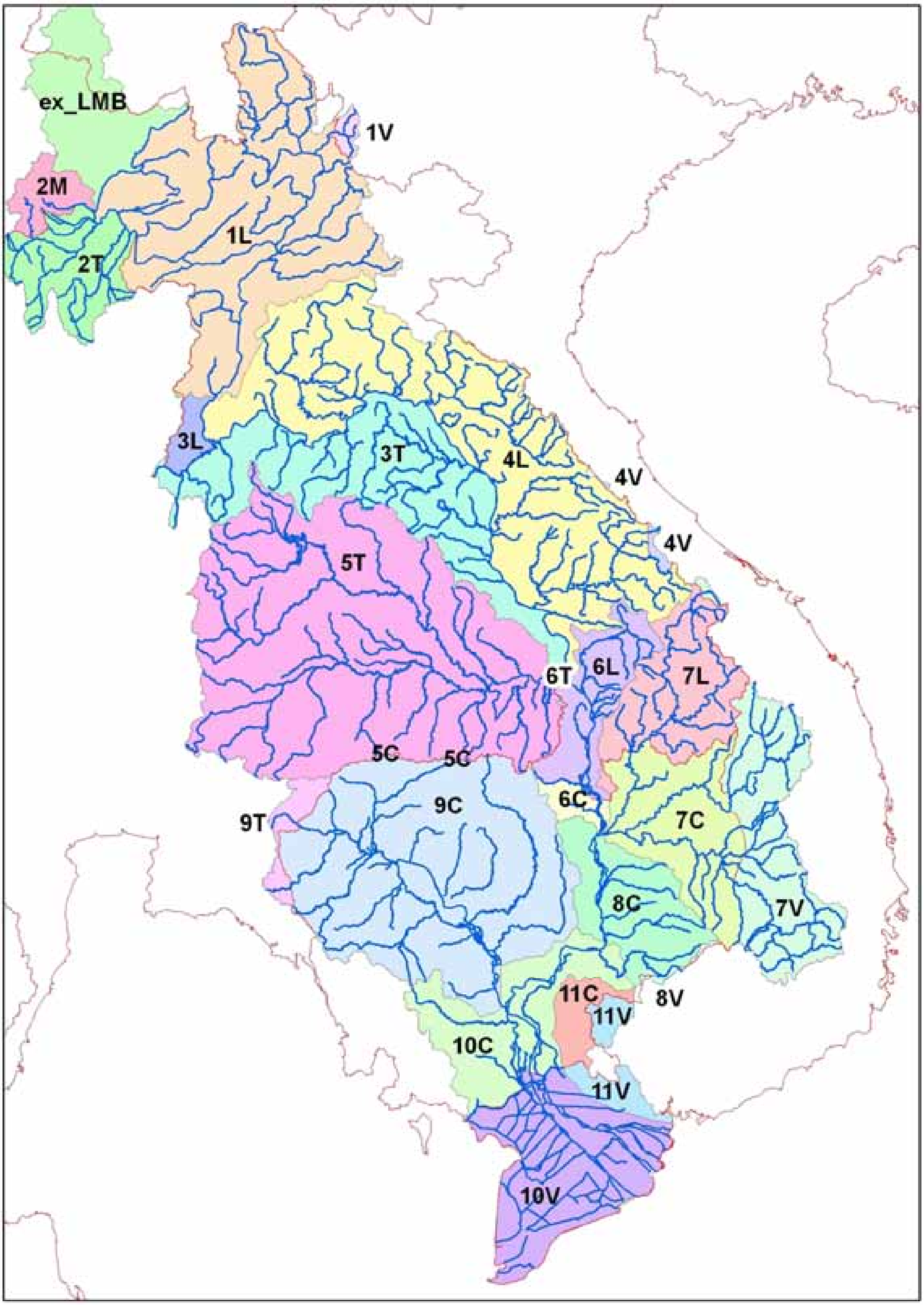


Figure 2.1 The sub-basins or sub-areas in the Lower Mekong Basin; the letters refer to the countries (M= Myanmar, T = Thailand, L = Lao PDR, V = Vietnam, C = Cambodia).

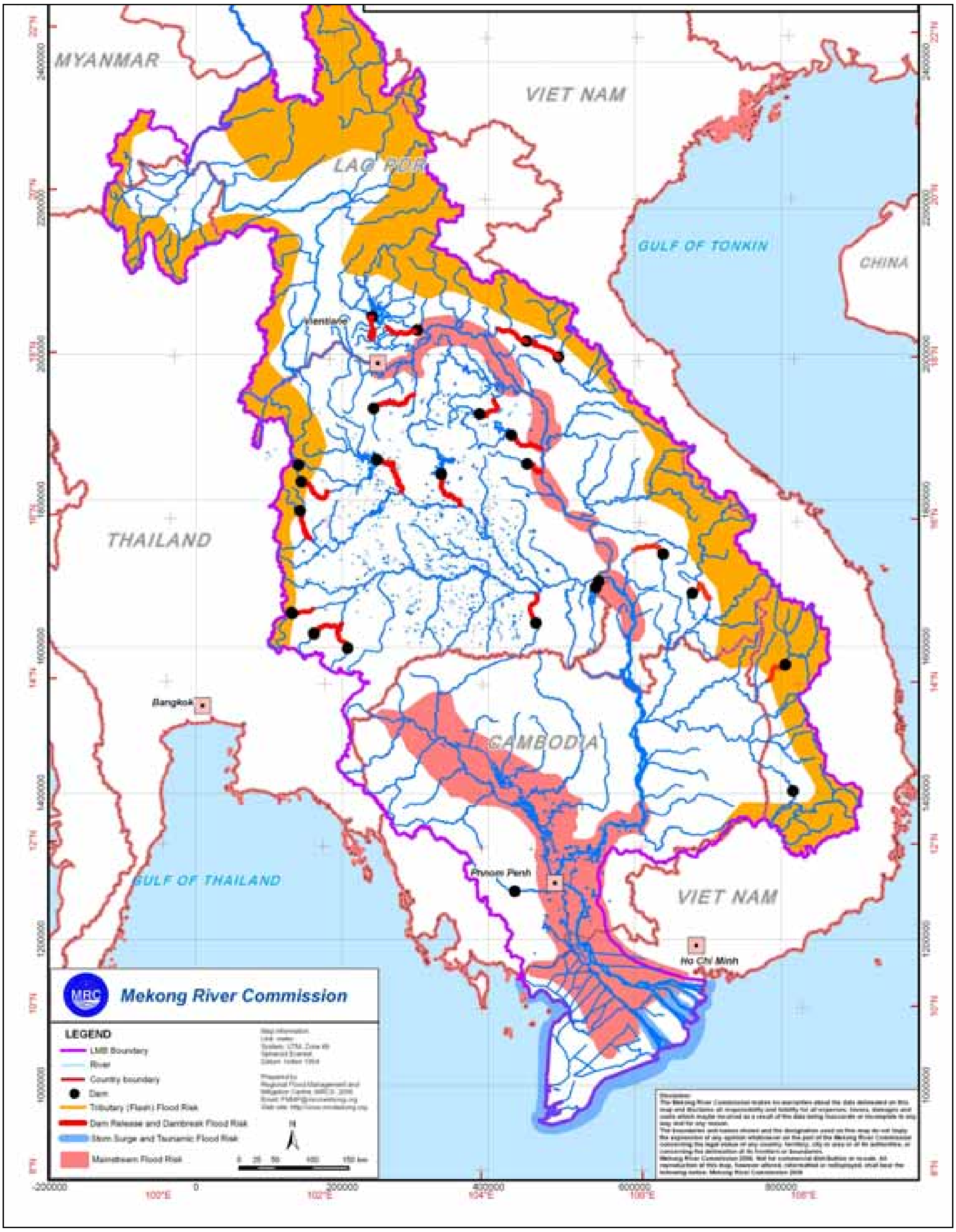


Figure 2.2 Overview of flood types in the Mekong River.

Combined floods are floods that occur in the downstream sections of the tributaries, where the flood level is determined by the combination of tributary flow and the water levels in the Mekong, backing up the tributary levels and impeding the drainage. Also, 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 stay for weeks. In view of the shallow areas along the Mekong downstream of Vientiane a large number of tributaries in their lower reaches face this type of flooding.

Floods in the Cambodian flood plain concern the conveyance and storage of the flood along the Mekong and its flood plain downstream of Kratie to Phnom Penh, inclusive of the flooding around Tonle Sap Lake and the inflow to and outflow from the lake via the Tonle Sap River.

Floods in the Mekong delta deals with the conveyance of floodwater 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 levels rise slowly due to the storage in Tonle Sap Lake and in the Mekong flood plains. Flooding here is recognized as essential for soil fertility, biodiversity and aquaculture. At the same time, it hampers use of agricultural land. The flood levels in the Mekong Delta in its downstream part are essentially the result of upstream and lateral inflow and downstream water levels at sea.

In Table 2.1 an overview is presented of the occurrence of the type of floods in the sub-areas of the Lower Mekong Basin.

Table 2.1 Overview of flood types per sub-area (sub-basin)

Sub-area	Type of flood	Is-sue	Assessment of hydrological hazard	Assessment of flood hazard
SA1 Northern Laos	Tributary	yes	From rainfall statistics, discharge statistics or regional approach	Rainfall-runoff + hydraulic model/satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	no	-	-
SA2 Northern Thailand	Tributary	yes	From rainfall statistics, discharge statistics or regional approach	Rainfall-runoff + hydraulic model/satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	yes	HYMOS/other databases	As above
SA3 Nong Khai/ Songkhram	Tributary	yes	For some basins via statistics rest via regional approach	Models available for Nam Loei, Huai Mong and Nam Songkhram/ satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	yes	HYMOS/other databases	As above
SA4 Central Laos	Tributary	yes	From rainfall statistics, discharge statistics or regional approach	Models available for Nam Ngum, Se Bang Fai and Se Bang Hieng/ satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	yes	HYMOS/other databases	As above
SA5 Mun-Chi	Tributary	yes	For 12 via statistics, rest via RID data or regional approach HYMOS/RID/other databases	Hydraulic models/ satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	no	-	-
SA6 Southern Laos	Tributary	yes	From rainfall statistics, discharge statistics or regional approach	Rainfall-runoff + hydraulic model/satellite imagery
	Mainstream	yes	Annual Flood Report	Hydraulic model/satellite imagery
	Combined	yes	HYMOS/other databases	As above
SA7 Se San/ Sre Pok/ Se Kong	Tributary	yes	From rainfall or discharge statistics or regional approach	Rainfall-runoff + hydraulic model/satellite imagery
	Mainstream	no	-	-
	Combined	yes	HYMOS/other databases	Hydraulic model/satellite imagery

Sub-area	Type of flood	Is-sue	Assessment of hydrological hazard	Assessment of flood hazard
SA8 Kratie	Tributary	yes	From rainfall statistics	Rainfall-runoff + hydraulic model/ satellite imagery
	Mainstream	yes	Annual Flood Report	Satellite imagery u/s Kratie + model d/s Kratie
	Combined	yes	No data	-
SA9 Tonle Sap	Tributary	yes	MRC database	Rainfall-runoff + hydraulic model/ satellite imagery
	Mainstream	yes	HYMOS/other databases	Hydraulic delta model/satellite imagery
	Combined	yes	MRC database	As above
SA10 Mekong Delta	Tributary	yes	HYMOS/other databases	rainfall-runoff+ hydraulic model/satellite imagery
	Mekong delta	yes	HYMOS/other databases	Hydraulic delta model/satellite imagery

2.3 Tributary floods

2.3.1 General

To develop appropriate flood hazard assessment procedures for the tributaries of the Mekong the capacity of the monitoring systems is to be considered. The state of the hydrological monitoring infrastructure in the Lower Mekong basin is such that only a limited number of basins is equipped with rainfall and water level recorders. For most locations only daily rainfall is available. The water level gauging network is generally less dense and the monitoring interval is often too large to properly describe flash flood. Very often only daily water levels is available fully unsuitable for flash flood analysis. With respect to flow, discharge measurements usually cover only the lower stages and occasionally include flood data. Dependent on the data availability one of the following three procedures is feasible:

1. **Flood hazard derived from rainfall extremes.**
   This method is advocated for small basins when little or no data is available on historical flows. It starts with the specification of the meteorological hazard is terms of design rainstorms of desired return periods. The design rainstorms are adjusted to net rainstorms and transformed into design discharge hydrographs at the required location using appropriate unit hydrograph and hydrologic routing techniques to arrive at the hydrological hazard. Finally, the flood hazard is determined by transforming the peaks of the discharge hydrographs into water levels by means of flow simulation using a hydraulic model.
2. **Flood hazard derived from observed flows.**
   When a homogeneous discharge series (>15 years) is available for the concerned river reach, the hydrological hazard can be derived from statistical analysis of annual flood peaks and flood volumes. A hydraulic model of river and flood plain is subsequently used for the transformation of hydrological hazard into flood hazard. A selection of representative flood hydrographs, covering the full spectre of flood peaks and flood volumes, are transformed into water levels using the hydraulic model. The levels and flood volumes are input to a Monte Carlo procedure to derive the frequency of occurrence of water levels as a function of time and space. Comparing the levels for selected frequencies with a DEM flood hazard maps can be created.
3. **Flood hazard determined from regional flood statistics.**
   The distribution of annual flood peaks can also be obtained from regional flood statistics when available. It requires knowledge of the average annual flood peak. For un-gauged streams this value may be estimated from basin characteristics.

2.3.2 Flood hazard derived from rainfall extremes

When using rainfall extremes for the assessment of the flood hazard the following main steps are involved:

Collection of relevant information
1. Database development and field visit
2. Determination of design rainstorms for different return periods
3. Transformation of design rainstorms into design hydrographs
4. Transformation of design hydrographs into design levels.

These steps are elaborated below.

Step 1 Collection of relevant information

Data required for flood hazard assessment includes:

Digital Elevation Model (DEM) of the area and topographical maps;
1. Soils, geological land use maps (past and present);
2. Data on historical floods;
3. Layout of hydro-meteorological network in the river basin, its operation and maintenance;
4. Collection of time series of rainfall, climatic variables, and when available of water levels, stage-discharge measurements, discharges and sediment of the river basin;
5. Data on hydraulic infrastructure, dimensions and operation in times of flood;
6. Survey data of river (cross-sections) and flood plain (DEM) at and upstream and downstream of the reach under investigation and of relevant hydraulic parameters including bed material, vegetation, embankment elevation, etc
7. Data on morphological development of the river and its environs, and
8. Planned land use and infrastructural developments.

Step 2 Database development and field visit

The collected information is next organized in a database consisting of GIS-related and time oriented data. In the database a clear distinction is to be made between original/raw data, data under validation and fully validated data.

Thorough validation, correction and completion procedures should be applied to arrive at a reliable set of information. Since this procedure relies heavily on quality rainfall data, available records have to be thoroughly screened using graphical and tabular comparisons (mind rainfall amounts during weekends and holidays in view of possible non-availability of observer), nearest neighbour validation and double mass analysis. Nearest neighbours (i.e. closest stations) are used to fill in missing data. Reference is made to standard textbooks for detailed explanation of the procedures.

In this data collection and validation process one or more field visits is essential to validate collected information and to assess its sufficiency. Key rainfall stations have to be visited and monitoring practices need to be reviewed. Interviewing inhabitants and officials on the extent of historic floods, land use changes and developments is essential. As a result additional data may be collected or a (temporary) monitoring program is set up and executed.

Step 3 Design rainstorms

The determination of design storms involves the following steps:

1. Assess the time of concentration Tc of the basin up to the location for flood hazard assessment. This is the travel time required for a drop of water from the most upper part of the catchment to the outlet. Tc is a measure for the delay in the translation from rainfall to runoff.
2. Determine the basin rainfall from point rainfall for smallest interval available if applicable.
3. Development of intensity (or depth)-duration-frequency curves for return periods of 2 to 100 years, for durations of 5 min to 24 hours. If no short interval rainfall is available then the short duration intensities are derived from daily rainfall data. In that case EV1 or GEV-distributions are fitted to the observed distribution of annual maximum daily rainfall, and the rainfall for selected return periods is determined. These values should be adjusted to 24 hr values by applying a correction factor of 1.12. Next, when needed, the 24 hr values are corrected for possible orographical effects, based on regional rainfall characteristics as function of elevation. Then regionally acceptable values for the coefficients b and n in the following intensity duration relation are to be obtained:

   $$I = \frac{a}{(b+D)^n} \tag{2.1}$$

   where: I = rainfall intensity (mm/hour)
   D = rainfall duration (hours)
   a,b,n = constants

   Values for coefficients for Phnom Penh e.g. are b = 0.23 and n = 0.86 (Watkins *et al.*, 1984).

   Finally, the Rainfall Ratio Method is used to derive the rainfall for durations shorter than 24 hrs. The Rainfall Ratio method assumes that the constants in equation (2.1) apply for all durations less than 24 hours and all return periods. In that case the rainfall of duration D for any return period is derived from the 24 hour rainfall extreme via equation (2.1) as follows:

   $$RR_D = \frac{D}{24}\left(\frac{b+24}{b+D}\right)^n \tag{2.2}$$

   where: RRD = rainfall ratio for conversion of 24 hr rainfall into D hr rainfall
   D = rainfall duration (hours)

4. In case of single point rainfall, correct the point rainfall for spatial distribution by application of an Area Reduction Factor (ARF) as a function of basin area (A) and rainfall duration (D). For e.g. convective rainfall the function is applied in Cambodia with D in hours and A in km^2:

   $$\begin{aligned} &for \quad D \le 8hrs: \quad ARF = 1 - 0.04\,D^{-0.33}A^{0.50} \\ &for \quad D > 8hrs: \quad ARF = 1 - 0.02\,A^{0.50} \end{aligned} \tag{2.3}$$

5. The design rainstorms for selected return periods can be obtained by the incremental intensity of the rainfall totals of the calculated durations up to the time of concentration:

   $$I_j = \frac{R_{A,D_j} - R_{A,D_{j-1}}}{D_j - D_{j-1}}\left(\frac{mm}{hr}\right) \quad for: \quad D_j > D_{j-1} \tag{2.4}$$

   where: *I*j = jth incremental intensity (mm/hr)
   $R_{A,D}$ = areal rainfall of duration D

6. The incremental intensities are subsequently arranged around the peak value. The location of the peak is determined by the storm advancement coefficient r which is the ratio of the time to peak relative to the total duration of the design storm Tc. The advantage of this procedure is that up to Tc all design intensities are included in the design storm. Other options are triangular hyetographs, where the occurrence of the peak value is determined by the storm advancement coefficient. When possible the arrangement is according to observed hyetographs in the region. The availability of short duration rainfall then is a necessity.
7. Repeat the above step for required return periods to arrive at a set of hyetographs.

Step 4 From design storm to design hydrograph

The transformation of a design rainstorm into a design hydrograph involves the following:

1. Determination of the net rainfall by estimation of losses, to be distributed among the ordinates of the hyetograph;
2. Development of a unit hydrograph of the basin up to the required location, and
3. Convoluting the net hyetograph to the design hydrograph using the unit hydrograph developed under the previous activity.

To determine the rainfall losses, use can e.g. be made of the SCS-Curve Number method, applied for wet antecedent moisture conditions. This method requires information about soils, land use and treatment of the land to arrive at a curve number. The Curve Number (CN) method is extensively described in hydrological textbooks (e.g. Viessman, 1989).

To develop a unit hydrograph of the basin it is advocated that use is made of the Clark method. This method is based on the routing of a time-area diagram with a time base equal to the concentration time Tc through a linear reservoir, simulating channel storage.

When the unit hydrograph has been established, the net design rainstorm is convoluted to a design hydrograph, which comprises the hydrological hazard with a return period equal to the return period of the design rainstorm. This assumption is valid in view of the wet antecedent moisture conditions assumed in the computation, reducing the abstractions that cause the difference between extremities of storms and discharge hydrographs under less wet initial conditions. By repeating this process for design rainstorms of different return periods' peak, discharge values are obtained for the locations and a frequency distribution can be obtained.

Above procedure is applicable to relatively small catchments, say up to 1,000 km2. With some modification, this procedure can also be applied to larger areas. Then use is made of a segmented approach to the transformation of excess rainfall into runoff to allow spatial variation in the excess rainfall and runoff characteristics. In that case the basin up to the location of interest is divided into segments and the rainfall-runoff transformation is applied to each segment. The output of each segment is subsequently routed to the area of interest. This routing can be done by simple hydrologic routing methods or with the hydraulic model extended to the outlet of the uppermost segment.

Step 5 From design hydrographs to design levels

By means of hydraulic model simulation the peak discharges are transformed into water levels of required return periods. The hydraulic model is schematised according to detailed bathymetric survey data on river and flood plain and estimated or calibrated hydraulic roughness. The calculations should include existing flood protection for calibration and planned protection works for investigation of alternatives, as these may back up future water levels further upstream.

2.3.3 Example of flood hazard derived from rainfall extremes

An example of above procedure is provided for a hypothetical basin in Upper Se San near Pleiku, assuming that only daily rainfall series are available. For the development of a design storm the following parameters have been assumed:

- Basin area is 50 km^2;
- Rainfall intensity parameters for disaggregation of daily rainfall (equation 2.1) b = 0.23 and n = 0.86 apply;
- Storm advancement coefficient r = 0.3;
- ARF for convective storms in tropical countries apply; and
- Rainfall conditions are similar to Pleiku with orographic adjustment factor of 1.25.

Daily rainfall series for Pleiku (station 140703) are available for the period 1927-2006, with gaps. After validation and homogeneity tests EV1 and GEV distributions have been fitted to the annual maximum rainfall of the station. The results are shown in Table 2.2 and Figure 2.3.

Table 2.2 Parameters of EV1 and GEV distributions fitted to annual maximum daily rainfall at Pleiku and rainfall values (mm) for selected return periods.

Parameters/ Return period (years)	**Pleiku**	
	EV1	**GEV**
k	-	0.0048
α	30.12	30.26
u	98.08	98.11
2	109	109
5	143	143
10	166	166
25	194	194
50	216	215
100	237	236
500	285	283
1000	306	304

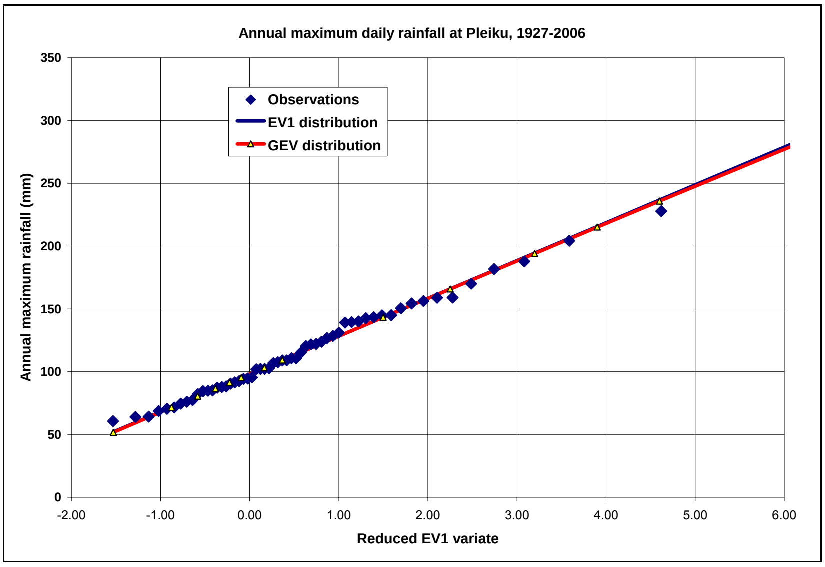


Figure 2.3 EV1 and GEV-fit to annual maximum daily rainfall at Pleiku, Period 1927-2006.

The depth-duration-frequency curves have been derived for intervals of 5 min to 24 hrs starting off from the daily rainfall extremes for T = 2 to 100 years, using equation (2.2). The results are presented in Table 2.3 and shown in Figure 2.4.

The calculation of the T = 50 year design storm is indicated in Table 2.4. The result is presented in Figure 2.5. It follows from a re-ordering of the derived incremental intensities. Here a basic interval of 15 minutes has been assumed. The sensitivity of the design hydrograph for the choice of this interval is to be investigated, once the basin Unit Hydrograph is known. This procedure is to be repeated for other selected return periods.

Table 2.3 Short duration rainfall (mm) at Pleiku derived from daily rainfall extremes.

Duration		**Rainfall ratio**	**Return Period in years**					
	hrs	**RR**	**2**	**5**	**10**	**25**	**50**	**100**
5 min	0.083	0.15	18	23	27	32	35	39
10 min	0.167	0.24	29	38	44	52	58	63
15 min	0.250	0.30	37	49	56	66	73	81
30 min	0.500	0.42	52	68	79	92	102	112
1 hr	1	0.54	66	87	101	117	131	144
2 hr	2	0.65	79	104	121	141	157	172
4 hr	4	0.75	91	120	139	162	181	198
8 hr	8	0.84	103	135	157	183	204	224
12 hr	12	0.90	110	144	167	196	218	239
18 hr	18	0.96	117	153	178	208	232	254
24 hr	24	1.00	122	160	186	217	242	265
Day	**Day**		**109**	**143**	**166**	**194**	**216**	**237**

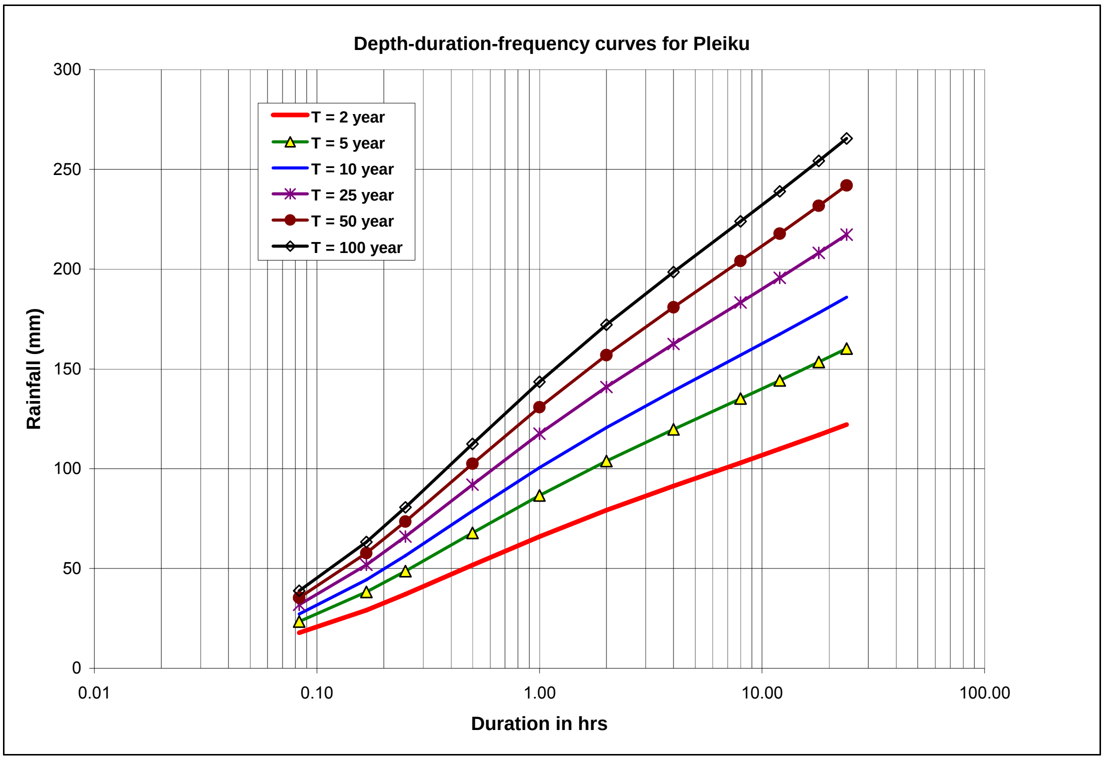


Figure 2.4 Depth-duration-frequency curves for Pleiku.

Table 2.4 Computation of design storm ordinates for 15 min intervals.

Time (hrs)	**0.25**	**0.50**	**1.00**	**2.00**
Point Rainfall (mm)	73	102	131	157
Correction for orography	92	128	164	196
ARF	0.55	0.64	0.72	0.78
Areal rainfall (mm)	51	82	117	152
Incremental intensity (mm/hr)	202	127	70	35
No of 15 min increments	1	1	2	4

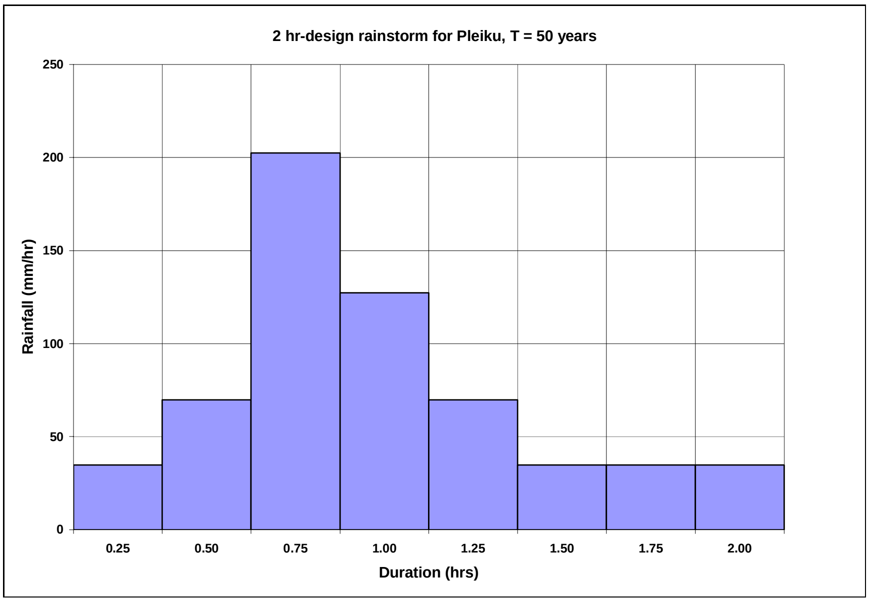


Figure 2.5 A 2hour-design rainstorm for Upper Se San derived from Pleiku.

In the development of the flood hazard the next step is the transformation of the design storm into the design hydrograph. This involves first the assessment of the excess rainfall. For this the Curve Number Method can be used.

Subsequently, the Unit Hydrograph of the basin is determined, for which the use of the Clark Method is advocated. The method is based on the routing of a time-area diagram (with a time base equal to the time of concentration Tc) through a linear reservoir, simulating channel storage. For the diagram isochrones are constructed representing points of equal travel time to the segment outlet; see Figure 2.6.

The time area diagram fully represents the physical runoff characteristics from (mountainous) catchments. This diagram can be thought of as the outflow from the basin if only translation and no deformation take place of an instantaneous unit supply of rain. Flow paths, slopes and hydraulic roughness determine the celerity and can readily be obtained from a DEM or a topographic map. Beside the concentration time it requires the estimation of a recession coefficient k for routing of the time-area diagram. It is noted that the output from the reservoir represents the instantaneous unit hydrograph (IUH). This has to be transformed into a Unit Hydrograph (UH) of the required interval by multiplication with observed rainfall depths. The two parameters Tc and k can be also be obtained from observed rainfall and discharge hydrographs.

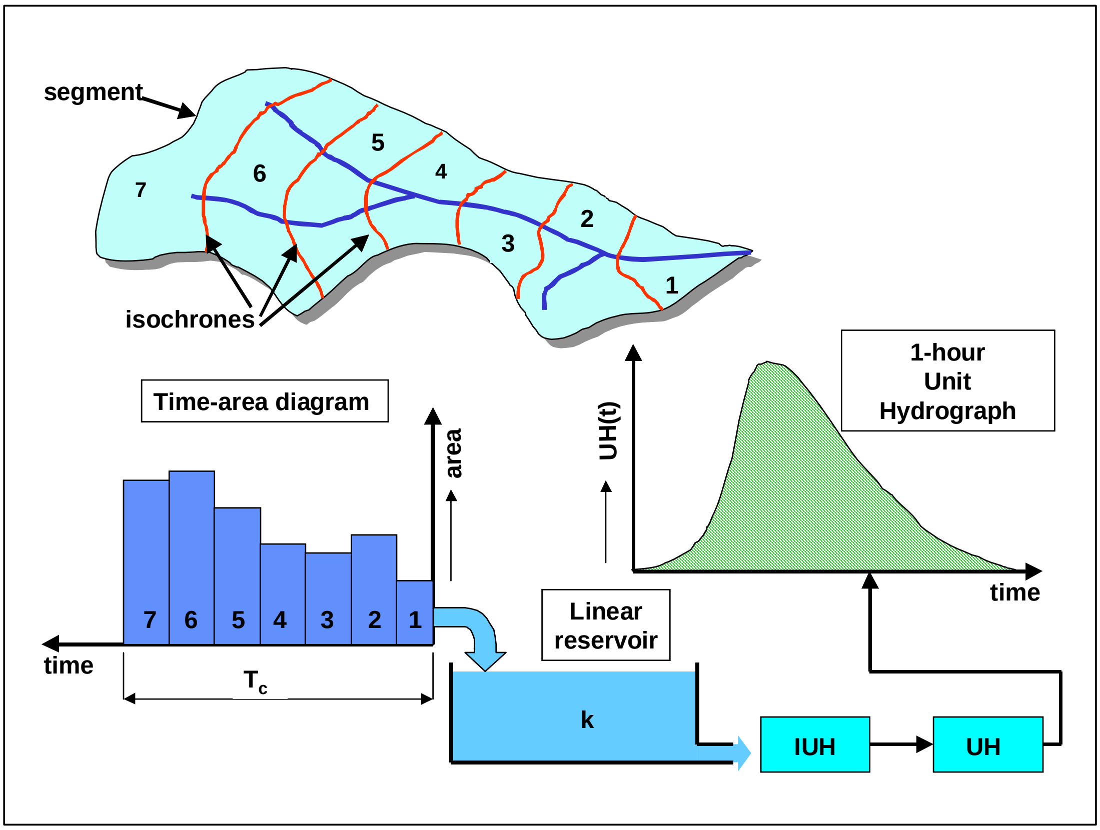


Figure 2.6 Principle of the Clark Unit Hydrograph method.

The time of concentration is equal to the time interval between cessation of rainfall and the time the hydrograph has receded to its inflection point. Note that this is only applicable when drainage conditions and infrastructure have not or will not change. If changed it is determined from physical features of the segment as length and slope. The recession coefficient k is determined from the slope of the recession part of the surface runoff hydrograph. Using this Unit Hydrograph the excess hyetograph is convoluted to arrive at the design flood for the selected return periods. Based on these results a frequency distribution of the floods resulting from the selected rainfall duration (equal to the time of concentration) is prepared.

It is to be verified whether storms of shorter or longer duration lead to higher peaks. This will be dependent on the intensity distribution in the rainstorm and the way the losses are distributed over the rainfall ordinates.

The frequency distribution of flood peaks can be transformed to design flood levels by means of backwater calculations. If storages upstream play a role, then also the full flood hydrograph should be routed through the hydraulic network, with realistic initial values for the storages.

2.3.4 Flood hazard determined from observed flows

When discharge series of sufficient length (≥ 15 years) are available then the hydrological hazard can be determined by statistical analysis of these data, provided that the series are reliable and homogeneous. This procedure involves the following steps:

1. Collection of relevant information.
2. Database development and field visit.
3. Assessment of the hydrological hazard in terms of flood peaks and flood volumes.
4. Transformation of selected flood hydrographs to flood levels using a hydraulic model.

5. Flood hazard is assessed by means of a Monte Carlo procedure, interpolating between the simulated water levels based on samples from the flood peak and volume distributions.
6. Preparation of flood maps by selection of flood levels, durations etc. of the same return period.

Step 1 Collection of relevant information

See also Step 1 in the procedure described in Section 2.3.2, since the required data for this type of flood hazard assessment does not differ much from the one above. Here, special emphasis is on the hydrometric network layout and operation, sampling and measurement procedures, station and equipment maintenance, gauge range and re-settings, available water level series, stage-discharge data and assumed discharge ratings with extrapolation procedures and discharge series.

Step 2 Database development and field visit

See also Step 2 in the procedure described in Section 2.3.2.

Thorough validation, correction and completion procedures should be applied to arrive at a reliable set of discharge data. It requires inspection of all hydrometric stations relevant for assessment of the hydrological hazard and validation of the key stations. Flood marks are levelled and discussed with local people. When lateral inflow is to be determined from rainfall also the rainfall network should be inspected. The hydraulic infrastructure and flood protection works should be included in the field visit, to ascertain their capacity and operation in times of flood and their effect on the shape of the hydrograph due to storage and/or backwater. Developments in the basin, which may have affected the hydrograph and specifically the peak value, have to be quantified.

Screening of the historical water levels involves inspection of the behaviour of hydrographs, comparison with hydrographs at nearby stations, stage relation curve analysis to identify outliers and gauge shifts and comparison of hydrographs with hyetographs on logic of response. Special attention is given to differences between instantaneous peak levels and maximum daily average levels, which latter information is generally only available in the databases. The peak of the hydrographs should later be adjusted for this phenomenon.

Stage relation curves (with appropriate time shifts to account for flood wave celerity) may be applied to fill in gaps. With respect to the stage-discharge data the stage data is first compared with the stage-hydrograph. The computation of the discharge from field data is checked and its accuracy is assessed. Possible backwater and unsteady flow effects are to be identified by means of a first order backwater calculation and assessment of the Jones correction, respectively. The establishment of the discharge ratings is to be inspected, with special emphasis on the extrapolation. The latter should be physically based!

Next, the discharge rating is applied to the water level series for computation of the discharge series. A comparison is made with the series in the database. Discharge hydrographs at neighbouring stations are compared graphically and the consistency is checked by means of water balances and double mass analysis. Similarly, peak values are validated. Subsequently, peak values are analysed on possible trends and other anomalies, graphically, statistically and from documents on drainage conditions. Trends and anomalies are to be eliminated.

Special attention is to be given to the variability of the discharge ratings at locations due to morphological developments in the river bed. The variation of the water level for distinct high discharges through the years is to be determined in order to assess the additional uncertainty in the water level when a specific discharge rating is used in the model.

Step 3 Assessment of hydrological hazard

The features of the hydrograph which are of importance for flood hazard assessment include the peak value in view of maximum levels and the flood volume which determines the duration of flooding. The following activities are required:

1. For flood peaks:
   - Creation of a homogeneous series of annual maximum flows of sufficient length;
   - Application of extreme value analysis to the annual maximum series to derive frequency distributions for the flow extremes;
   - For locations upstream of Vientiane it is advised to compare the obtained distribution with the regional flood frequency curve described in Section 2.3.5.

2. For flood volumes:
   - Selection of 20 to 25 largest floods;
   - Derivation of a regression relation between flood peaks and flood volumes (V = f(Q)) and its scatter, or “standard error”, (Se). The regression line gives the “average” or “expected” value of the flood volume, for given values the flood peak. The expected flood volume increases with increasing flood peak. The relation is not perfect, though, i.e. there will be some scatter (volumes above and volumes below the expected value). Figure 2.7 shows an example of such a regression line and the deviation from the line for a single point. The value Se is the standard deviation of all points with respect to the regression line and will be used (step 3) in the procedure to take the effect of scatter into account;
   - Derivation of representative dimensionless flood hydrographs from the selected hydrographs. The base of the hydrograph should be long enough to represent the full duration of characteristic floods (from M days before till N days after the peak. For each flood assign the time of Qmax to time step t=0 and determine for t = -M, …, t=0, ..., t=N the discharge relative to Qmax (=Q/Qmax) and repeat the procedure for all other selected peaks. Then, apply a frequency analysis on Q/Qmax for each time t = -M, …, t=0, ..., t=N. The result is a distribution function of Q/Qmax for each time step. So, for any give probability, p, of (non-)exceedance the value of Q/Qmax is known for all time steps. Connection of these values gives the (dimensionless) hydrograph for p. In this manner, for a variety of p-values hydrographs are defined and used in the next step.

3. Creation of flood peak-flood volume matrix for hydraulic simulations:
   - Selection of flood peaks of return period 2, 5, 10, 25, 50 and 100 year;
   - Determination of a range of flood volumes for the selected flood peaks, based on the scatter around the flood volume-flood peak regression relation, V = f(Q). For each selected peak value a very low (R-1.96 Se), a low (R-Se), medium (R) , high (R+Se) and very high flood volume (R+1.96 Se) by scaling of the representative flood hydrographs to the flood peak of selected return periods. This results into 6 x 5 = 30 hydrographs;
   - Adjustment of flood hydrographs for differences between daily average flow maxima and instantaneous peak flows;
   - Lateral inflows, assumed to be relatively small, are introduced as a percentage of the selected flood hydrograph.

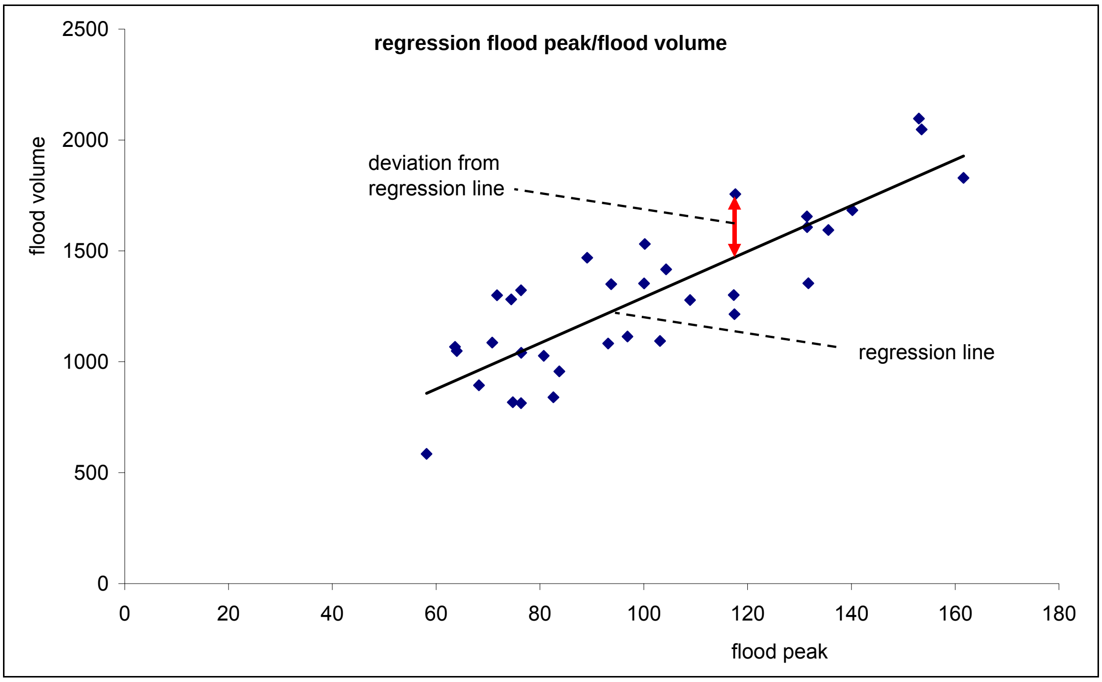


Figure 2.7 Hypothetic regression relation between flood volume and flood peak. As an example, this Figure shows the deviation from the regression line for a single observation.

Step 4 Transformation of flood hydrographs to flood levels

An accurate hydraulic model is to be developed for the river and flood plain under consideration, where the model boundaries are chosen in agreement with the hydrometric network and the limits of the area of interest. It is advised to select a 1D-2D hydraulic model, where the rivers are represented 1D and the flood plain 2D, readily derived from a DEM. This approach has clear advantages over a quasi-2D approach, which is a 1D model with storage cells for the flood plain, where human subjectivity is involved in the schematisation of the connection between river and flood plain. The 1D-2D model has also advantages over a full 2D model, as in the latter narrow river cannot be properly represented. The model should be calibrated for river and flood plain conditions representing the base case. Special attention is to be given to the position of the river bed in comparison with possible bed shifts due to morphological developments.

The 30 selected hydrographs are subsequently routed in the model through the river and flood plain system and the computed water level as function of time and space are stored in a database for further elaboration in a Monte Carlo procedure for flood hazard assessment. These simulations are repeated for development scenarios under consideration, after adjustment of the hydraulic model for the scenario conditions.

Step 5 Flood hazard assessment

The probability of exceedance of a water level at any location is determined by application of the Monte Carlo method. This method consists of a large number (*N*) of paired samples of the peak discharge and flow volume. In this procedure the derived frequency distribution of peak discharges is used to sample the peak discharges. Subsequently the flood volume is derived from the peak discharge, taking the sum of:

1. the regression line to derive the “expected” volume, given the value of the peak discharge;

2. a sample from the normal distribution with mean 0 and standard deviation S_e (see step 2) to derive the deviation from the expected volume.

Application of this procedure ensures that sampled volumes are correlated to the sampled peak discharges in the same manner as the correlation that was obtained from the data. For each sampled pair the water levels at locations of interest are derived from 2-dimensional interpolation in the grid of the 6 x 5 simulated hydrographs. The result is a N-year synthetic series of water levels $h_1, \ldots, h_N$, at each location. From this series the T-year flood levels can be easily derived with e.g. Gringortens formula:

$$p_i = \frac{r_i - 0.44}{N + 0.12} \tag{2.5}$$

where: p_i = probability of exceedance of synthetic water level hi
N = total number of Monte Carlo samples
r_i = rank number of the maximum synthetic water level h_i
(1 = highest, N = lowest)

Step 6 Preparation of flood maps

The mapping of the hydraulic modelling results is described for mainstream flows in Section 2.7. For tributary floods the mapping principles are the same, but the interpolation method is more critical because of the hilly terrain.

2.3.5 Flood hazard derived from regional flood statistics

Adamson (2007) proposed the use of a regional approach for flood hazard assessment. The method has been developed for the upper part of the LMB for 16 drainage basins with areas ranging from 200 to 6000 km^2 and 1 basin of 19,700 km^2. The technique is generally applicable provided the regional curve is valid for the concerned basin. Its development involves the following steps:

1. Creation of a regional sample of annual maximum flood peaks by pooling the individual annual maximum values, scaled to their individual mean annual flood value. Discordance and homogeneity test should be applied to assure regional homogeneity of the selected stations (see Hosking and Wallis, 1997).
2. Subsequently, an extreme value distribution is fitted to the scaled ranked annual extremes. For the LMB basins considered by Adamson (2007) the TCEV (Two Component Extreme Value) distribution fits to the observed frequency distribution of pooled values. The regional curve for the upper part of the LMB is shown in Figure 2.8. The TCEV-distribution was chosen to account for the different phenomena creating the discharge extremes, i.e. monsoon and typhoons, where the latter causes extremes far beyond the monsoon range.
3. To apply the TCEV-values to un-gauged sites a regional relationship between the mean annual maximum flood discharge and one or more climatic and/or basin characteristic(s) has been developed. For the upper part of the LMB the following relation with drainage area was found:

$$Q_{ave} = A^{0.75} + err. \tag{2.6}$$

where: Q_{ave} = mean annual maximum flood (m^3/s)
A = drainage area (km^2)

The error about regression is considerable (S_e is about 50% of Q_{ave}) and it is advised to enter more characteristics in the relation.

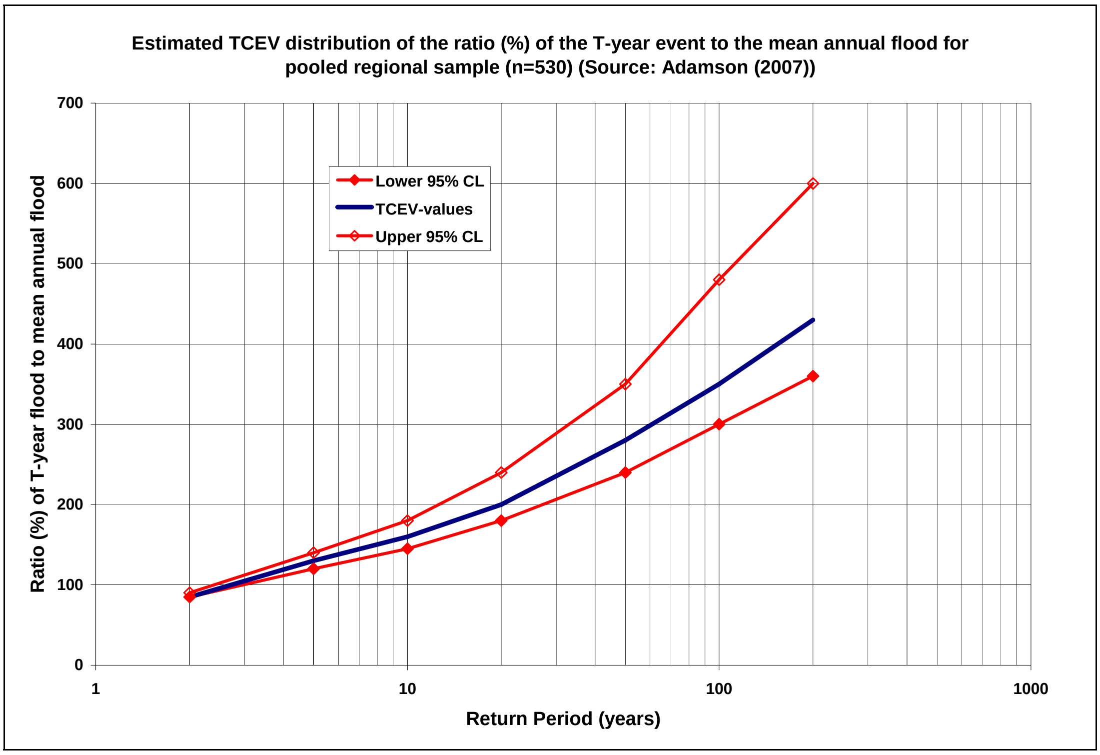


Figure 2.8 TCEV-distribution of the ratio of the T-year event to the mean annual flood for the pooled regional sample (Upper part of LMB, from Adamson, 2007).

Following remarks are made to the use of the regional approach:

- In principle the method is very attractive and easy to use, provided that the base data are properly validated and a much improved relationship is established for the mean annual flood and meteorological and basin characteristics.
- The data set used in Adamson (2007) has been taken from the MRC database. Inspection of the data reveals inconsistencies in the presented station flow extremes. A thorough validation of the data set is required before the presented regional curve can reliably be used.
- Using Adamson's data set, Q_{ave} appears to correlate well with the mean annual flow, which in turn should be well correlated with the annual rainfall. The latter quantity can generally be made available for un-gauged streams in view of the better distribution of rain gauges. Furthermore, stream length, basin slopes and land use data can be made available nowadays from available DEM, which inclusion might improve the estimate of Q_{ave}
- An adjustment is required for instantaneous peak values relative to daily average maximum values applied in above approach. In the case of flash floods a considerable adjustment is expected as the duration of the flood may be just a number of hours.

2.4 Mainstream floods

2.4.1 General

The hydrological hazard along the Mekong River is determined by the discharge peaks on the river creating the maximum water levels and by the flood volumes determining the duration of flooding. Transformation of hydrological hazard into flood hazard requires a hydraulic model of river and flood plain to transform flows into levels. The model is run for combinations of selected hydrographs covering the full spectre of possible combinations of flood peaks and flood volumes. Special attention is required to account for variations of the river bed due to morphological activities, which affects the discharge ratings along the river. The Monte Carlo sampling technique is used to derive exceedance probabilities of water levels and flood damages by interpolation between the simulation results for a very large number of combinations of peak discharges, flood volumes and river bed conditions.

The flood hazard assessment for mainstream floods includes the following steps:

1. Data collection.
2. Database development and field visit.
3. Hydrological hazard assessment in terms of flood peaks and flood volumes.
4. Flood hazard assessment by transformation of selected flood hydrographs to flood levels and application of the Monte Carlo sampling to arrive at flood levels and durations for distinct return periods.
5. Preparation of flood maps by selection of flood levels, durations etc. of the same return period.

The steps are elaborated in the following sub-sections.

2.4.2 Data collection

For assessment of the hazard of mainstream floods following data needs to be collected:

1. Identification of key hydrological stations (Qh-stations) along the Mekong enclosing the problem area, which defines the study area;
2. Survey data of Mekong River (full river bathymetry) and flood plain in the study area and beyond and relevant hydraulic parameters including bed material, vegetation, embankment elevation, etc.;
3. Updated Digital Elevation Model (DEM) of the flood plain in the study area;
4. Soils map of the flood plain;
5. Land use maps of the flood plain, including past, present and future land conditions;
6. Data on hydraulic infrastructure in and downstream of the study area, its dimensions and operation in times of flood and planned developments;
7. Historical flood maps (flood levels, extent, depth and duration);
8. Layout, operation and maintenance of the hydro-meteorological network around the study area including also nearest upstream and downstream stations along Mekong and stations on the tributaries where relevant;
9. Collection of time series of water levels, stage-discharge measurements, discharge ratings and discharges series of the relevant monitoring stations as well as series of rainfall and climatic variables in the region;
10. Changes in runoff characteristics of basins upstream of the study area affecting the homogeneity of the historical discharge series (reservoirs, land use changes).

Below, an overview is given of the agencies to be consulted to obtain the required information.

Cambodia

Ministry of Water Resources and meteorology (MOWRAM)

- Department of Hydrology and River Works (DHRW), water level, discharge and rainfall time series;
- Department of Meteorology (DOM), rainfall, climatic data (air temperature, relative humidity, wind direction, wind velocity, duration of sunshine, radiation)

Ministry of Public Works and transport (MPWT)

- Department of Waterways River and lake bathymetry, hydrographic atlas;

- Department of Road and transport

Ministry of Agriculture, Forestry and Fishery (MAFF)

- Department of Agronomy and Agricultural Land Improvement (soil map, land Use maps)

Phnom Penh Municipality:

- Department of Public Works and Transport of Phnom Penh Municipality, city flood protection dikes/drainage in and around Phnom Penh

Ministry of Land Urban Planning Land Use and Construction (MUPLC

- Department of Land Use planning, Commune Land Use Planning (CLUP)

Lao PDR

Water Resources and Environment Administration (WREA)

The WREA in a new organization grouping the previously Department of Meteorology and Hydrology (DMH) of the Ministry of Agriculture and the Waterways Administration Division (WAD) of the Ministry of Communication, Transport, Post and Communication. WREA now collect and supply all related water data in Lao PDR including establishment and management of hydrological and meteorological network.

The Hydrographic Atlas data of the Mekong mainstream is also transferred to WREA.

Thailand

Ministry of Agriculture (MAF)

- Royal Department of Irrigation (RID), manage, collect and disseminate hydro-meteorological data in most of the Mekong tributaries especially the Nam Mae Kok, Nam Mae Ing, Nam Chi and Nam Mum

Ministry of Natural Resources and Environment

- Department of Water Resources management hydro-meteorological networks previously under the Department of Energy Development and Promotion, this includes all the Thai Mekong mainstream stations. Climatic and water quality data previously supported by the Mekong Committee were also collected and disseminated by this department including bathymetric survey and hydrographic atlas.

Ministry of Information and Communication Technology (MICT)

- Department of Meteorology (TMD), meteorological data, climatic data, weather forecasting,

Ministry of Interior

- Department of Disaster Prevention and Mitigation, Department of, Local Administration, Department of Public Works, town and country planning, flood mapping.

Vietnam

Ministry of Natural Resources science and Environment (MoNRE)

- Department of Water Resources Management
- Hydro-meteorological Services of Vietnam, Southern Region Hydro-meteorological Center: hydrological, meteorological, water quality, salinity data collection network management, data collection and dissemination, flood, salinity and weather forecasting
- Sub National Institute for Agricultural Planning and Production (NIAPP) produce flood maps in the Mekong delta, soil suitability maps.

- Southern Institute of Water Resources Research (SIWRR), hydraulic works (sluices, hydropower, reservoirs, sea, dikes, embankments), river training works, coastal zone management (river morphology, strategies and work for river bank protection), irrigation, drainage, soil reclamation, water supply and drain. Operate and maintain meteorological, hydrological data, cross-sections for Mekong Delta and Dong Nai basin.

2.4.3 Database development and field visit

The collected information is to be organized in a database consisting of GIS-related and time oriented data. In the database a clear distinction is to be made between original/raw data, data under validation and fully validated data.

During the field visit the data on flood protection and hydraulic infrastructure in the study area will be checked, including maintenance and operation in times of flood. All key hydrometric stations will be visited and monitoring and discharge measurement practices be reviewed. Gauge stations and gauge histories will be inspected, including gauge reach, staff gauge connections, bench marks, gauge zero controls and shifts, gauge damages and repairs as well as records from manual and automatic gauges compared. Flow measurement equipment calibration and functioning will be tested. Inhabitants and officials will be interviewed on the extent of historic floods, flood protection developments and land use changes. Flood marks are levelled and discussed with local people. As a result of the field visit when required additional data may be collected or a (temporary) monitoring program set up and executed.

2.4.4 Data validation and processing

Thorough validation, correction and completion procedures should be applied to arrive at a reliable set of discharge data:

- Screening of the historical water levels involves inspection of the behaviour of hydrographs, comparison of hydrographs at nearby stations, stage relation curve analysis to identify outliers and gauge shifts. Stage relation curves (with appropriate time shifts to account for flood wave celerity) may be applied to fill in gaps.
- Stages of discharge measurement data are first compared with the stage hydrograph. The computation of the discharge from field data is checked and its accuracy is assessed. Possible backwater and unsteady flow effects are to be identified by means of a first order backwater calculation and assessment of the Jones correction, respectively. The establishment of the discharge ratings is to be inspected, with special emphasis on the extrapolation. The latter should be physically based, taking into account flood protection works in and downstream of the section! The variability of the discharge ratings at locations due to morphological developments in the river bed is to be assessed, by determining the variation of the water level for distinct high discharges through the years. Particularly, this change is assessed for the natural bank full discharge.
- The discharge rating is applied to the water level series for computation of the discharge series. A comparison is made with the series in the database. Discharge hydrographs at neighbouring stations are compared graphically and the consistency is checked by means of water balances and double mass analysis. Similarly peak values are validated. Subsequently, peak values are analysed on possible trends and other anomalies, graphically, statistically and from documents on drainage and storage conditions. Trends and anomalies are to be eliminated.

2.4.5 Hydrological hazard

The hydrological hazard is determined by peak flow and flood volume, taking into account their interrelation. A matrix of flood hydrographs is to be established covering the full spectre of possible hydrographs with peak values T ≥ 2 years. The development of this matrix involves the following activities:

1. Creation of homogeneous discharge series for the key station at the upper boundary of the concerned river reach;
2. Estimation of the marginal distributions of annual flood peaks and flood volumes (1 June-30 November) at this upper boundary. The observed distributions of flood peaks and flood volumes are generally well represented by a GEV distribution;
3. Development of a regression relation of flood volume (V) on flood peak (Q_p) ($V = f(Q_p)$) and estimate its standard error S_{eV}, similar to step 3 in Section 2.3.4;
4. Specification of the matrix of flood hydrographs for distinct discharge peaks similar to step 3 in Section 2.3.4.

Changes in the stage-discharge rating due to bed variations can be accounted for by changing the hydraulic roughness of the hydraulic model commensurate with the change in the water level. For this purpose the changes in the water level for natural bank full flow from year to year is assessed. The effect can be obtained from comparison of applied discharge ratings or plots of discharge series versus water level series, (provided that shifts in gauge zeros have been eliminated). The differences are given relative to the levels from the discharge rating used in the calibration of the hydraulic model (see Section 2.3.6) and are determined for all key stations in the modelled reach. According to Manning's equation for a wide cross-section, if the water depth at bank full discharge changes from h_1 to $h_2 = h_1 + \Delta h$, then without changing the cross-sections one has to adjust the hydraulic roughness n_1 to n_2 as follows to correct for the water level change:

$$n_2 = n_1\left(\frac{h_2}{h_1}\right)^{5/3} \tag{2.7}$$

Note that the stage-discharge relation at the downstream boundary has to be adjusted accordingly, to avoid unwanted backwater effects.

2.4.6 Flood hazard assessment

The hydrological hazard in terms of peak flow statistics is transformed into water levels by means of a hydraulic model of the concerned Mekong river reach. An accurate hydraulic model is to be developed for the river and flood plain under consideration, where the model boundaries are chosen in agreement with the hydrometric network and the limits of the area of interest. It is strongly advised to select a 1D-2D hydraulic model, where the Mekong river is represented 1D and the flood plain 2D, readily derived from a DEM. This approach has clear advantages over a quasi-2D approach with storage cells, where human subjectivity is involved in the schematisation of the connection between river and flood plain. The model should be calibrated for river and flood plain conditions representing the base case. Special attention is to be given to the position of the river bed in comparison with possible bed shifts due to morphology.

Subsequently, with the model the 30 selected hydrographs are routed through the river and flood plain system and the computed water level as function of time and space are stored in a database. Next, above procedure is repeated at least twice with adjusted hydraulic roughness and downstream stage-discharge relations to cover the full range of water level changes for bank full discharge. These results are added to the database for elaboration in a Monte Carlo procedure for flood hazard assessment. These simulations are repeated for development scenarios under consideration, after adjustment of the hydraulic model for the scenario conditions.

The final step is the execution of a Monte Carlo analysis in the same manner as described in step 5 of Section 2.3.4.

2.4.7 Example: Mekong near Nhakon Phanom (Thailand)

Preparations for Monte Carlo analysis

Figure 2.9 shows the GEV-function fitted to the series of observed annual maximum discharges of the Mekong river at Nakhon Phanom. From this function, discharges with return periods of 2, 5, 10, 25, 50 and 100 year are derived (Table 2.5). Subsequently, the relation between peak flows and flood volumes (total flow volumes from July 1st until November 30th) is derived from regression analysis (full line in Figure 2.10). Also the spread around this line is depicted in Figure 2.10 by the 4 graphs at distances -1.96 S_e, -S_e, 0, +S_e, +1.96 S_e from the regression line (S_e is the standard deviation from the regression line). Then, for each selected flood peak flood volume of Table 2.5, the 5 accompanying flood volumes are specified according to the spread in the flood volume-peak discharge relation. Figure 2.11 shows the resulting 30 (6×5) grid points in combination with the lines of Figure 2.10.

For each of the 30 grid points a model simulation with Isis is executed to derive water levels at various locations for a range of hydraulic conditions. The simulations serve as the basis for the Monte Carlo analysis. For these simulations, Isis requires 30 hydrographs of daily discharge as input series. These (synthetic) hydrographs need to have the same features (i.e. peak discharge and flow volume) as the 30 grid points. In order to obtain realistic synthetic hydrographs, observed hydrographs are selected and (slightly) adapted. The observed hydrographs that closest resemble the features of the grid points are selected. This selection procedure is depicted by the green lines in Figure 2.12). The observed hydrograph is then “scaled” in such a way that its peak discharge and flow volume are exactly equal to that of the associated grid point. Figure 2.13 shows an example of such scaling. In this example the peak was slightly altered, but the remainder of the hydrograph was slightly lowered to decrease the flow volume. The resulting hydrograph is still very much realistic since it closely resembles the observed hydrograph.

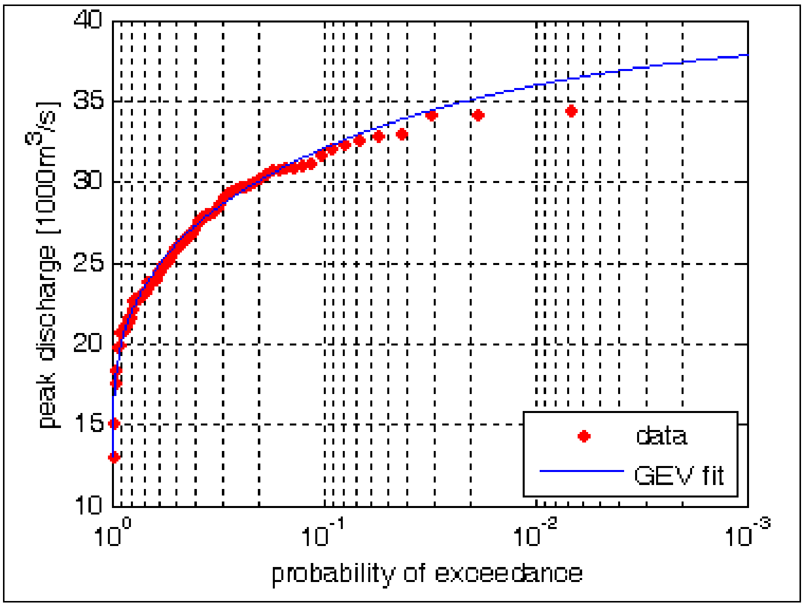


Figure 2.9 Fit of the GEV function to annual maximum daily discharge of the Mekong at Nakhon Phanom.

Table 2.5 Parameters of the GEV distribution fitted to annual maximum daily discharge of the Mekong at Nakhon Phanom and discharges (m^3/s) for selected return periods.

parameter	value
k	0.309
α	4,685
u	24,475
return period (years)	**discharge (m^3/s)**
2	26,098
5	30,097
10	32,070
25	33,989
50	35,090
100	35,970

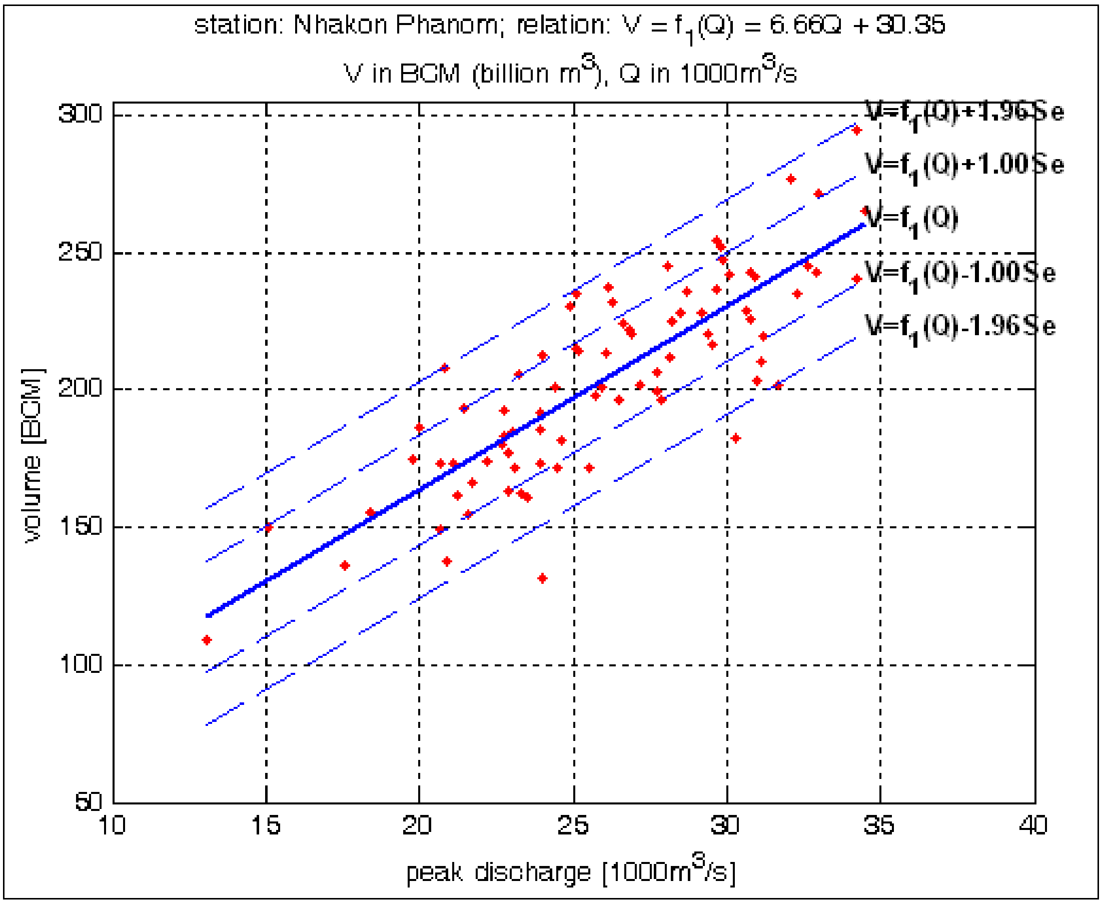


Figure 2.10 Peak discharge-Flood volume relation at Nhakon Phanom.

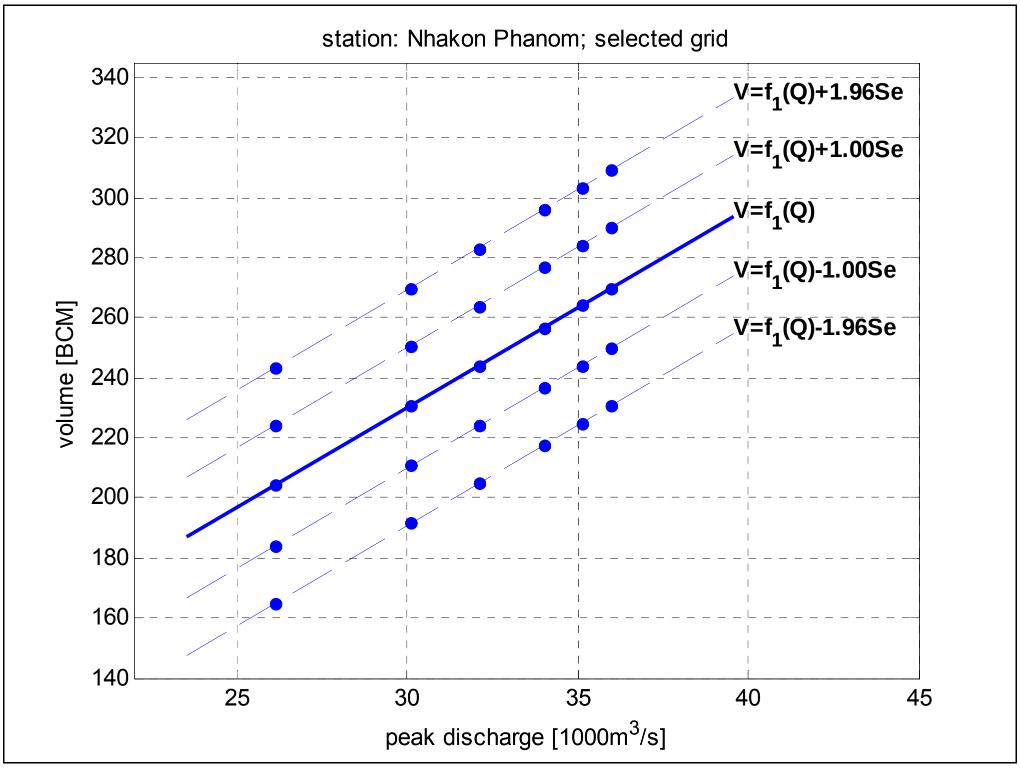


Figure 2.11 Defined 2D grid of discharges (with return periods 2, 5, 10, 25, 50 and 100 years) and volumes (based on the regression line and lines of deviation from the regression line).

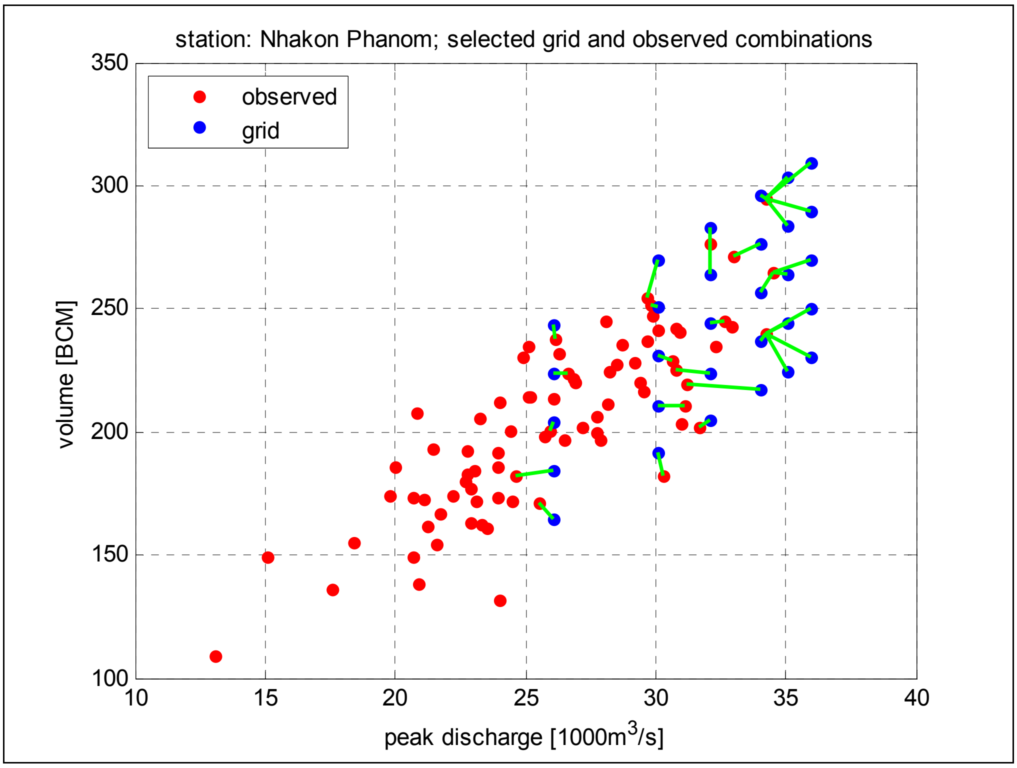


Figure 2.12 Observed combinations of peak discharge and flow volume (red dots) and selected 2D grid (blue dots). The green lines show the observed combinations that closest resemble the grid combinations.

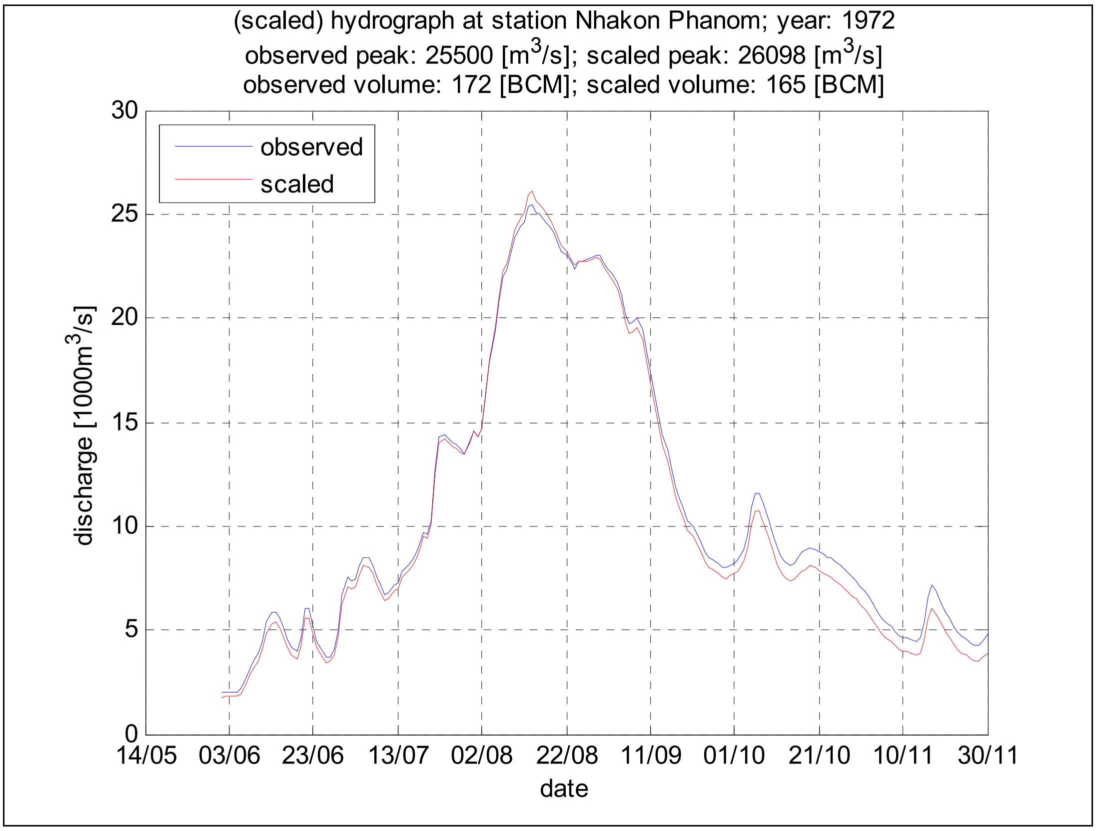


Figure 2.13 Example of scaling an observed hydrograph to make it suitable for serving as one of the grid points in Figure 2.12.

Monte Carlo analysis and results

For this example a Monte Carlo analysis with N=100,000 samples was executed. For the resulting *N* water levels the probability of exceedance is estimated through application of formula (2.5) of Section 2.3.4. For a floodplain just downstream of Nakhon Phanom, the resulting frequency curve for the water level is shown in Figure 2.14. It starts with a basic level of just over 130 [m+MSL]. This is the output of the Isis-model if the floodplain location does not flood during the year. The probability that this happens is approximately 0.5 per year. Naturally, for increasing water levels the probability of exceedance are lower. The 100-year water level is approximately equal to 134.8 m+MSL (where the graph crosses the line of $x = 10^{-2}$ per year). In a similar matter the 100-year water level can be determined for other locations. Based on the results for all locations a spatial map can be produced with the GIS-procedures as mentioned in Section 2.7).

2.5 Combined floods

2.5.1 General

Combined floods are floods that occur in the downstream sections of the tributaries, where the flood level is determined by the combination of tributary flow and the water level in the Mekong, backing up the stages on the tributary and impeding the drainage.

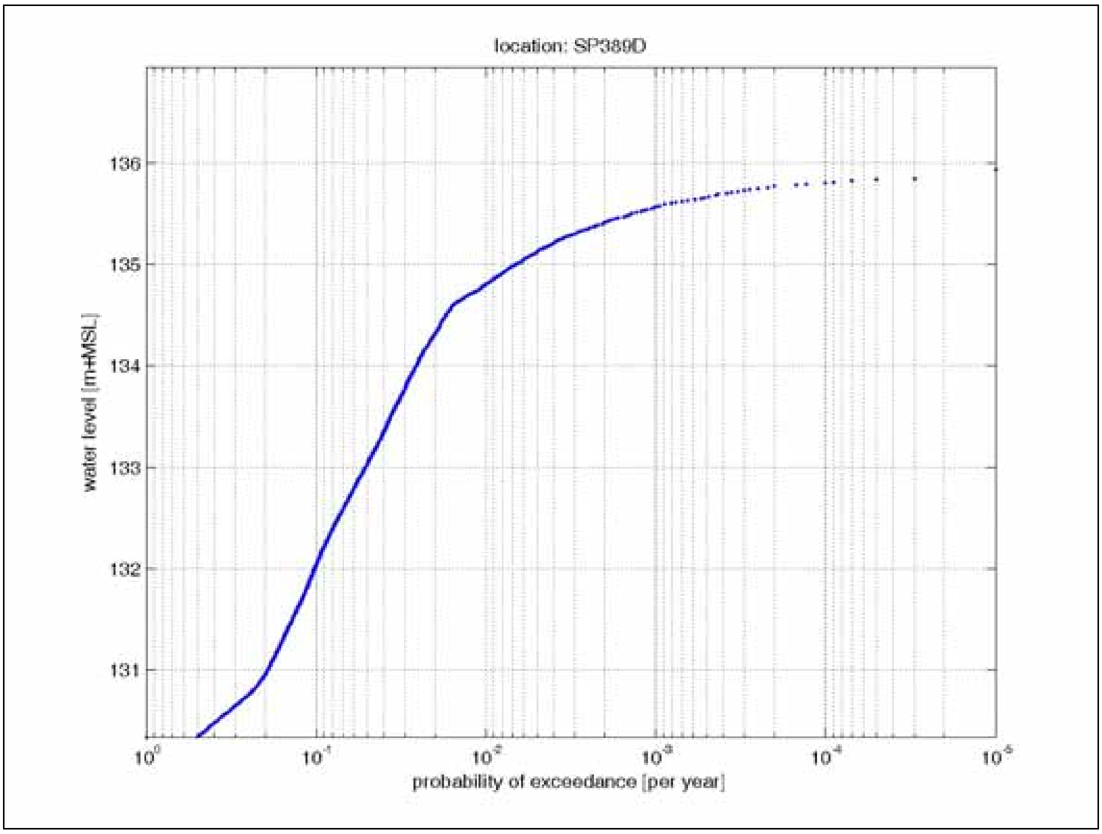


Figure 2.14 Derived frequency curve for maximum annual water levels at a location in the floodplain just downstream of Nhakon Phanom.

The hydrological hazard of tributary runoff with high water levels at the confluence with the Mekong is transformed into water levels in river and flood plain in the backwater affected zone near the mouth by means of a hydraulic model, which is run for the full spectre of possible combinations of upstream inflow and downstream levels. The hydraulic model should cover the tributary with flood plains from a backwater free location to the confluence, whereas the Mekong reach around the confluence is enclosed by key hydrometric stations, applying discharge hydrographs upstream and a stage-discharge relation downstream.

The simulation results are used in a Monte Carlo procedure to derive the exceedance probabilities of water levels and flood damages. The procedure uses in principle three or four random variables, representing the main causes for high water levels in the downstream part of the tributary backed up by the mainstream:

1. maximum discharge in the Mekong at the confluence;
2. total volume of the flood in the Mekong at the confluence;
3. total volume of the tributary flood, and
4. maximum discharge in the tributary.

Note that it may not always be necessary to explicitly take the tributary peak flow into account, particularly when flood plain inundations and associated damages are considered. In such cases the tributary flood volume, rather than the peak plays an important role. On the other hand, tributary peak flow becomes of importance when flood protection works along the tributary are to be designed and tributary flood volumes have little value. In practice, to limit the combinations, generally one of the two is considered and only rarely both.

Special attention is required to account for variations of the river bed due to morphological activities, which affects the conveyance of the rivers and hence the resulting stages. This may lead to the introduction another variable in the Monte Carlo procedure: the river conveyance.

Finally, combining the water levels of equal probability and comparing the results with a DEM flood maps of levels, depth and duration can be created.

The flood hazard assessment for combined floods includes the following steps:

1. Data collection.
2. Database development and field visit.
3. Hydrological hazard assessment in terms of flood peaks and flood volumes on the Mekong and the tributary.
4. Flood hazard assessment by transformation of a selected combination of flood hydrographs to flood levels using a hydraulic model and interpolating between the simulated water levels by means of a Monte Carlo procedure to arrive at flood levels and durations for distinct return periods.
5. Preparation of flood maps: see Section 2.7.

The steps are elaborated in the following sub-sections.

2.5.2 Data collection

For assessment of the hazard of combined floods following data is required and needs to be collected:

1. Identification of key hydrological stations (Qh-stations) on the tributary to beyond the backwater reach of the mainstream and the along the Mekong enclosing the problem area. This defines the study area;
2. Survey data of tributary and Mekong River (full river bathymetry) and of flood plains in the study area and beyond and data of relevant hydraulic parameters including bed material, vegetation, embankment elevation, etc.;
3. Updated Digital Elevation Model (DEM) of the flood plain in the study area;
4. Soils map of the flood plains;
5. Land use maps of the flood plain, including past, present and future land use;
6. Data on hydraulic infrastructure in and downstream of the study area, its dimensions and operation in times of flood and planned developments;
7. Historical flood maps (flood levels, extent, depth and duration);
8. Layout, operation and maintenance of the hydro-meteorological network around the study area including also nearest upstream (and for Mekong also downstream) stations along the tributaries and Mekong where relevant;
9. Collection of time series of water levels, stage-discharge measurements, discharge ratings and discharges series of the relevant monitoring stations as well as series of rainfall and climatic variables in the region, particularly when lateral inflow downstream of the key station on the tributary is substantial;
10. Changes in runoff characteristics of basins upstream of the study area affecting the homogeneity of the historical discharge series (reservoirs, land use changes).

2.5.3 Database development and field visit

The same database development strategy as outlined for mainstream floods applies here, and therefore reference is made to Section 2.3.3. The same holds for the field visit, with the following addition. When lateral inflow is substantial and can only be estimated from rainfall records attention should also go to the rainfall/ climatic stations in and around the contributing area. Station layout, equipment exposure, operating practice and maintenance is to be inspected/ reviewed, to judge the suitability of a station for use in rainfall-runoff modelling.

2.5.4 Data validation and processing

Data validation and processing should involve the steps presented in Section 2.3.4. In case rainfall-runoff modelling (SWAT) has to be applied to derive lateral inflows, rainfall and climatic data of the contributing area is to be validated and processed as well. This involves that the historical series are first screened graphically by comparison with nearby station records. Erroneous date entries can be identified by tabular comparison. The monitoring practice during weekends and holidays is to be inspected and when needed adjusted. Next the data have to be subjected to nearest neighbour tests and double mass tests. Series are to be adjusted when needed and completed based on reliable nearby stations. The resulting series are subsequently transformed to areal rainfall for sub-basins used in the SWAT rainfall-runoff model framework and compared with the series applied previously for the modelling. In case of differences a recalibration of the SWAT model for the concerned areas is to be carried out. It is noted though that in several cases rainfall-runoff modelling may not be required to estimate the lateral inflow, like in the Se Bang Fai example discussed in Section 2.4.7.

2.5.5 Hydrological hazard

The hydrological hazard is determined by peak flow and flood volume on the Mekong, determining largely the water level at the confluence, and the tributary flood volume and flood peak on the tributary, including their interrelation. A matrix of flood hydrographs is to be established covering the full spectre of possible hydrographs starting off from the peak flow on the Mekong with values $T \geq 2$ years. The development of this matrix involves the following activities:

1. Creation of homogeneous discharge series for the key stations at the upstream boundaries of the hydraulic model on the tributary and the Mekong.
2. Estimation of the marginal distributions of annual flood peaks and flood volumes (1 June-30 November) at these upper boundaries (Mekong and tributary). The observed distributions of flood peaks and flood volumes are generally well represented by a GEV distribution.
3. Development of the following regression relations between peak flows and flood volumes with their standard errors:
   - flood volume Mekong (V_M) on flood peak Mekong (Q_{pM}): $V_M = f_1(Q_{pM})$;
   - flood volume tributary (V_T) on flood volume Mekong (V_M): $V_T=f_2(V_M)$;
   - flood peak tributary (Q_{pT}) on flood volume tributary (V_T): $Q_{pT}=f_3(V_T)$;
     Note that this relation is not required when tributary peak flows do not play an important role. If, on the other hand, tributary flood volume is not of much importance it may be eliminated and replaced by tributary flood peak, see Section 2.4.1;
   - Plot the regression relations with year-numbers to the points and draw in the graphs parallel to the regression line lines at +/- 1x S_e and +/-1.96 x S_e distance.
4. Specification of the matrix of flood hydrographs for distinct discharge peaks:
   - Selection of flood peaks and volumes (6×5=30) and associated hydrographs for the Mekong in the same manner as in Section 2.4.7;
   - Determination of range of tributary flood volumes for each of the 30 selected Mekong flood volumes from the scatter about the regression relation tributary flood volume – Mekong flood volume: for each selected Mekong flood volume a low ($R-1.96\ S_{eVT}$), medium (Rf_2) and a high tributary flood volume ($R+1.96\ S_{eVT}$) is obtained. This results into 6×5 x 3 = 90 combinations of Mekong flood peaks and flood volumes and tributary flood volumes (a 3D-grid, see next page);
   - Derivation of 90 synthetic hydrographs, by scaling observed hydrographs in the same matter as in Section 2.4.7.

The steps in the development of the matrix up to a level of 3 variables are given in Figure 2.15.

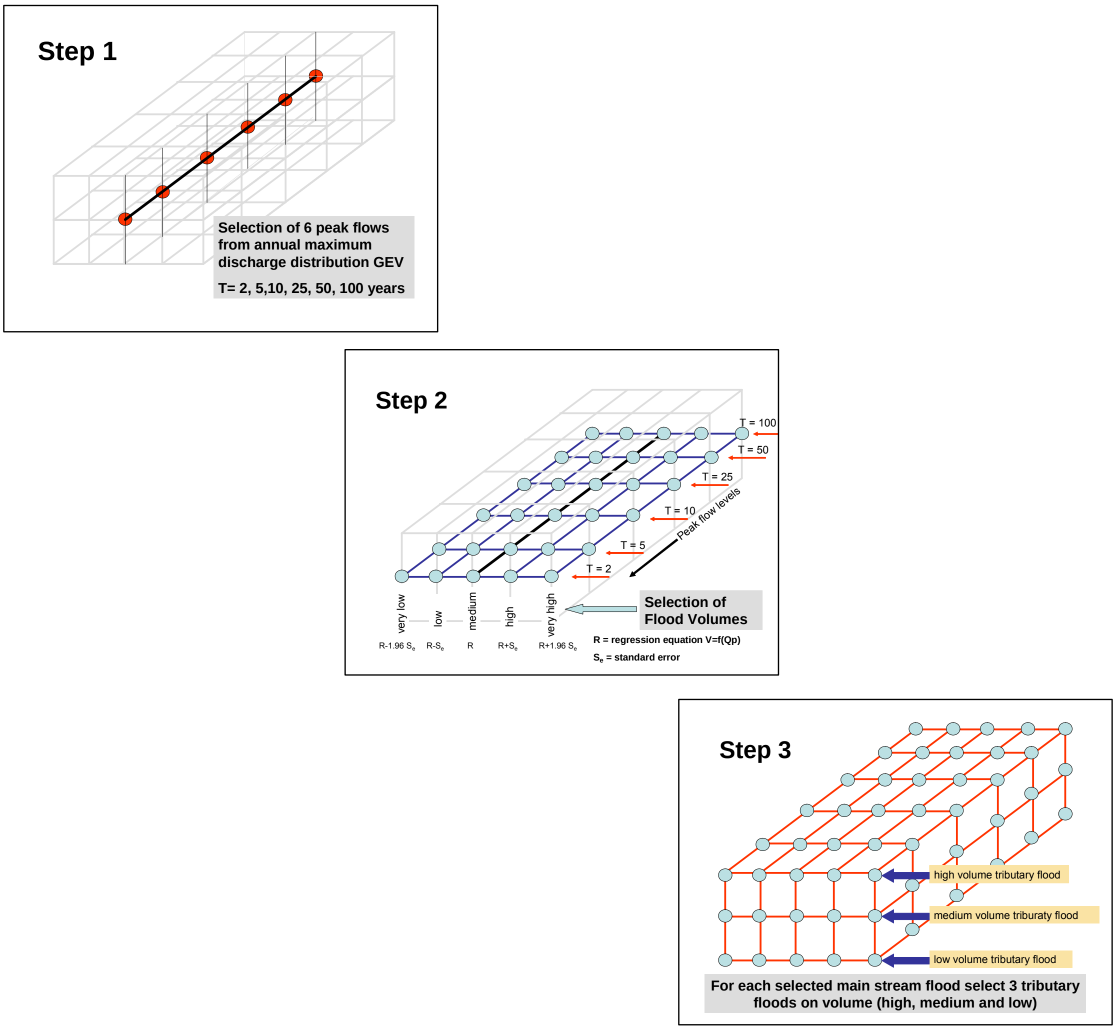


Figure 2.15 Development of the flood simulation matrix for combined floods.

As for the mainstream floods, changes in the stage-discharge ratings (mainstream and/or tributary) due to bed variations will be accounted for by repeating the model simulations with different hydraulic roughness. The roughness change will be commensurate with the maximum observed changes in the water level for bank full discharge relative to the model values used for the calibration.

2.5.6 Flood hazard assessment

The hydrological hazard in terms of statistics and relations between:

- peak flow and flood volume on the Mekong, and
- flood volume and/or flood peak on the tributary

is transformed into water levels in the rivers and flood plains in a hydraulic model of the tributary confluence with the Mekong. The model requirements are specified in Section 2.3.6.

The 30 selected Mekong hydrographs and 90 tributary floods are subsequently in the model routed through the rivers and flood plains system and the computed water levels as function of time and space are stored in the database. If relevant, in view of bed changes, the simulations are repeated at least twice with adjusted hydraulic roughness and downstream stage-discharge relations to accommodate the conveyance changes and added to the simulation database for further elaboration in a Monte Carlo procedure. Also, a full repetition of simulations will be required for the analyses of development scenarios.

The final step is the execution of a Monte Carlo analysis in the same manner as described in step 5 of Section 2.3.4. The only difference is that in this case 3D-interpolation is required instead of 2D interpolation.

2.5.7 Example: combined floods in the lower Se Bang Fai (Lao PDR)

Combined flooding takes place in the flood plains along the lower Se Bang Fai, where the water levels are affected by backwater from the Mekong. The Se Bang Fai drains an area of 10,240 km^2 and discharges to the Mekong at That Phanom, which is located between the key Mekong stations Nakhon Phanom upstream and Mukhdahan downstream. The flow in the Se Bang Fai is measured a.o. at Mahaxai and Ban Se Bang Fai at Highway Bridge 13, see Figure 2.16. Station Mahaxai controls an area of 4,520 km^2, whereas the drainage area at Ban Se Bang Fai amounts 8,560 km^2, respectively 44 and 84 % of the entire basin. Between Mahaxai and Ban Se Bang Fai the Se Bang Fai is joined by the Nam Oula and Se Noy. The monthly average flows in the Se Bang Fai at Mahaxai and the Mekong at Nakhon Phanom are presented in Table 2.6.

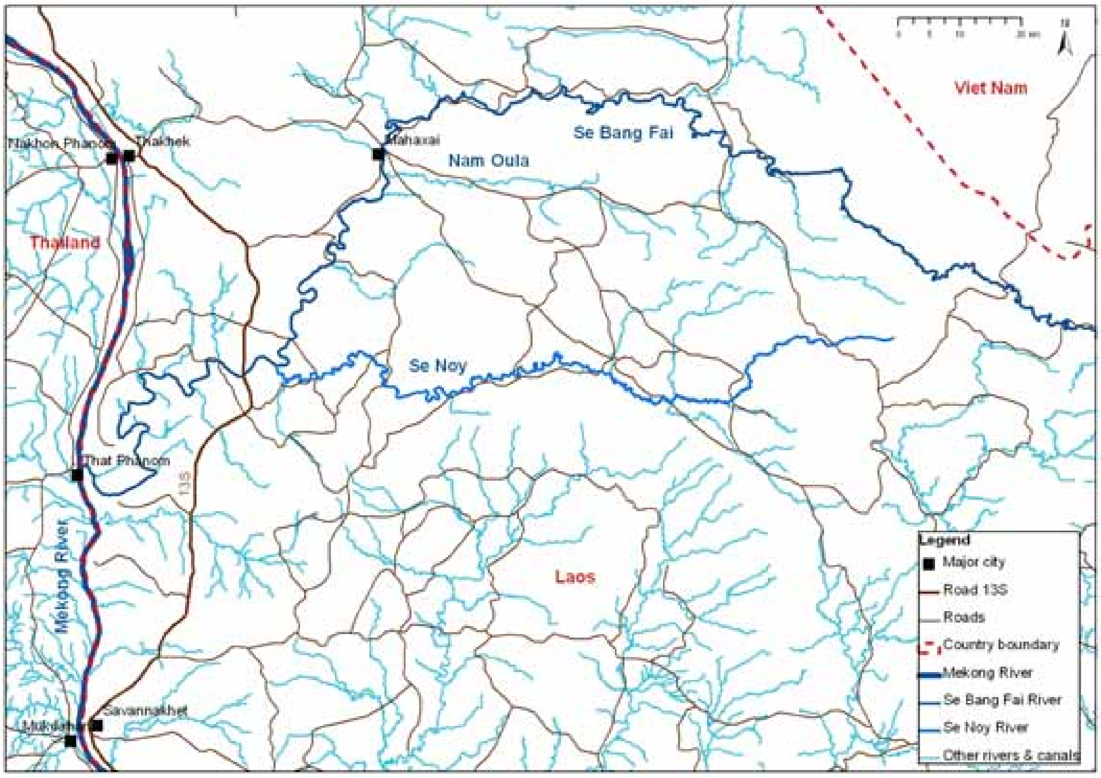


Figure 2.16 Layout of Lower Se Bang Fai basin.

Table 2.6 Average monthly and annual flow (MCM) in Se Bang Fai at Mahaxai and Mekong at Nakhon Phanom.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mahaxai	60.0	41.5	37.2	34.7	90.8	565.6	1601.4	2370.7	1687.9	635.9	240.5	105.8	7504.4
Nakh. Phanom	6,277	4,469	4,130	4,000	6,492	17,722	35,993	54,457	51,055	29,808	14,860	9,111	238,376

Floods in the Se Bang Fai may occur from June to early October, coinciding with high water levels on the Mekong. The water levels in the Se Bang Fai at Highway Bridge 13 at Ban Se Bang Fai are seriously affected by backwater from the Mekong, whereas Mahaxai is backwater free.

Hydrological hazard assessment

The hydrological hazard in the lower Se Bang Fai is determined by the discharge of the river at Mahaxai and lateral inflow further downstream and the water levels on the Mekong at the confluence near That Phanom. The following data is available to describe the hazard:

- The Se Bang Fai discharge record for Mahaxai is available for the Period 1988-2006.
- Tributary inflow between Mahaxai and Ban Se Bang Fai is estimated as a function of the flow at Mahaxai, to bypass questionable inflow estimation from a very limited number of rainfall stations. Actual flow measurements at Ban Se Bang Fai were considered to establish the function, in view of backwater effects on the stage-discharge relation for that site.
- The water level at That Phanom is determined by the Mekong discharge at Nakhon Phanom augmented with the flow from the Se Bang Fai and by the conveyance capacity downstream of the confluence, represented by the stage-discharge relation of Mukhdahan. For Nakhon Phanom discharge series have been used of the Period 1924-2005.

The discharge series have been thoroughly validated along the lines of Section 2.3.4, and where needed, they have been adjusted; see the Se Bang Fai FHA Report for details. Subsequently, the hydrological hazard in terms of marginal distributions of peak flows and flood volumes and their interrelations have been quantified. Statistics for Nakhon Phanom have been presented in 2.4.7. Statistics for Mahaxai are presented in Table 2.7, Figure 2.19 and Figure 2.20.

Next, the matrix of flood hydrographs for distinct discharge peaks is specified, starting off from the flood peaks at Nakhon Phanom. This was already described in Section 2.4.7. The result consists of 30 (6×5) combinations of peak discharge and flow volume and 30 associated discharge hydrographs. For each of these 30 Mekong flood volumes 3 Se Bang Fai flood volumes are selected at distances -1.96 S_{eVSBF}, 0,+1.96 S_{eVSBF} from the Se Bang Fai flood volume-Mekong flood volume regression relation, see Figure 2.20. The result is a 3-dimensional grid for peak discharge and volume in the Mekong (at Nakhon Phanom) and flood volume in the Se Bang Fai (at Mahaxai) as depicted in Figure 2.17. The grid contains 90 points (6×5×3), meaning 90 discharge hydrographs for Mahaxai are required. This is done through rescaling of observed hydrographs, in a similar matter as described in Section 2.4.7. Figure 2.18 shows an example of a scaled hydrograph.

Table 2.7 GEV-parameters, peak-discharges and flood volumes (June-November) for distinct return periods in the Se Bang Fai at Mahaxai.

Parameter	**Peak discharge (m^3/s)**	**Flood Volume (MCM)**
k	0.341	0.221
α	498	2,304
u	1,614	6,105
T (years)		
2	1,757	6,916
5	2,177	9,045
10	2,398	10,188
25	2,626	11,386
50	2,765	12,126
100	2,881	12,755

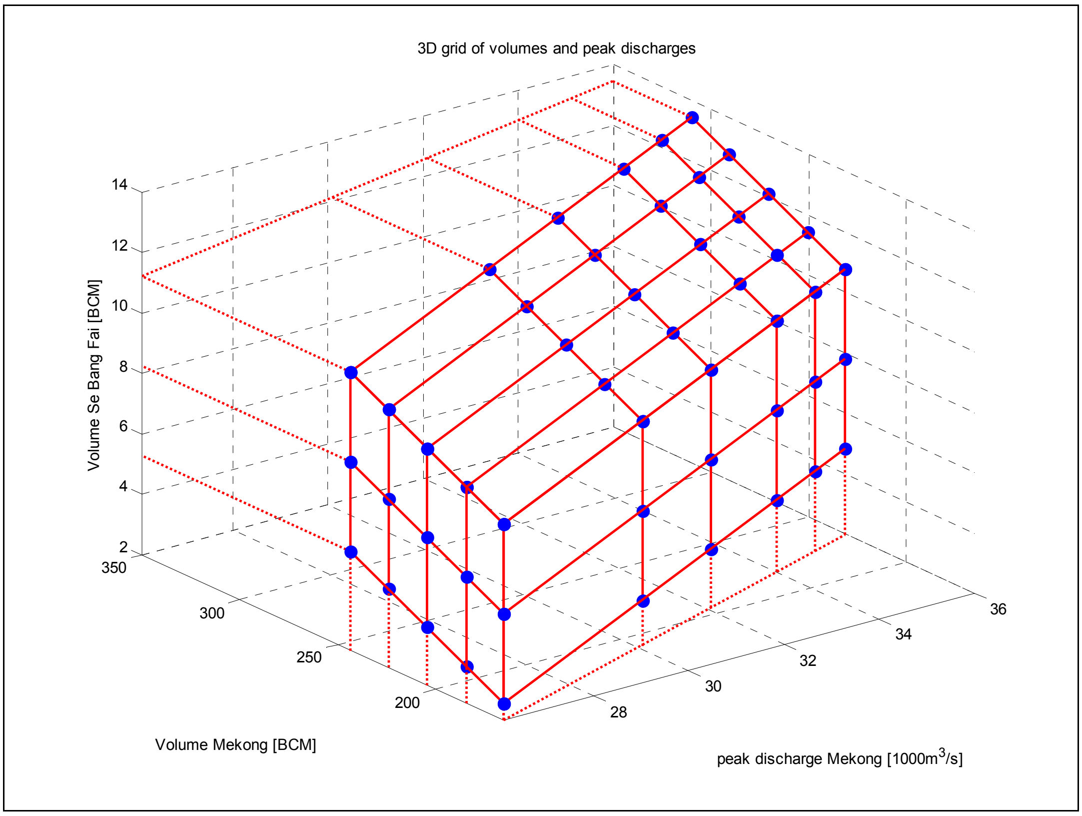


Figure 2.17 Impression of the 3D grid for peak discharge and volume in the Mekong (at Nakhon Phanom) and flood volume in the Se Bang Fai (at Mahaxai). The blue dots only show the 'outer side' of the grid; the full grid contains 90 dots.

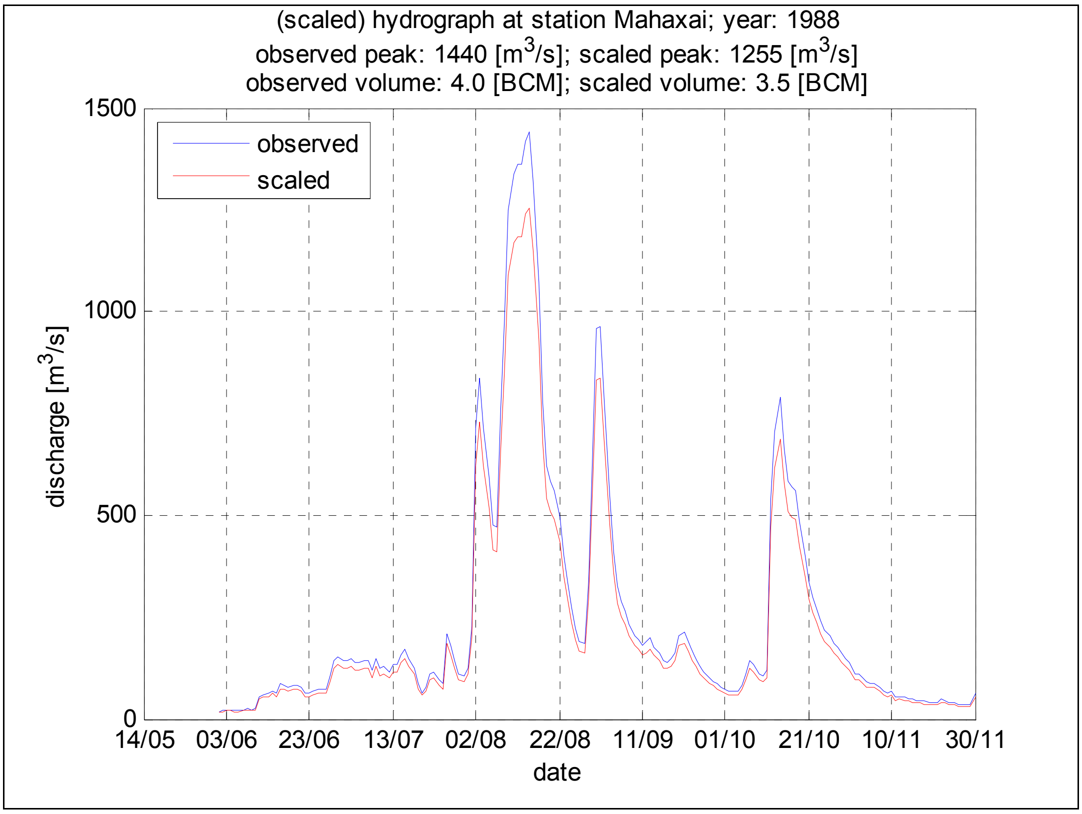


Figure 2.18 Scaling of an observed hydrograph for the Se Bang Fai at Mahaxai.

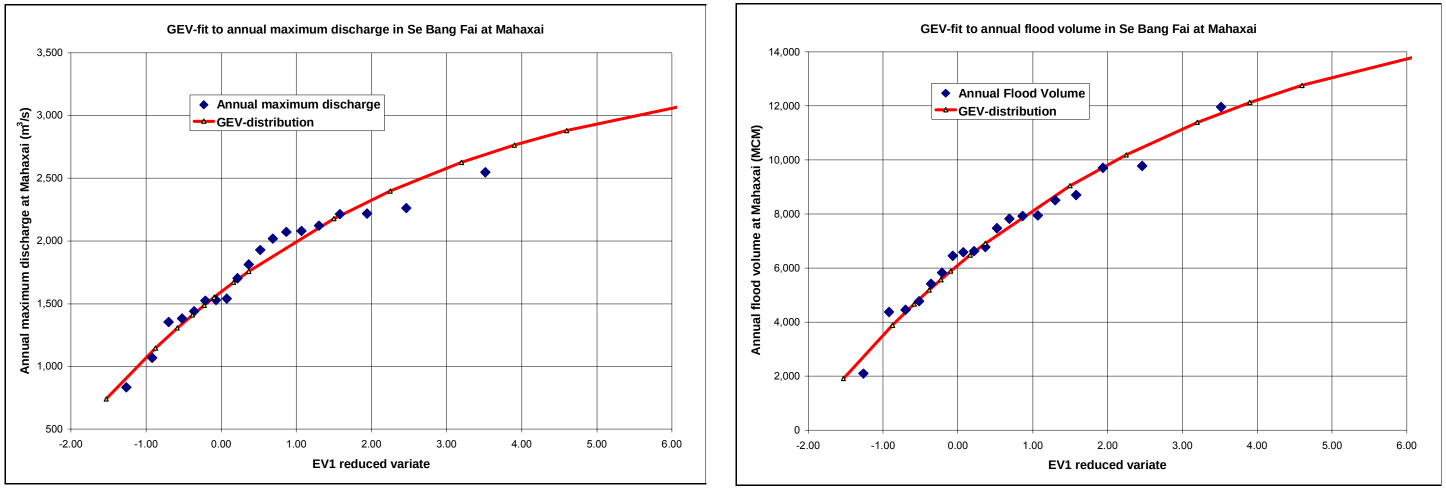


Figure 2.19 GEV-fit to marginal distributions of annual maximum discharge and flood volume at Mahaxai (Se Bang Fai).

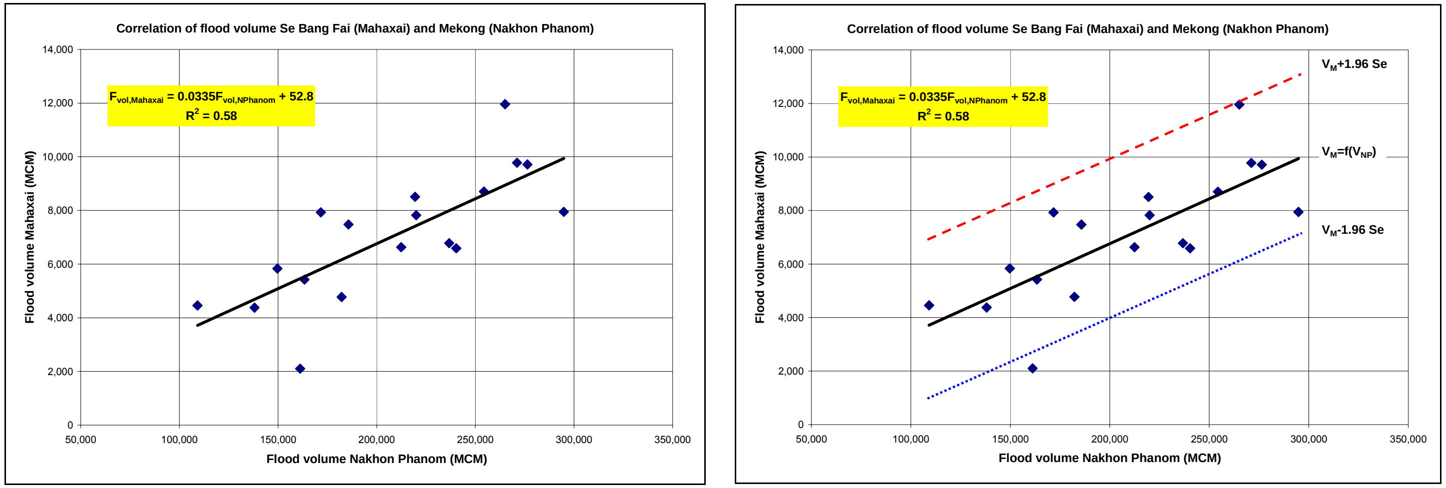


Figure 2.20 Flood volume – peak discharge relation for Nakhon Phanom and flood volumes relation between Mahaxai and Nakhon Phanom, without and with S_e-related selection lines.

Flood hazard assessment

The 90 flood hydrographs of Mekong and Se Bang Fai selected above are input to the hydraulic model of the Se Bang Fai delta model for transformation of flows into water levels. The model layout and boundary conditions are schematically displayed in Figure 2.21.

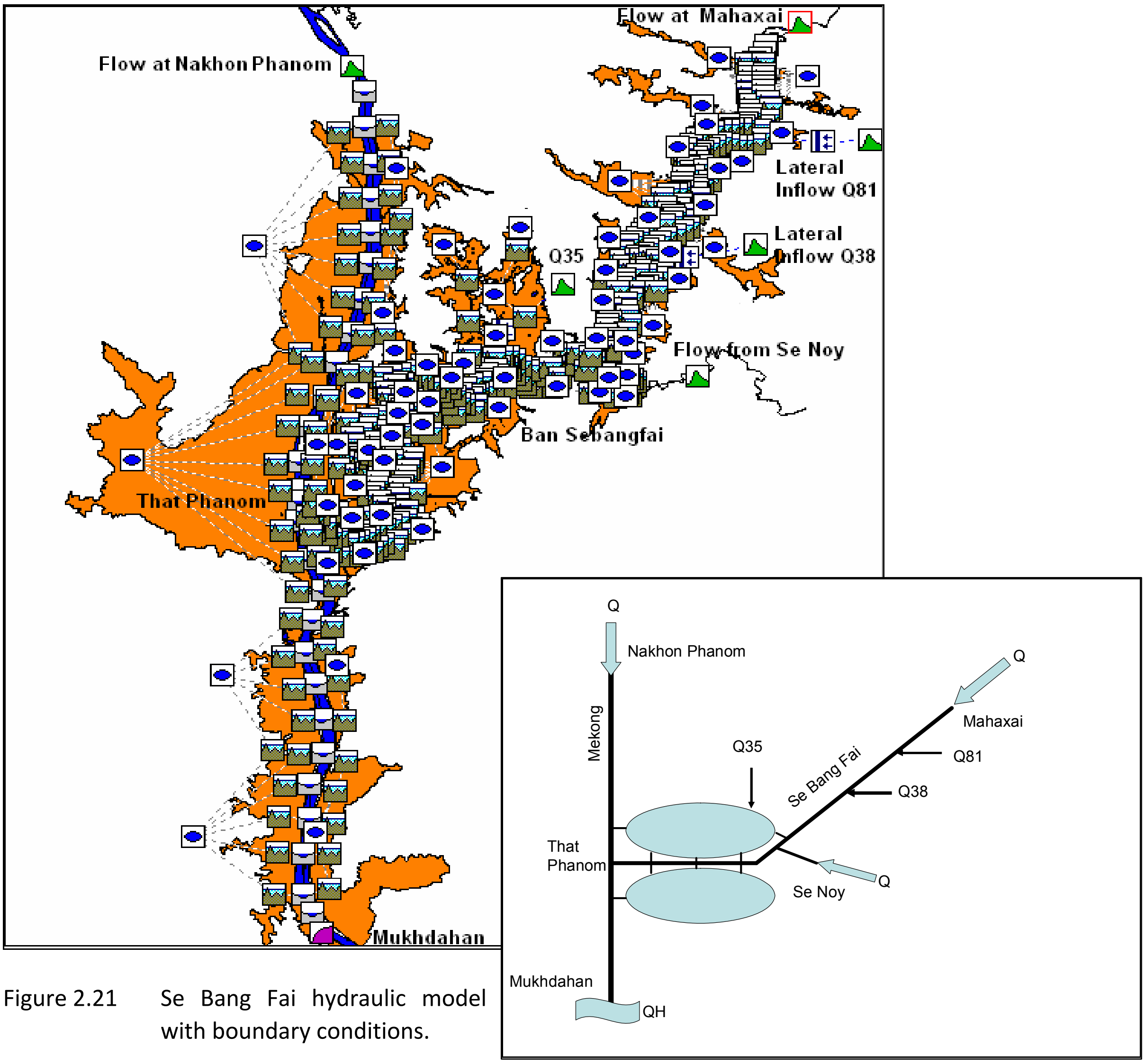


Figure 2.21 Se Bang Fai hydraulic model with boundary conditions.

The morphological development of the river bed, particularly of the Mekong, is taken into consideration by adjusting the hydraulic roughness of the river in accordance with the level changes for bank full discharge relative to the calibrated situation.

$$N_{new} = n_{cal} \left(\frac{h + \Delta h}{h}\right)^{5/3} \qquad (2.8)$$

where: h = water depth at $Q_{bankfull}$ [m]
Δh = change [m]

Also the Mukhdahan rating is adjusted to eliminate unwanted backwater effects on the levels at That Phanom. The hydraulic model is the run with same hydraulic boundaries again with adjusted Manning-roughness values.

Then by Monte Carlo sampling on the model boundaries interpolation is performed between the computed water levels for each grid cell in the hydraulic model to obtain a frequency distribution for the levels at each cell. Figure 2.22 shows an example of the frequency distribution at a location in the floodplain of the Se Bang Fai river, as derived from the Monte Carlo sampling method.

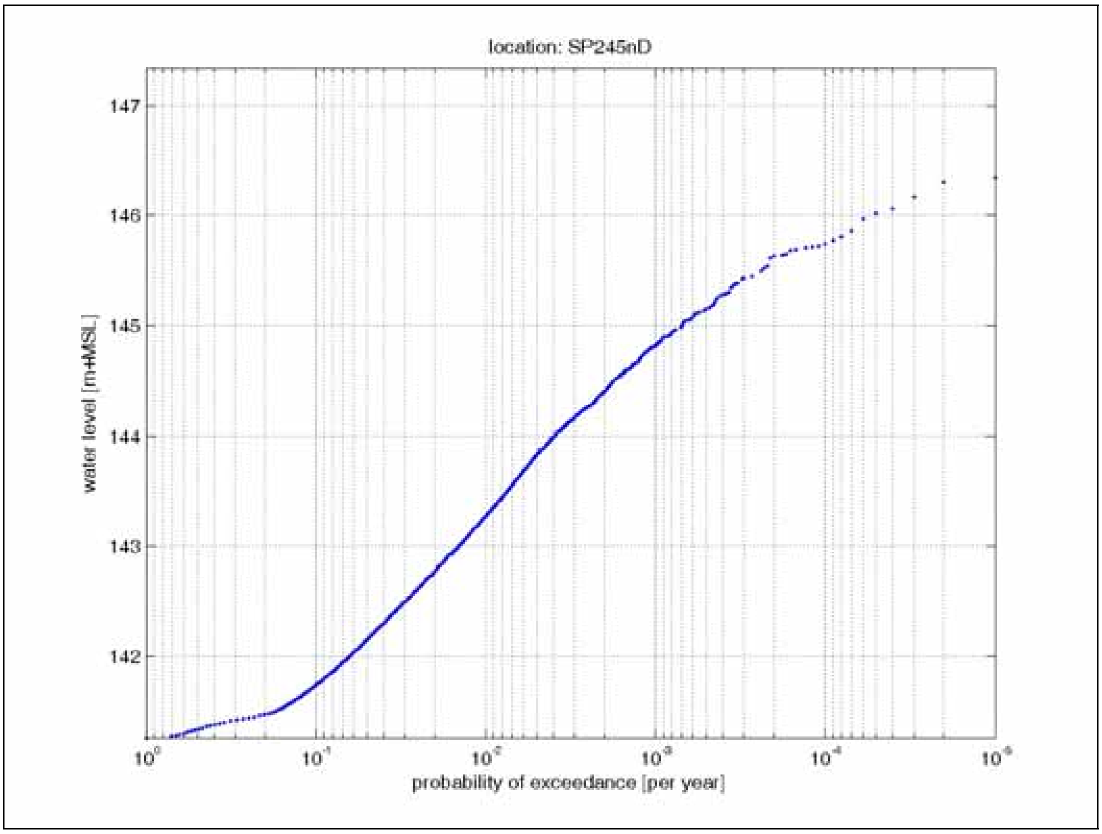


Figure 2.22 Derived frequency curve for maximum annual water levels at a location in the floodplain of the Se Bang Fai river.

Flood hazard mapping

Flood hazard mapping is described in Section 2.7.

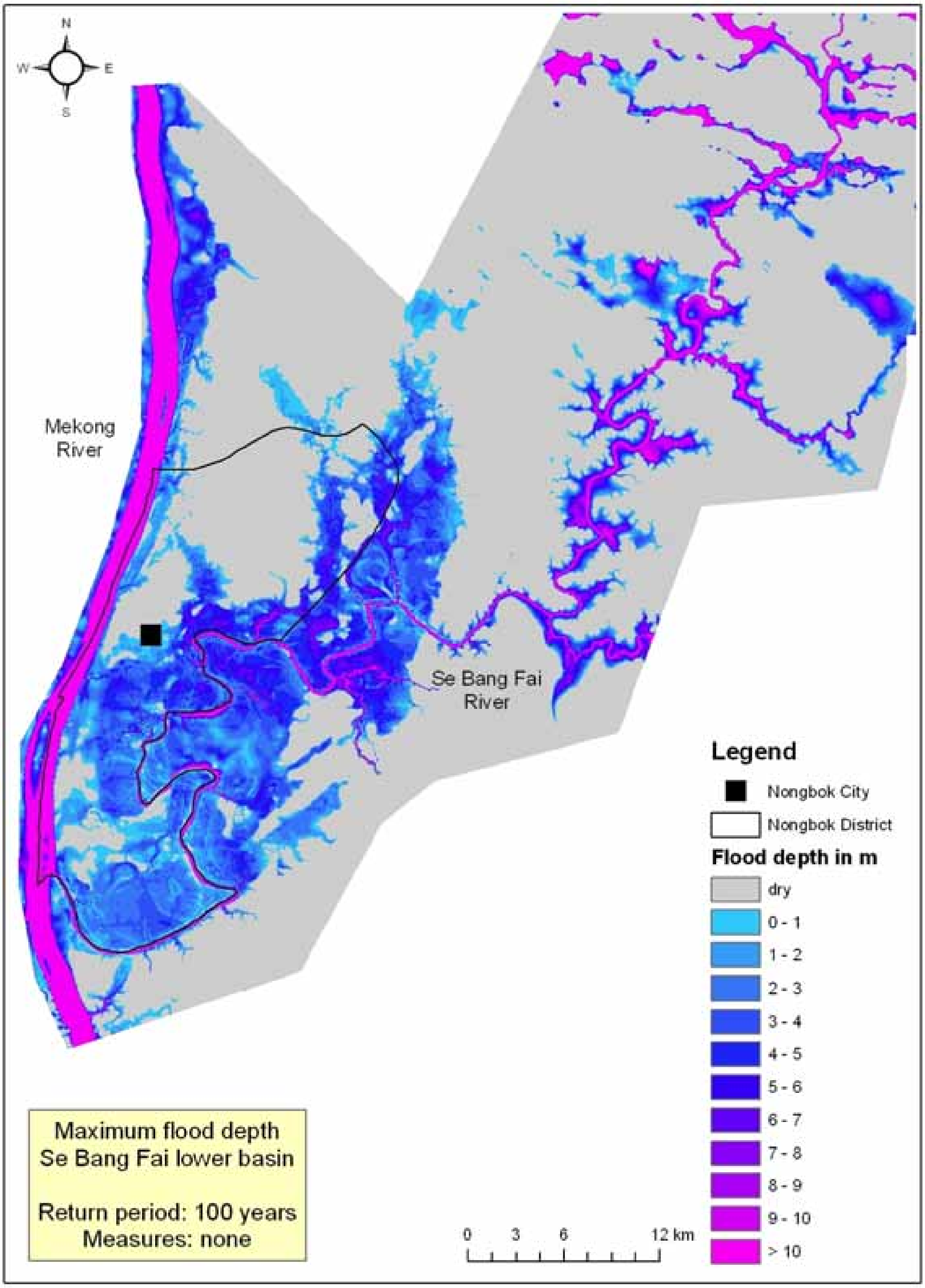


Figure 2.23 Flood depth and extent map Lower Se Bang Fai, T = 100 years.

2.6 Floods in the Mekong delta

2.6.1 General

The floods in the Cambodian flood plains and Mekong delta (see Figure 2.24) are classified as a special type of flood in the Lower Mekong Basin due to their special external and internal boundary conditions and the delta's unique hydraulic infrastructure. Whereas the flood levels near Kratie are mainly determined by the Mekong river only with some backwater from the Tonle Sap, further downstream more factors play a role. In the Mekong Delta in its downstream part the flood levels are essentially the result of upstream and lateral inflow, local rainfall and downstream water levels at sea. The flood in the Mekong delta is conveyed via the Mekong and Bassac Rivers and via their flood plains, including the *colmatage* canal system, which diverts and controls the flow from and to the River. In the delta the river regime is modified by the temporary storage in Tonle Sap Lake and in the Mekong flood plains, creating slowly rising and falling water levels.

Essentially, the hydrological hazard in the delta is formed by upstream and lateral inflow, local rainfall and downstream water levels at sea. The flood hazard in the Mekong Delta is determined by the frequency of flood water levels and flow velocities in the delta. These can be derived from the hydrodynamic Delta model based on the ISIS-software system. This model covers the Mekong Delta downstream of Kratie up to the Gulf of Thailand and South China Sea. It has been developed to compute water levels, flow velocities and discharges in the delta as a function of the hydrological hazard components.

To assess the flood hazard in the Mekong delta downstream of Kratie use is made of the fact that a relatively long historical discharge series is available for Stung Treng just upstream of Kratie. Furthermore, for the tributary inflow further downstream and to the Tonle Sap Lake long representative series have been created preserving the serial and cross-correlation with the Mekong flow. The series, which cover the period 1910-2006, are used as boundary conditions for a hydrodynamic model (based on ISIS-modelling package) to derive a 97-year series of water levels in the flood-prone areas. Further input to the model is formed by local rainfall, evaporation, water use and the year 2000 tidal conditions at the Gulf of Thailand and the South China Sea. The relevant statistics including the probabilities of flooding and related damages for return periods from 2 to 100 years can be derived directly from the series of water levels and depths computed with the model.

2.6.2 Data collection and field visit

The hydraulic model is calibrated to the delta conditions of the year 2000. To assess the flood hazard for development scenarios relative to the base case it is necessary that the hydraulic infrastructure pertinent to the scenarios is implemented. Hence, detailed information on layout, dimensions, capacities and operation of the hydraulic infrastructure and flood protection works relative to the model conditions is collected. In a field visit the existing infrastructure is to be compared with its schematization in the model. Where necessary the model has to be updated.

With respect to the hydrological boundary conditions the established 97-years series of upstream, lateral and downstream boundary conditions are a realistic representation of the variability of the hydrologic conditions in and around the Mekong delta.

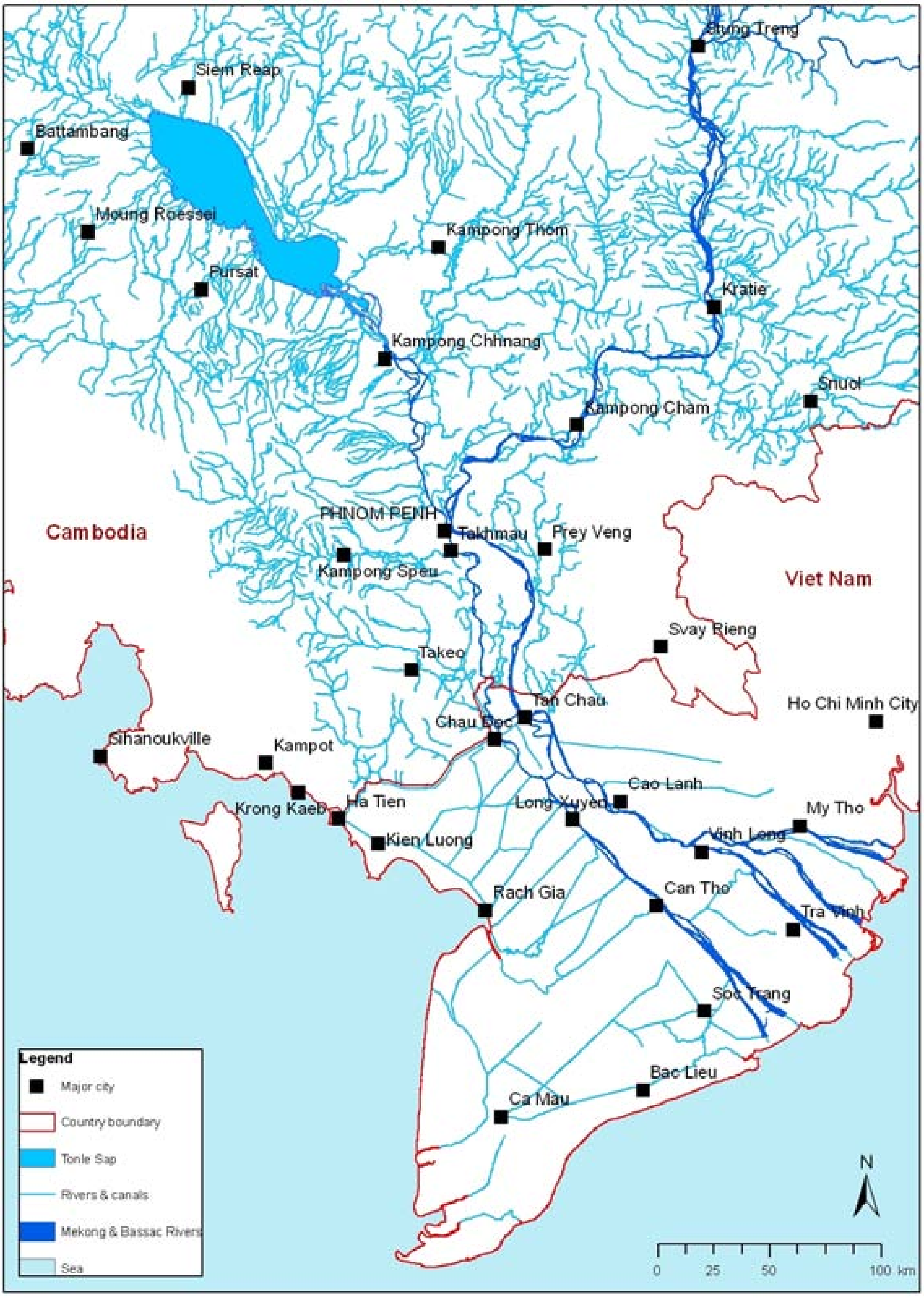


Figure 2.24 Hydraulic infrastructure of the Mekong delta.

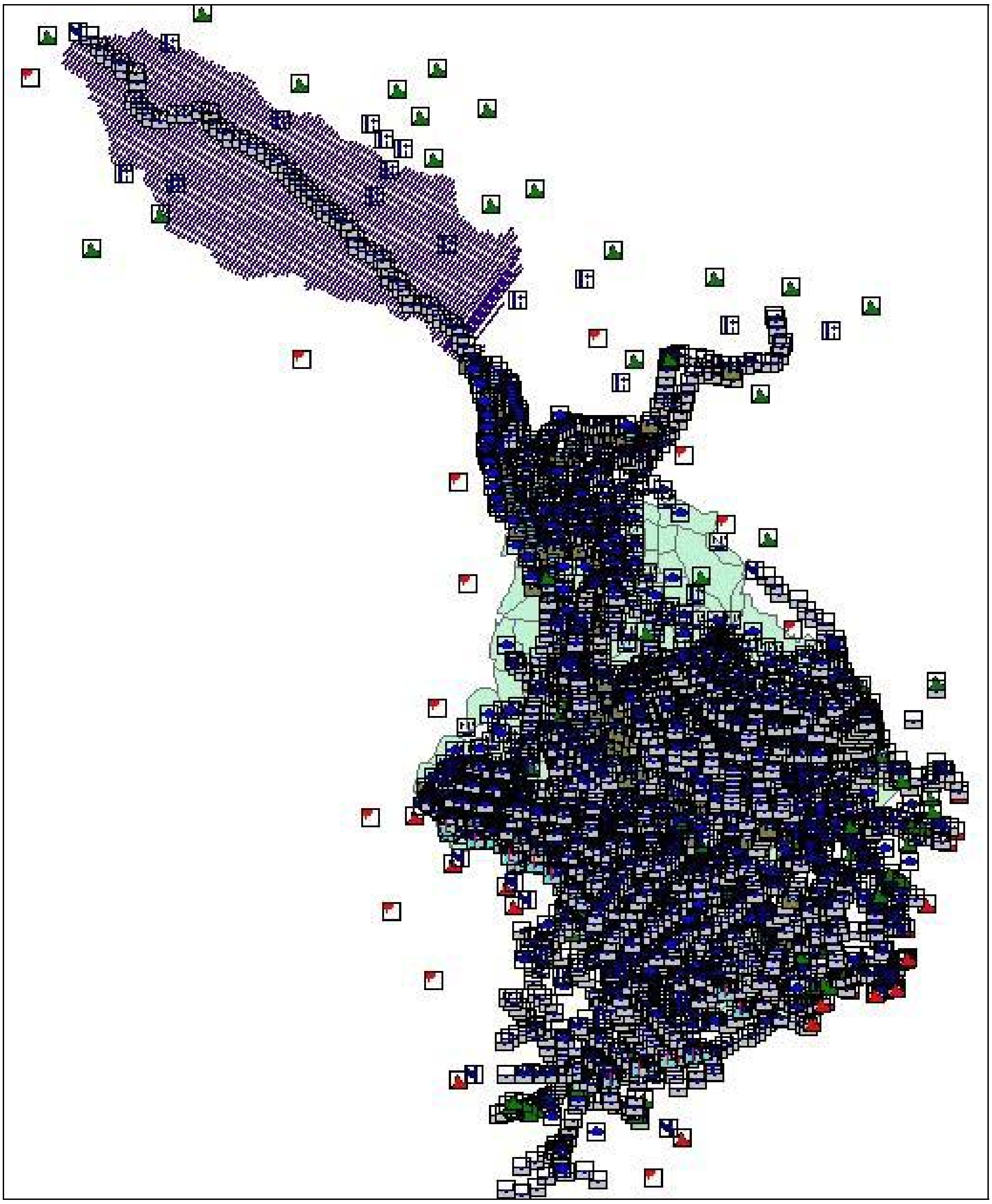


Figure 2.25 The schematization of the Mekong delta in the hydrodynamic delta model (ISIS) involves a large number of hydraulic nodes downstream of Kratie, next to 'reservoirs' (polygons) and 'river cross-sections' (polylines).

2.6.3 Database development

A database has been developed for flood hazard assessment in the Mekong delta including following type of data:

1. Model database, including schematization of the hydraulic infrastructure, hydraulic structure layout and operation and hydrological boundary conditions.
2. Result database, covering the simulated water levels and flow velocities of the base case and development scenarios as input for flood hazard assessment, etc.
3. A digital elevation model of the delta.
4. For distinct return periods the water levels, flood depth and flood duration.
5. Flood maps.

2.6.4 Hydrodynamic model development

The hydrodynamic model of the Mekong Delta is based on the ISIS modelling system for the simulation of unsteady flow in channel networks. It provides an implicit numerical solver for the de Saint Venant equations for 1 dimensional flow. At selected intervals it computes water levels and discharges on a non-staggered grid. Flood plains are included as storage cells connected to the stream channels via two-way weirs. The system was introduced to the MRC under the WUP-A programme and now serves as part of the Decision Support Framework (DSF). The model covers the Mekong Basin from Kratie to the South China Sea, including the Tonle Sap Lake and Floodplain, the Cambodian floodplains and the Vietnamese Mekong Delta. At various instances adaptations and recalibration have been implemented to the original one. The model used in FMMP-C2 is based on Delta Model Version-2009.

The schematization of the Cambodian and Vietnamese part of the delta in the model is presented in Figure 2.25.

The boundary conditions of the model comprise:

- upstream discharge at Kratie,
- tributary inflow to Tonle Sap Lake,
- tributary inflow to Mekong d/s Kratie and Tonle Sap Lake,
- rainfall,
- evaporation,
- water use, and
- downstream boundary condition at Gulf of Thailand and South China Sea.

Upstream discharge at Kratie

A 97-year discharge series has been established for Kratie, based on the record of Stung Treng, which is available since 1910. For several reasons preference has been given to the series of Stung Treng, including length of record, absence of gauge shifts and backwater effects, stable and predictable hydraulic control for high flows and availability of discharge records. The discharge measurements of Stung Treng, transferred to Kratie reveals excellent agreement with the current meter measurements at the latter location in the past. A serious problem and source of confusion is the difference between discharge ratings according to conventional discharge measurements and those based on ADCP records in use at Kratie since 2002. The latter, due to erroneous referencing of the measurements, lead to lower discharges for the same water levels then the ratings based on conventional discharge measurements, The differences increase for the higher stages. Therefore, unless concurrent current meter and ADCP-measurements are made at Kratie and Stung Treng, and discharge rating curves have been updated, it is advised to use the Stung Treng record, entirely based on conventional measurements. This record proved to be consistent with the flow at Pakse on the Mekong. Since the hydrodynamic model has been calibrated on recent discharge series at Kratie with flood volumes about 8% less then of Stung Treng the historical record of Stung Treng have been reduced with 8% to match with the discharge used for model calibration (note that this 8% reduction is not applied to the data and statistics presented below for Stung Treng).

The annual maximum discharge series and flood volume of the Mekong at Stung Treng are shown in Figure 2.26 and Figure 2.27.

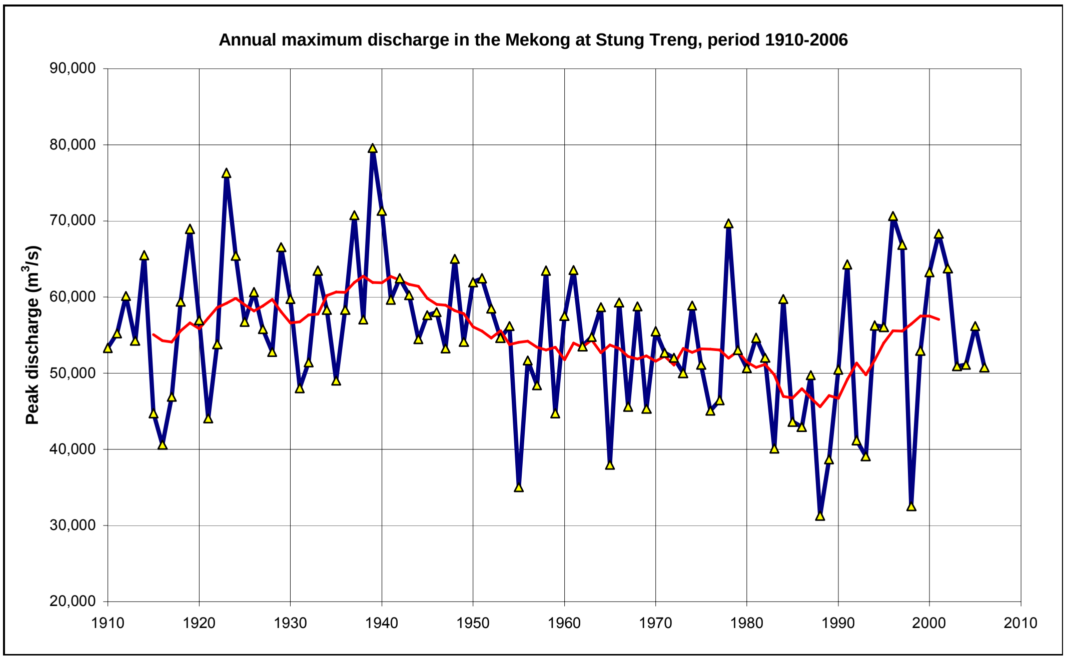


Figure 2.26 Annual maximum discharge at Stung Treng, period 1910-2006.

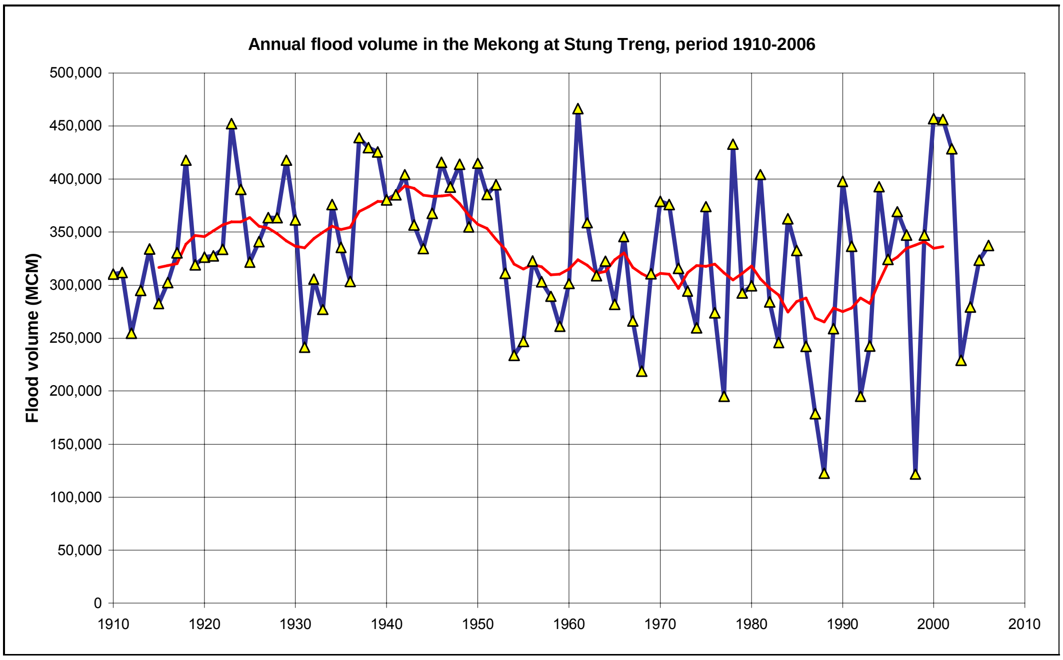


Figure 2.27 Annual flood volume at Stung Treng, period 1910-2006.

Tributary inflow to Tonle Sap Lake

The area draining to Tonle Sap up to the highways 5 and 6 enclosing the lake amounts 68,830 km^2. It comprises the drainage areas of 13 Stungs (rivers). Inflow series of daily discharges are available for the years 1997-2004. To extend the period to 1910-2006 a multiple regression equation has been used for the generation of monthly tributary flow. The flows have been regressed on the tributary inflow in the previous of month to preserve the serial correlation and the Mekong flow at Stung Treng in the same month to preserve the cross-correlation. A normally distributed random number was added to preserve the variance. The monthly flows were disaggregated to daily values based on their degree of resemblance with the observed years: daily values of observed years were scaled per month to the required generated value. The resulting seasonal inflow to the Tonle Sap is shown in Figure 2.28. The average monthly inflow as a percentage of the annual total in comparison to the Mekong discharge at Stung Treng is presented in Figure 2.29.

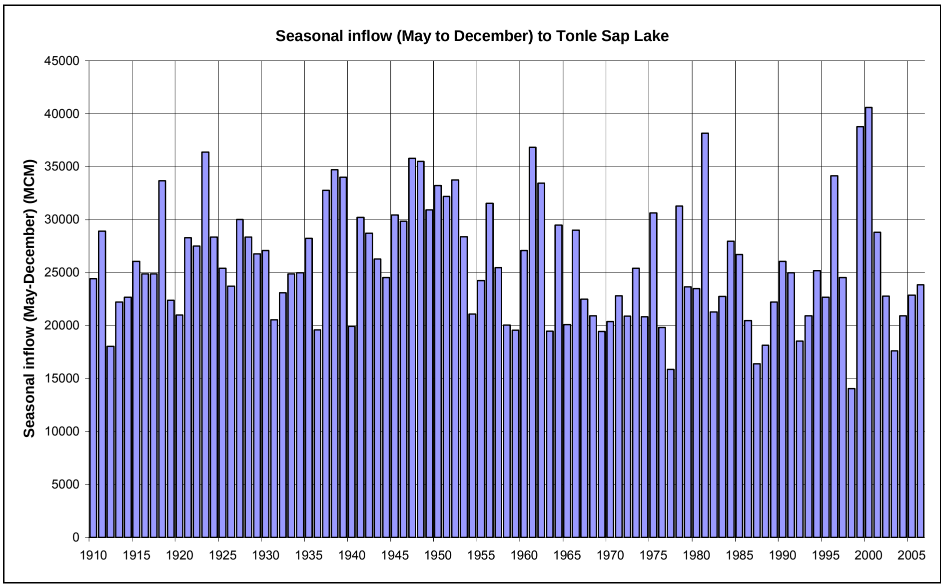


Figure 2.28 Seasonal inflow to Tonle Sap Lake, period 1910-2006, with period 1997-2004 observed.

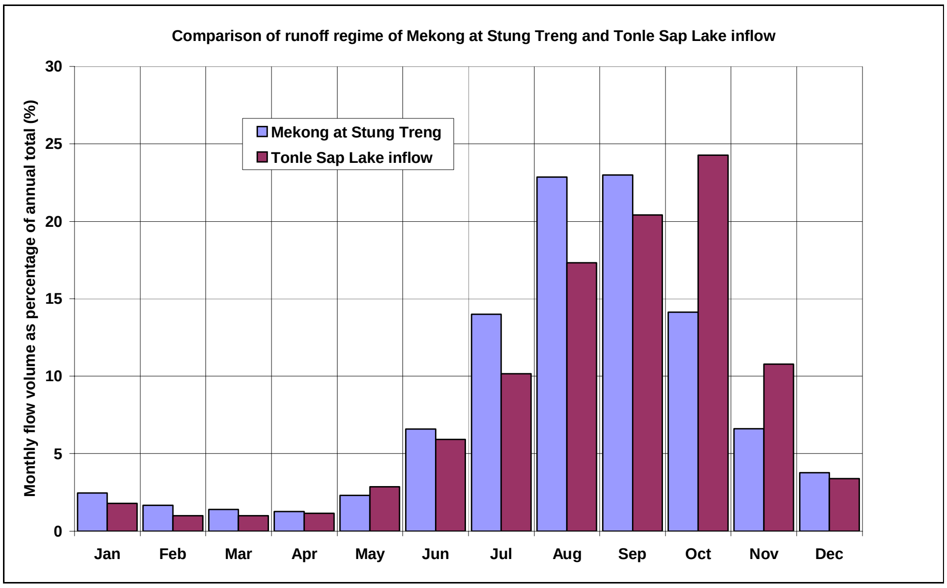


Figure 2.29 Average monthly flow regime of Mekong at Stung Treng and of Tonle Sap Lake as percentage of the annual totals.

Tributary inflow to Mekong

Apart from the inflow to the Tonle Sap Lake, the Delta Model also requires inflow series for the tributaries Prek Te, Prek Chhlong, Prek Thnot, East Vaico River, and West Vaico River. The daily flow series for the period 1985-2006 is available from the DSF files created by the SWAT model. Since the SWAT-series show no correlation with the flow in the Mekong a pragmatic approach was used to extend the series by applying a block-wise repetition of the series 1985-2006 for the years 1910-1984.

Rainfall

Daily rainfall series of 9 locations in Cambodia and of 5 locations in Vietnam are required as input to the hydraulic model of the Mekong Delta. Data is available for the locations for the period 1985-2006. The annual maximum daily values generally are in the order of 100 to 150 mm, occasionally with larger values up to 400 mm in Can Tho in 1985. Analysis shows that seasonal rainfall at the selected locations hardly correlates with Tonle Sap inflow and not at all with the flow in the Mekong. Hence, a block-wise repetition of the series 1985-2006 was applied for the period 1910-1984.

Evaporation

For the same locations as rainfall also evaporation data is required as input into the model. For the locations in Vietnam daily series is available from 1985 onward with the exception of 2002. The series available for Cambodia are shorter. In view of the limited variability of potential evaporation in a particular month from year to year, long term monthly averages have been applied in case data was not available.

Water use

At 128 nodes in the network of the Delta model water is abstracted for agriculture, domestic and industrial use. The variation in the total abstraction varies from about 1,400 m^3/s in January down to almost 0 m^3/s at the end of September. The total annual abstraction amounts 16.5 BCM. During the flood season the demand is about 4.4 BCM in total, i.e. an abstraction of less than 300 m^3/s.

Sea boundary

In total at 19 nodes water level boundaries are defined in the Delta Model. These boundaries are taken from hourly observations made at the 6 stations listed in Table 2.8. The hourly observations used in the Delta Model are records of the year 2000. From a comparison with long historical records it was revealed that the use of this series will not introduce a bias regarding peak water levels.

Table 2.8 Overview of water level stations at sea boundaries.

Station	**River**	**Province**	**Remark**
Rach Gia	Cai Lon	Kien Giang	Draining to Gulf of Thailand
Song Doc	Song Ong Doc	Ca Mau	As above
Ganh Hao	Ganh Hao	Ca Mau/Bac Lieu	Draining to South China Sea
My Thanh	Bassac	Soc Trang/Tra Vinh	Draining to South China Sea
Ben Trai	Cua Cung Hau	Tra Vinh/Ben Tre	Southern Mekong outlet, draining to South China Sea
Vam Kinh	Cua Dai	Ben Tre/Tien Giang	Northern Mekong outlet, draining to South China Sea

2.6.5 Flood hazard assessment

The Isis model is used to simulate the 97 years for which discharge series at Stung Treng are available. The main output of the model consists of water levels at all river sections and floodplains in the model schematisation. For each location, the series of 97 annual maximum water levels is derived from the model output. The estimates of the probabilities of exceedance of the water levels are then obtained with Gringortens formula (see equation (2.5) in Section 2.3.4). Since the series of annual maxima is close to 100 years, the estimated 100-year water level is by definition approximately the same as the maximum observed water level.

2.7 Flood hazard mapping

2.7.1 General

The MRC uses the ISIS hydraulic model (and sometimes the VRSAP model) to calculate water levels (+MSL) in part of the Mekong basin (see previous sections). The water levels are calculated for (among others) ISIS river cross-section nodes and reservoir nodes. A cross-section is a line perpendicular to the river in an area where the river can flow more or less unobstructed. A reservoir node represents a ‘reservoir’ or ‘cell’ (polygon), being a (mostly embanked) area with an even water level. Through interpolation of the node water levels with a GIS, spatially continuous water levels are established: see Figure 2.30. After subtracting the ground levels (+MSL, stored in a DTM or DEM) the water depth, i.e. the flooding level, is retrieved: see Figure 2.31 and Figure 2.32. Flood maps have been created for various flooding frequencies (return periods or probabilities), for year-maximum levels and for maximum levels up to 1 August. Flood damage and flood risk maps for agriculture, housing and infrastructure are based on the water depth maps and economic/ damage data.

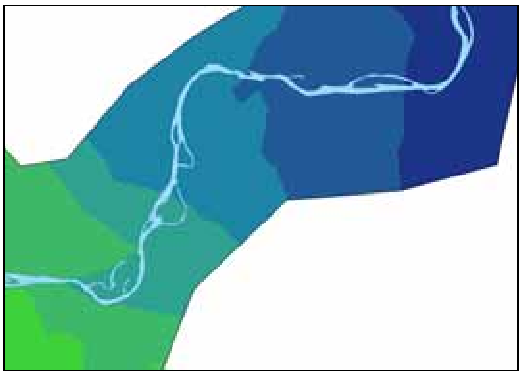


Figure 2.30 Water level map, based on interpolation of ISIS nodes.

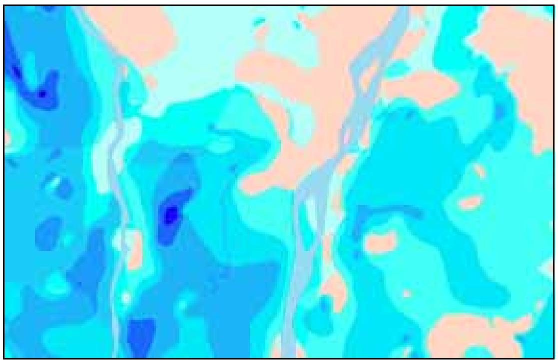


Figure 2.31 Water depth map, the result of a water level map minus the DTM (ground) levels.

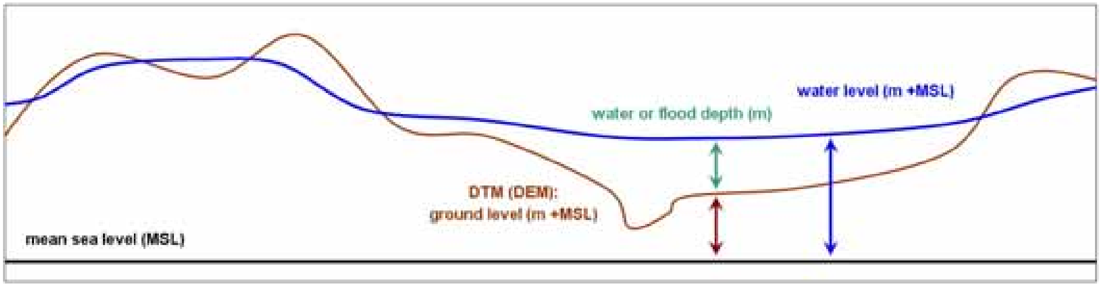


Figure 2.32 The water or flood depth is obtained by subtracting the ground level (DTM) from the water level (hydraulic simulation + GIS interpolation).

The map layers in a GIS need all to have the same datum and projection to be able to combine them. The standard datum at the MRC for the whole Mekong basin is Indian 1954, while the standard MRC projection is UTM (northern zones). As the data sets from the hydraulic model use another datum, they were converted to Indian 54.

The mapping of the hydraulic modelling results can be divided in three steps:
A: Transfer of modelling results (water levels) into a ‘georeferenceable’ table;
B: Creation of spatial data;
C: Creation of flooding maps.

The three steps (see Sections 2.7.2, 2.7.3 and 2.7.4) and each of its data sets and performed actions are schematised and numbered in the flow chart in Appendix 5. In the description below the flow chart numbering is followed.

2.7.2 Transfer of modelling results (A)

The transfer of modelling results (water levels) into a ‘georeferenceable’ table involves the following steps:

A-1, A-2:

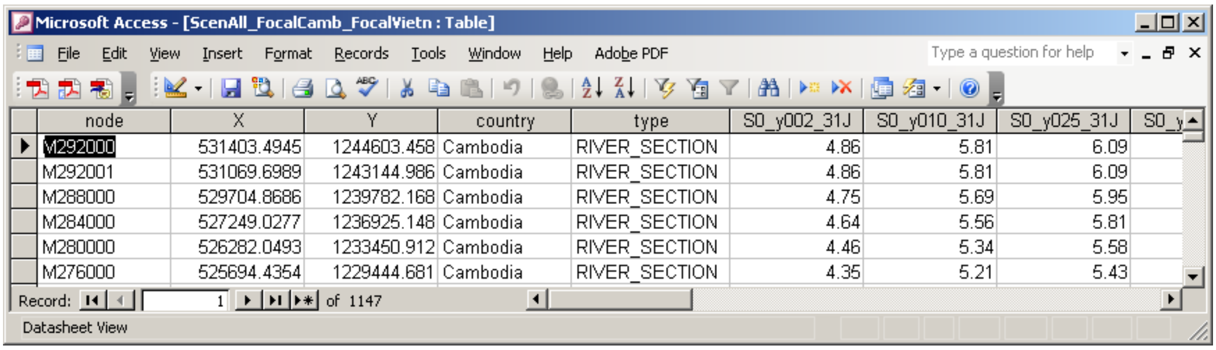
> The hydraulic model, ISIS, can export the (unique) node ID’s (names), their x/y-coordinates, and the calculated water level per node, into a comma-separated file (CSV).

A-3, A4, A-5:

> Some of the ISIS output may be processed with MatLab, as that software provides suitable tools to determine e.g. the maximum water levels associated with certain return periods. Otherwise, the data can be imported into a spreadsheet and transferred to a database like Access.

A-6, A-7:

> In Access separate data sets can easily be combined into one table by using queries (based on node ID’s). One table with all data reduces the work to be done in the GIS.



node	X	Y	country	type	S0_y002_31J	S0_y010_31J	S0_y025_31J	S0_y
M292000	531403.4945	1244603.458	Cambodia	RIVER_SECTION	4.86	5.81	6.09	
M292001	531069.6989	1243144.986	Cambodia	RIVER_SECTION	4.86	5.81	6.09	
M288000	529704.8686	1239782.168	Cambodia	RIVER_SECTION	4.75	5.69	5.95	
M284000	527249.0277	1236925.148	Cambodia	RIVER_SECTION	4.64	5.56	5.81	
M280000	526282.0493	1233450.912	Cambodia	RIVER_SECTION	4.46	5.34	5.58	
M276000	525694.4354	1229444.681	Cambodia	RIVER_SECTION	4.35	5.21	5.43	

Figure 2.33 Example of ISIS data imported into Access, with node info and water levels for different scenarios, various return periods (probabilities), and different periods of the year.

2.7.3 Creation of spatial data (B)

ISIS calculations are mainly based on node and water level info in a data-file (DAT-file, ASCII format). The cross-section nodes have x/y-coordinates specified; the reservoir nodes have also their central (point) coordinates in the DAT-file, but not their outline coordinates.

ISIS has also a GIS-component containing the river cross-sections (lines) and the reservoir outlines (polygons). The cross-section and central reservoir node coordinates in the GIS should correspond with the coordinates in the DAT-file, but the GIS files are not always updated simultaneously with the DAT-file update.

So for the reservoir outlines the GIS-files from ISIS have to be used, for the cross-sections there is the option to use the DAT-file or use the sometimes not updated ISIS GIS-files. Extracting the relevant cross-section info from a DAT-file for use in a GIS is time-consuming (the DAT-file for the Lower Mekong Basin contains more than 170,000 lines).

The methodology described below uses the ISIS GIS-data and not the DAT-file. It shows how to work around the inaccuracies in the GIS-files. If the ISIS GIS-files have been synchronised with the DAT-file the methodology is in essence the same, but some steps can be skipped (e.g. steps B-9 to B-12; see Appendix 6), also depending on the information supplied with the GIS files.

B-1: The data stored in the Access table is imported in ArcGIS and georeferenced using the x/y-coordinates.

B-2, B-3, B-4:
ISIS calculates with (among others) reservoir nodes and (river) cross-section nodes: see Figure 2.34. For the creation of maps, these two types need different processing. Therefore the one data-table originating from Access is split in two: one containing the reservoir nodes, and another containing the cross-section nodes. These two tables may be split again in case different areas inside the basin are considered (e.g. focal area in Cambodia and focal area in Vietnam).

B-5, B-6, B-7, B-8:
A spatial (GIS) component of ISIS contains cross-sections (polylines) and reservoirs (polygons). However, the relation between the calculation nodes and the lines/ polygons is not always one-to-one (if the GIS is not updated). The cross-section layer and reservoir layer are added to ArcGIS and duplicate lines or polygons are removed, if necessary.

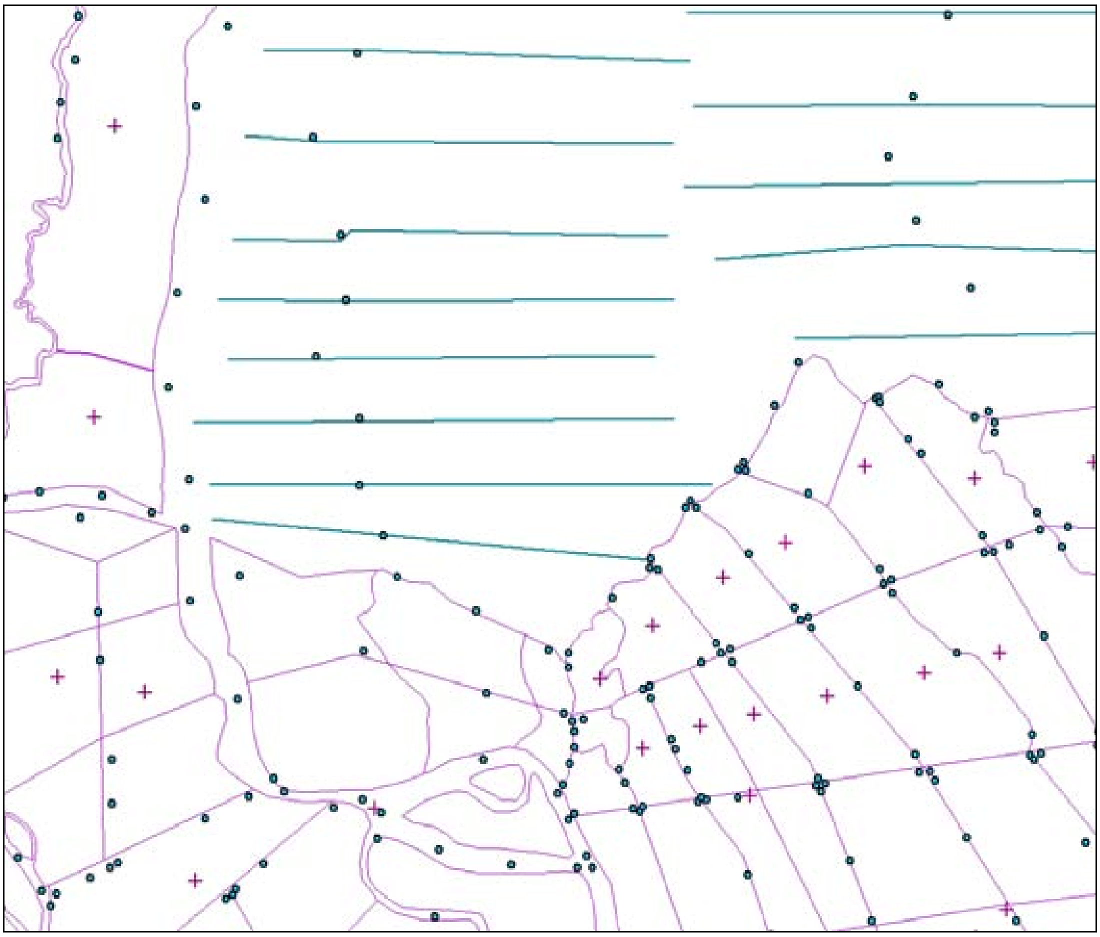


Figure 2.34 ISIS calculates with (among others) reservoir nodes (+) and cross-section nodes (dots). A spatial component of ISIS contains cross-sections (blue lines) and reservoirs (purple polygons). However, the relation between the calculation nodes and the lines/ polygons may not always be one-to-one if the GIS-files are not updated.

- Creation of a river cross-section point data set for interpolation

To be able to create a data set that covers every location within the area-of-interest with water levels or water depths, the node information from ISIS needs to be prepared for interpolation and conversion to a ‘raster’. That involves the nodes of the reservoirs and river cross-sections.

The cross-section polylines each represent a horizontal water level. If the GIS-files are not updated and do not contain the node names, only part of the polylines can be associated with cross-section nodes that have the ISIS water levels calculated. In that case the following steps were realised for the cross-sections:

B-9: In ArcGIS a buffer of 150 m is drawn around the cross-section polylines.

B-10: If only one ISIS cross-section node falls inside a buffer, the (attribute) data of the node is copied to the buffer. If more than one node falls inside, the buffer is deleted.

B-12, B13:
The polylines inside the (remaining) buffers get the data of the buffer (= data of the cross-section node) attached.

B-15: The polylines with attached data are then converted into a series of points (e.g. 15 per polyline), so all points have the data of the original ISIS cross-section node. The layer with the buffers can be removed (deleted).

- Creation of a reservoir point data set for interpolation

Like the cross-sections, reservoirs represent a horizontal water level. Basically the same is done here as for the cross-sections, only in two steps.

B-11, B-14:
The reservoir polygons that have only one ISIS reservoir node inside get the data of that node. If more than one node falls inside, the reservoir polygon is deleted (the GIS-files have apparently not been ‘synchronised’ with the DAT-file). The resulting layer contains reservoir polygons with the info of one reservoir node attached.

There are two options: 1) the reservoir info is merged with the cross-section info for joint interpolation to obtain the water level (in step C-2), or 2) only the cross-sections are used for interpolation. The choice depends on the number of available cross-section points in the area, the scenario, the flood type in the area, and the height of the reservoir embankments in the area. Steps B-16 and B-17 can be skipped in case of option 2.

B-16: Each polygon is converted into a series of points on the polygon outline (e.g. 15). These nodes have the same data as the polygon and thus as the original ISIS reservoir node.

- Merging the cross-section point data with the reservoir point data for interpolation

B-17: All original cross-section nodes (B-3), the derived cross-section points (from the polylines; B-15), all original reservoir nodes (B-4), and the derived reservoir points (from the polygons; B-16) are put into one layer (C-1). This layer (which may be split in e.g. a Cambodian and Vietnamese layer) will be the basis for water level point interpolation: see Section 2.7.4.

2.7.4 Creation of flooding maps (C)

The water level (flooding) maps will be created basically in two steps: 1) the point data, with water levels (B-15 or B-17, depending on the chosen option), will be interpolated to create a raster that will cover the area(s) of interest, and 2) the reservoir polygons will be converted into a raster and put on top of the raster resulting from step 1 (i.e. replace it's values).

There are many methods to create a continuous surface based on spatial points with values. The type of data, the spatial distribution of the points, the range in the values etc. determine the appropriate method. A few methods have been considered: IDW, Spline, Kriging, Natural Neighbours. Although no in-depth analysis has been done, the Natural Neighbours (NN) method and the Inverse Distance Weighting (IDW) method seem to be suitable for the LMB. Both NN and IDW have the option to include 'barriers' or 'linear discontinuities', which suits the inclusion of e.g. embankments or canals in the interpolation. Details on the interpolation methods can be found on Internet.

C-1, C-2, C-3:

The node/ point water level values (e.g. year-maximum water levels with a return period of 10 years) may be interpolated with the NN method (raster size is 50 m like DTM), resulting in a rectangular raster covering the area with the points used as input.

C-4, C-5, C-6:

A reservoir raster file is created by converting the polygons to raster, using the required water level values from the polygon attribute table as raster cell values.

C-7: The polygon-based raster (reservoirs; C-6) is put 'on top'[2] of the point-based raster (cross-section nodes, reservoir nodes; C-3) to assure that the reservoir areas have indeed a horizontal water level.

C-8, C-9, C-10:

The raster is 'cut out' more precisely using a mask (polygon) with the exact delineation of the area of interest (or using several masks to cut out various areas of interest). The result is a raster of the area(s) of interest with each raster cell (50 x 50 m) having a water level value. The raster values (e.g. year-maximum water levels with a return period of 10 years) can then be classified using suitable class limits.

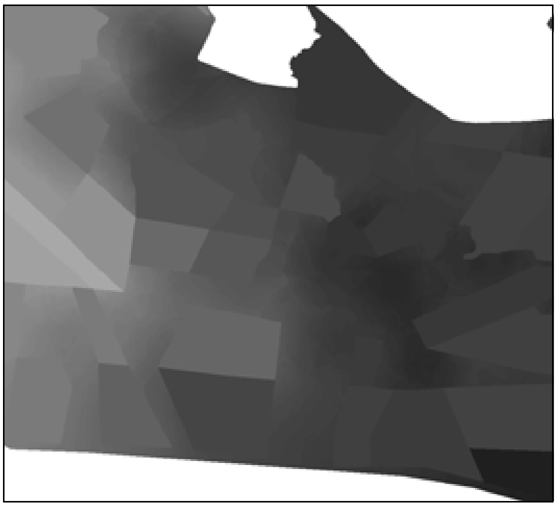


Figure 2.35 Example of a raster, with the reservoir raster (angular areas) superimposed on the point-based raster.

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[2] Using the ArcGIS Map Calculator with the 'con' statement (e.g. *con(isnull([reserv]),[xsec],[reserv])*)

C-11, C-12, C-13:

If water depth maps are required, the DTM with the ground elevation should be subtracted from the water level raster, and classified.

The previous steps result in a flood (water) depth map, similar to the one in Figure 2.36.

2.7.5 Data sources

Data retrieved from the ISIS model (with x/y-coordinates):

a) The polygons that represent reservoirs (i.e. areas with horizontal water level).
b) The polylines that represent river cross-sections (i.e. lines with horizontal water level).
c) Model calculation nodes for the reservoirs and cross-sections (not for spills etc.). These nodes (from the DAT-file) may not coincide one-to-one with the polygons and polylines mentioned above if the ISIS GIS-files are not updated (see introduction in Section 2.7.3).
d) The calculated maximum water levels (referenced to MSL) for various return periods, for various periods of the year (e.g. 'early floods'), for various areas ('focal areas'), and/or for various scenarios (measures).

Data used from the MRC/FMMP GIS:

e) DTM (Digital Terrain Model) or DEM (Digital Elevation Model). In 2009 two DTM's were being used at the MRC, *b-dtm50upd* and *dem0603*, both based on interpolation of 10 m contours (on some map sheets 20 m contours), spot heights and rivers/ streams (from 1:50,000 and 1:100,000 topographical maps, depending on the area). *b-dtm50upd* is a 50 x 50 m raster, while *dem0603* is a 100 x 100 m raster. Both have significant areas with errors: in *b-dtm50upd* it concerns two large areas near Kampong Chhnang and Kampong Cham, in *dem0603* many smaller areas all over the LMB. As *dem0603* is used in ISIS and the erroneous areas are smaller, this DEM has been used.

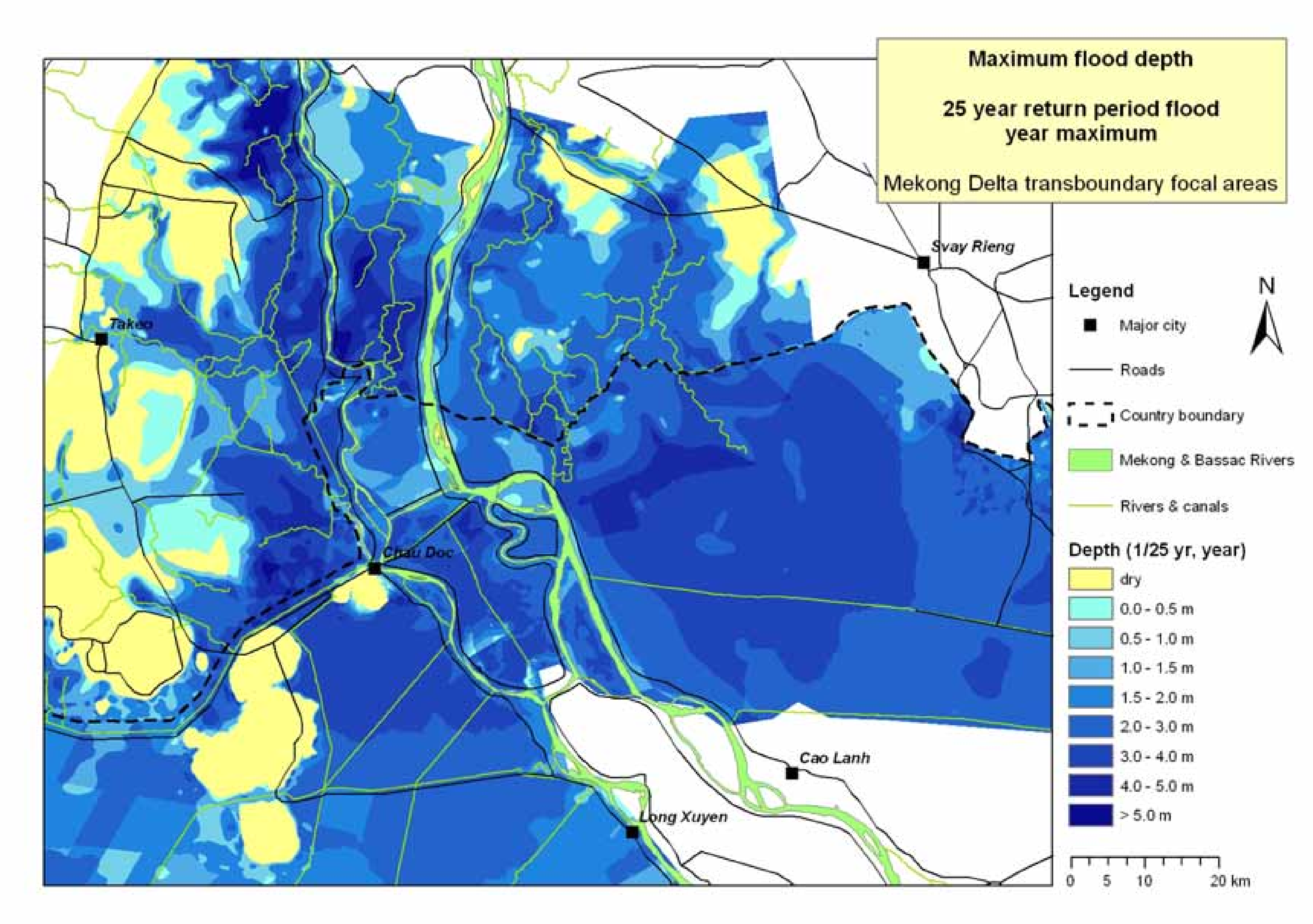

Figure 2.36 Example of a flood depth map.

CHAPTER 3

FLOOD DAMAGE ASSESSMENT

3 FLOOD DAMAGE ASSESSMENT

3.1 Introduction

This chapter focuses on flood damage assessment. It outlines the classification of damage and benefits (Section 3.2) and approaches for damage assessment (Section 3.3). Existing damage models (Section 3.4) and economic and financial issues in damage assessment (Section 3.5) are discussed. Methods for the assessment of other damage types are summarized in Section 3.6. In Section 3.7 is described how the results of damage estimates can be presented. In order to develop damage models data collection is very important and this topic is treated in Section 3.8. Finally, examples of damage assessments for the Lower Mekong Basin are presented in Section 3.9.

The next Chapter (4) will demonstrate how the results of damage assessment can be combined with flood hazard analyses to estimate the risk.

3.2 Classification of flood damages and benefits

3.2.1 Flood damages

The consequences of a flood encompass multiple types of damage. All these different types of consequences can be observed after large flood disasters, for example after the flooding of New Orleans due to hurricane Katrina in 2005. The term “flood damage“ refers to all varieties of harm caused by flooding. It encompasses a wide range of harmful effects on humans, their health and their belongings, on public infrastructure, cultural heritage, ecological systems, industrial production and the competitive strength of the affected economy. However, flooding may also have benefits and this topic is separately discussed in the next Section (3.2.2).

An overview of different types of damages / consequences is given in Table 3.1. The damage is divided into tangible and intangible damage, depending on whether or not the losses can be assessed in monetary values. Tangible damages can be directly priced in monetary terms, because a market value exists for the damaged goods or services. Other types of damages, such as casualties, health effects or damages to ecological goods and to all kind of goods and services which are not traded in a market and those are far more difficult to assess in monetary terms. They are therefore indicated as ‘intangibles’.

Table 3.1 Classification of flood damages.

	Tangible	Intangible
Direct	Physical damage to: - Housing, structure and assets; - Infrastructure and public utilities; - Agriculture.	- Loss of life; - Health effects; - Environmental damages.
Indirect	- Temporary relocation; - Cleaning & sanitation; - Loss of income; - Industrial production losses; - Others.	- Societal disruption; - Increased vulnerability of survivors.

Another distinction is made between the direct damage, caused by physical contact with floodwaters, and damage indirectly following from the flood. Direct damage includes, for example, damage to buildings, economic assets, loss of standing crops and livestock in agriculture, loss of human life, immediate health impacts, and loss of ecological goods. Indirect damages are damages caused by disruption of physical and economic linkages of the economy[3], and the extra costs of emergency and other actions taken to prevent flood damage and other losses, see e.g. (Parker *et al.*, 1987). This includes, for example, the loss of production of companies affected by the flooding, induced production losses of their suppliers and customers, the costs of traffic disruption or the costs of emergency services.

The main damage categories are:

1. **Direct and tangible damages**

- **Damages to properties and infrastructure**
  In the targeted areas such as houses, schools, offices, commercial & industrial buildings and installations, hydraulic works, energy, transportation and other infrastructures and supplies/assets of individuals and businesses. These damages depend on the magnitude and duration of the flood. The damages to properties are the costs of replacement or restoration of an affected structure and inventories.

- **Agricultural damages**
  Crop damages depend on the depth, timing and duration of a flood. The bigger the flood, the more submerged cultivated area sustains bigger losses. However, if flood occurs after harvesting, there would be no crop damage at all. Damage to livestock and agricultural equipment depends on the magnitude and duration of the flood. The damages to livestock are the costs of livestock lost or the loss of income due to a distress sale. The damages to agricultural equipment/tools are the cost of replacement or restoration of these assets.

2. **Indirect and tangible damages**

- **Costs of temporary relocation and rescue**
  are the costs that local government agencies and NGOs incur before, during and after the flood to support affected people living during the flood and recovering at after the flood.

- **Costs of cleaning and sanitation**
  after the flood are mainly labour mobilization by individuals, households, enterprises and institutions to clean their houses and buildings.

- **Income losses and higher costs of living**
  could 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 of time during high flood water level; Higher costs of living could due to temporary relocation, and the purchase of 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 illness**
  of humans and livestock related to poor environmental conditions and increased water-born diseases. These costs include additional cost of healthcare: for families and individuals, and additional expenditures by local government for disease prevention and treatment, and for sanitation control during the flood.

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[3] Alternative definitions of indirect damage exist. For example, Merz *et al*. define indirect damage as damage that occurs outside the flooded area (Merz *et al*., 2004). E.g. companies can lose supply and demand from the flooded area.

- **Other costs**
  include the negative impacts of flooding on tourism revenue, loss of income or revenue for people or enterprises outside the target areas, loss in social stability, problems in income distribution and confidence of people in the Government and other forward and backward economic linkages are omitted from the study as no data are available or could be collected on these issues.

Important indirect damages categories are the loss of life and injuries and the health effects. It is noted that part of these health effects could be monetized by estimating the (increased) cost of treatment and medical care. Other important indirect damages are environmental losses, e.g. due to pollution, and societal disruption in general. Methods for the estimation of loss of life are briefly discussed in Section 3.6.

3.2.2 Flood benefits

Flooding in the Mekong basin causes not only damages, but benefits as well. For a complete assessment it is important to also take these into account. Flooding has an important role in maintaining natural fishery, wetlands, and soil fertilities. They are primarily from:

- **Fishery**
  Flood water provides habitat for fishes breading grounds and nursing and growing environment. Natural fish is an important resource for people living in the LMB, especially Cambodia and Vietnam. The quantity of natural fish would be reduced in case of a low flood level; it depends on the magnitude, timing and duration of flood, but the best indicator is the flooded area.

- **Agricultural production**
  Flood water (i) brings sediments to the flood plain especially for acid sulphate soil areas; (ii) flushes toxic substances from the cultivated soil; (iii) kills the rats and pests; (iv) speeds up the process of plant residue disintegration; (v) improves soil structure; and (vi) provides soil fertility; This impact could be measured by net benefit from agricultural production after a year with a good flood as compared with a year with no flood.

- **Main land expansion**
  Flood water brings sediments to river mouths in Vietnam to make the Delta expanded into the sea. This impact could be measured as value of additional land formed by sediments from Mekong River.

- **Biodiversity conservation**
  Flooding plays an important role in maintaining biodiversity values for Mekong River Basin, especially in the wetlands in the LMD. There are a few studies on these positive impacts, but their values in monetary-terms are not available.

In general these benefits are associated with relatively small floods and processes that occur relatively frequently (e.g. annual or seasonal floods). The larger damages are generally associated with extreme events that are infrequent and have lower return periods. In the consideration of measures that prevent flooding it is also important to assess the adverse effects on the above benefits.

3.3 General approach for economic damage assessment

3.3.1 Scope of the analysis and level of detail

Before starting a damage assessment it is important to decide on the scope and level of detail of the damage evaluation. This depends on a) the spatial scale of the study, b) the objectives, c) the availability of resources, and d) the availability of data. These factors are outlined below.

a) **The spatial scope**
The size of the area under investigation is important. This size can vary from areas of national or even international scale to areas of local scale. Within could range from basin, country, district, village or even individual structure level. Due to the fact that very precise methods require more effort (i.e. time and money) than less detailed approaches and that the resources are usually limited, the most precise methods are often restricted to small areas under investigation, while studies with a research area of regional or even national size mostly have to rely on less detailed methods.

b) **The objectives**
The chosen method and the accuracy of the results of a specific study must match with the objective of the study. If the goal of the study is for strategy development and planning, a less precise (and consequently less costly and time-consuming) method might be sufficient. If on the other hand single flood protection measures have to be assessed, e.g. for a prioritization of investment, it is necessary to employ a more precise method. Nevertheless, it should be checked if it is worth being more precise, i.e. has it any effects on the results.

c) **The availability of resources**
Although it would be fine and desirable for every study to come to results with the highest level of precision, this is often not possible due to budget or time restrictions. If only a small budget and/or little time is available for a study, quick, easy and approximate methods have to be chosen in order to finish the study under these restrictions.

d) **The availability of data**
Indeed, the effort or costs to carry out a certain method of damage evaluation can be significantly reduced if necessary data already exists. Consequently, the availability of pre-existing data has an essential influence on the choice of an appropriate method. If, for example, adequate land-use data or a thoroughly developed set of damage functions already exists, this may facilitate the application of detailed approaches on a regional or even national scale. Furthermore, not only the question whether data are pre-existing, but also which data are pre-existing and available in a country or region can have a large impact on the choice of a method.

Selection of damage categories

The question in damage evaluation is which categories of damages should be included. On the one hand it would be desirable to take all types of damages from table 3.1 into account in the damage assessment. However, this may lead to extensive and costly studies and not for all damage types methods are available to assess and quantify those. Therefore it is often more practical to focus on the most important damage categories to keep the effort of the analysis reasonable. It is important that the selected categories constitute the largest part of the total damage. For example in the standardized damage method that is used in the Netherland the following main damage categories are considered: land use, infrastructure, households, companies and other. Within each main categories sub-categories are distinguished (e.g. agriculture, urban area, or recreation within the main category land-use).

Less important categories can also be included in a more simple way, e.g. by applying a typical damage multiplier. For "intangible" damage categories other approaches could be chosen to make these more explicit in the context of damage and risk evaluation in their own units, e.g. the number of lives lost (see for example Section 3.6 for a discussion of methods to estimate the loss of life).

3.3.2 Direct damage assessment

Methods for the estimation of direct economic damage to objects, such as structures, houses are well established, and the use of so-called damage functions is widespread, see below for further explanation and e.g. (Penning-Rowsell and Chatterton, 1977; Dutta *et al*., 2003; Kok *et al*., 2005; Jonkman *et al*., 2008) for further background.

To estimate the flood damage there needs to be insight in the following factors:

a) the intensity of flooding;
b) the number and type of land use functions affected and their value;
c) the susceptibility of land use functions against flooding.

These factors are schematically shown in Figure 3.1 and discussed below.

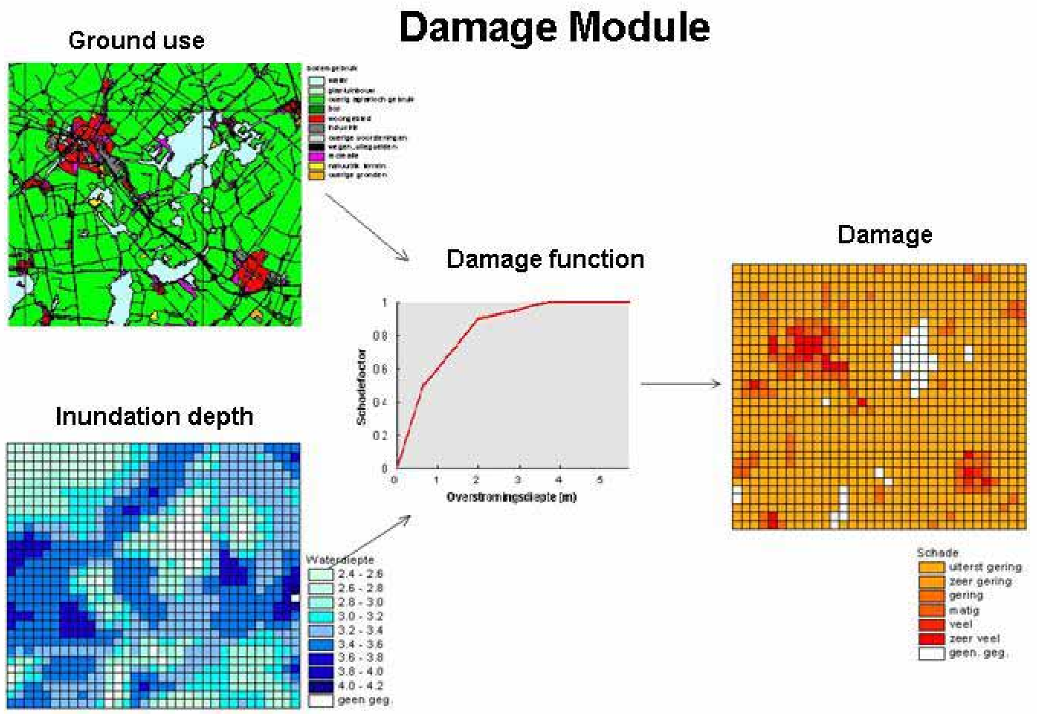

Figure 3.1 General approach for damage estimation.

Ad a **Intensity of flooding**

Data on the intensity of flood, i.e. the affected area, the flood water levels, inundation characteristics, have to be estimated. The area and depth of inundation are the most important information to be sampled here, but also the duration, time of occurrence, water velocity could have a significant influence on damage depending types of flood. Information on the intensity of flooding follows from the flood hazard assessment (see Section 2).

Ad b **Affected land use and values**

Depending on the number of damage categories that are considered different types of land use that correspond with damage categories are selected to be assessed. For example for damage to properties information on the location, number and type as well as the elevation of properties which could be affected by a certain flood event needs to be gathered. Such information is normally given by land use data. This can be either primary data from field surveys or secondary data, i.e. data from already existing sources. General information on data collection and surveys is given in Section 3.8.

Ad c **Susceptibility of land use functions against flooding**

In this step it is determined how the level of economic damage is related to the flood conditions. Often, so-called (*stage*) *damage functions* are used that relate the level of damage to the flooding conditions. The main parameter that is considered is flood depth, but it is noted that other flood characteristics, such flow velocity or flood duration could be relevant as well. Further details regarding damage functions are presented in Section 3.3.

The following general equation describes how the elements in the damage model are combined to estimate the total damage in a flooded area:

$$D = \sum_{i}^{m} \sum_{r}^{n} \alpha_i (h_r) D_{\max,i} n_{i,r} \tag{3.1}$$

where: $D_{\max,i}$ = maximum damage amount for an object or land use category i

i = damage or land use category

r = location in flooded area

m = number of damage categories

n = number of locations in flooded area

h_r = hydraulic characteristics of the flood at a particular location

$\alpha_i(h_r)$ = stage damage function that expresses the fraction of maximum damage for category i as a function of flood characteristics at a particular location r ($0 \le \alpha_i(h_r) \le 1$)

$n_{i,r}$ = number of objects of damage category i at location r

For each damage category a specific stage damage function is estimated and used in the physical damage assessment by correlating historical damage data with flood depth.

3.3.3 Damage functions

Damage functions relate the level of damage to the flooding conditions. In different countries such functions have been developed, for example in the Netherlands based on the 1953 flood event, see Kok *et al*. (2005). An example of a damage function is given in Figure 3.2 for damages to houses and their contents. The figure shows that the flood damage is 100 percent if the water depth exceeds 4.5 meters. As already noted, other damage functions have been developed in other countries. For example, in the United States the Federal Emergency Management Agency (FEMA) has developed the HAZUS model that includes damage functions for different damage categories[4].

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[4] see http://www.fema.gov/plan/prevent/hazus/ for more details

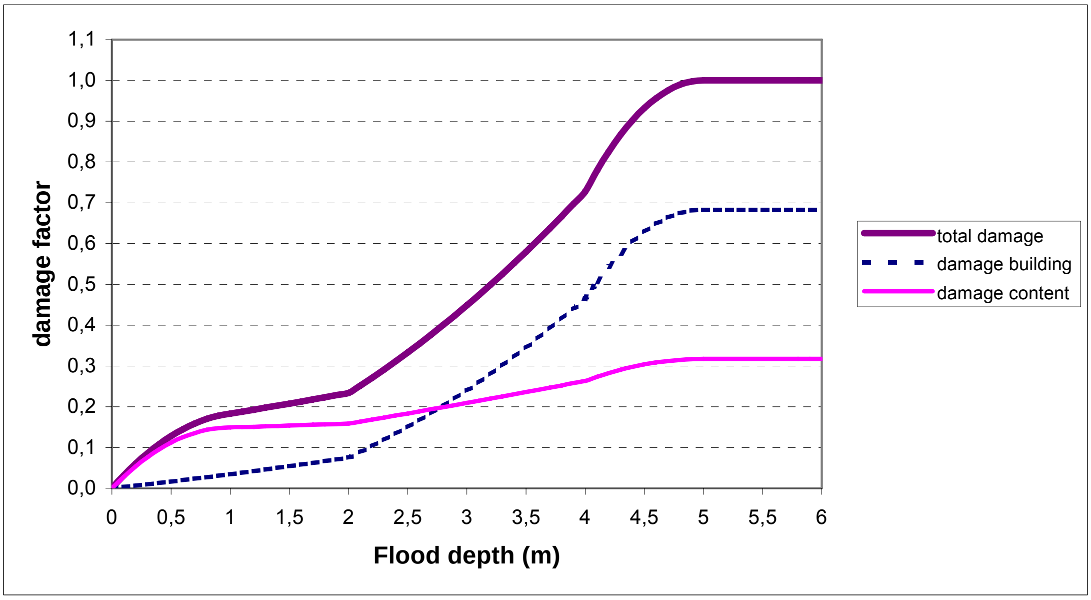

Figure 3.2 Example of a stage damage function for houses in the Netherlands (Kok et al., 2005).

Influence of flood characteristics on the damage function

Most stage damage functions include water depth as the main determinant of direct damage. However, it is noted that other flood characteristics, such flow velocity or flood duration could be relevant as well. Thieken *et al*. (2005) also investigate the influence of other factors, such as flood duration, contamination and preparedness for flood damage based on data for the 2002 floods in Germany. It needs to be mentioned that further factors like risk perception of the people in flood prone areas and their preparedness to be flooded can also influence the susceptibility of elements at risks and, hence, the potential size of the flood damage. Up to now such factors have not been included in damage functions − at least not explicitly.

In the application of damage functions to estimate the damage for agricultural land use, e.g. for crops or rice paddies, other factors are taken into account in addition to the flood depth. Firstly, the duration of the flooding can be taken into account as longer duration will cause more damage and / or could prevent harvesting. Secondly, there is a seasonal effect, as the damage will highly depend on the moment of occurrence of flooding relative to growth and harvesting pattern of the crops. A damage function has to be developed that reflects the relevant damage processes that are representative for the local type of flooding (moment during the year, duration) and characteristics of the land use (crop characteristics).

Relationship between structural damage and economic damage

An important source of economic damage is the structural damage to buildings, especially houses. Figure 3.3 shows how economic damage is connected to structural damage. The level of structural damage caused by the flood will be determined by the flood actions (or loads) and the building resistance (or strength) (Kelman and Spence 2004). The degree of structural damage depends on the intensity and magnitude of the flood actions, i.e. hydrostatic and hydrodynamic forces, and on the building’s resistance to flooding. The next step is the economic valuation of the physical damages. To convert the structural damage to economic estimates insight in the building’s pre-disaster market value and the replacement cost is required. Apart from damage to the structure, the damage estimation in monetary terms will also include damage to the inventory of the structure.

In the earlier presented damage functions the economic damage estimate is directly related to the flood characteristics. However, for some applications it could be relevant to have insight in the degree of structural damage and the number of damaged or destroyed buildings. In Appendix 2 existing methods for the analysis of structural damage have been summarized. For structural damage both the depth and flow velocity will be important. The level of structural damage is also important for human safety and loss of life as buildings are important shelters during flood events.

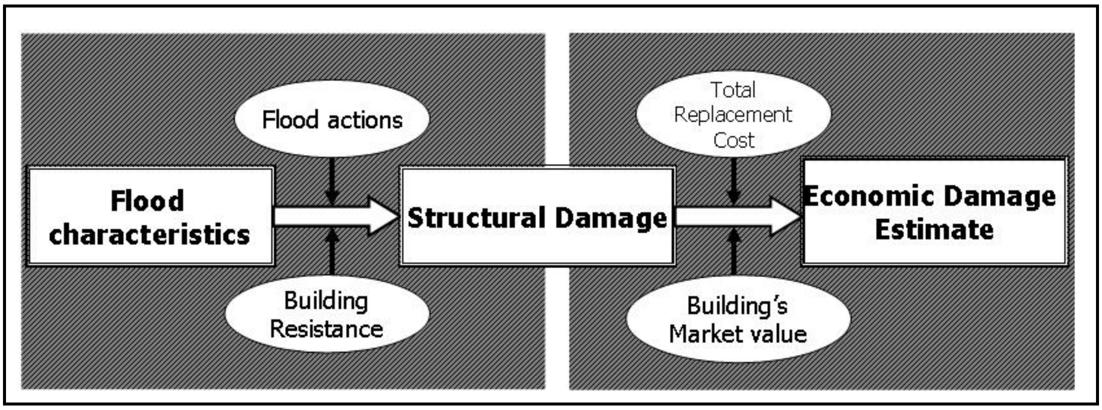

Figure 3.3 Scheme of structural flood damage analysis.

3.3.4 Relative and absolute damage assessments

There exist two basic approaches for damage assessment by means of damage functions. They differ in the way in which the information sources on land use, values of assets and damage functions are combined:

1. **The use of absolute damage functions for damage assessment**
   In this approach the damage functions describe the relationship between the flood depth or flood water level and the absolute damage value. This relationship can be determined by means of surveys on damage during historical floods. Combined with data on inundation depth and land use information, these absolute damage functions enable a direct estimation of the absolute damage amount for asset categories (agriculture, housing, infrastructure, etc.).

2. **The use of relative damage functions for damage assessment**
   In this approach the damage function describes the relationship between the flood depth and the damage as a fraction or percentage of the maximum damage value for a certain land use category. By bringing together land use information and asset values, the total value of assets at risk is calculated. By combining this total value with the earlier derived damage fraction the total damage is estimated.

Figure 3.4 schematically shows how the different elements are combined in the two approaches. The figure also shows the different formats of the damage functions for both cases. The main difference is that in the relative damage approach, the damage function produces a relative damage fraction (or percentage) as a function of water depth, whereas in the absolute damage approach a damage value follows directly from the damage function.

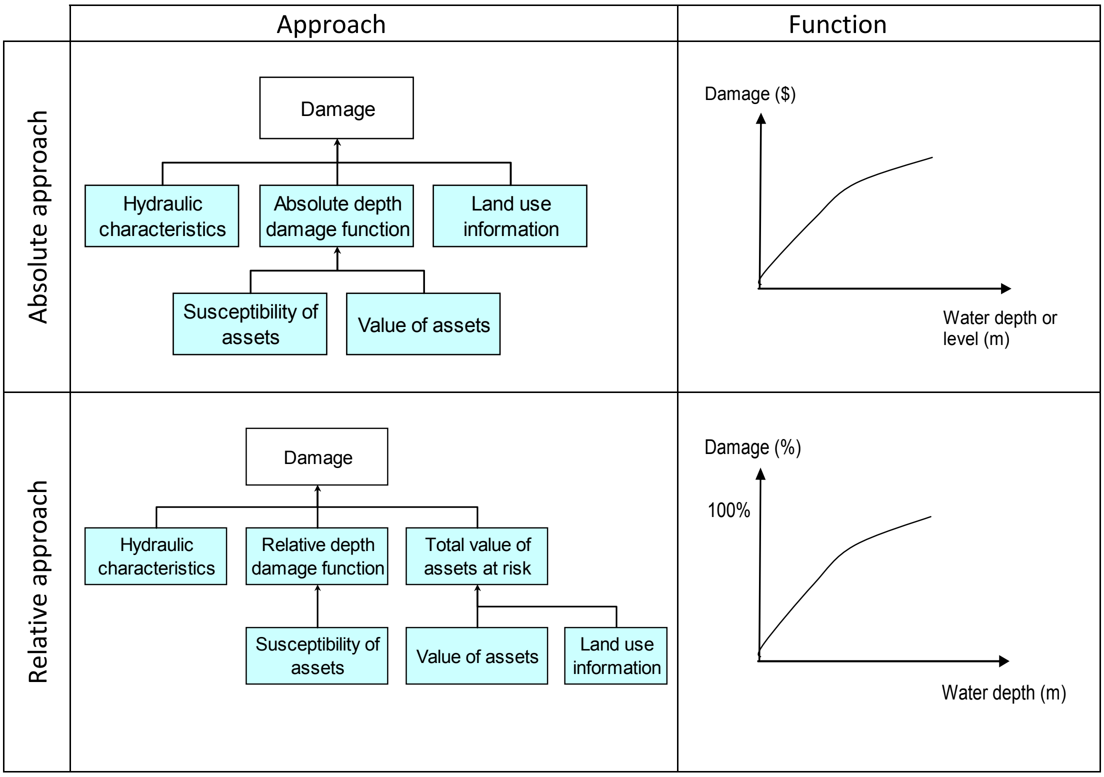

Figure 3.4 Absolute and relative damage approaches.

The two approaches have advantages and disadvantages. Absolute damage functions are only applicable to the region for which they have been derived. If a new region would have to be analysed, new data would have to be collected to derive the specific absolute damage functions for that area. Relative damage functions are more generally applicable. If they have been derived for a certain region and event, they can be applied to a wider region for which no historical flood damage data is available. However, extending the relative damage functions to other areas is only appropriate when damage processes and susceptibilities for these regions are similar. For example, it is then assumed that building types or agricultural land used are similar for these regions. The absolute damage approach is thus more suitable when large regional differences exist in the above factors.

Which of both approaches is chosen also depends on the kind of available data. For example if a comprehensive set of absolute damage functions already exists, the absolute damage estimation approach could be more appropriate. If on the other hand detailed data on the value of assets is at hand, the relative damage approach may be convenient.

An issue with using different data sets is the varying level of detail. If data at commune level is combined with data at district level and the results are presented at commune level, ‘false’ accuracy is suggested. One should be aware of this in all data processing steps of a damage assessment.

3.3.5 Assessment of indirect damages

Indirect damages are damages caused by disruption of physical and economic linkages of the economy, and the extra costs of emergency and other actions taken to prevent flood damage and other losses. This includes, for example, the loss of production of companies affected by the flooding, induced production losses of their suppliers and customers, the costs of traffic disruption or the costs of emergency services.

The losses due to business interruption and induced losses in other parts of the economy can be very significant, especially if important economic hotspots are flooded. This is the case for example, if an important airport if affected by flooding and has to be closed for a long period or if a cluster of important companies is affected. In general this effect is estimated by a model that includes the existing network of linkages within an economy. In such a model it can be investigated how the disruption of a one important facility or sector (e.g. an airport) affects other parts of the economy. This is generally done by so-called input-output models; see for example Van der Veen *et al*. (2003) for an example. However, these approaches have been investigated in academic literature and they are not yet readily applicable to full practice.

Therefore a more pragmatic approach is often chosen. The losses due to business interruption are generally estimated by assuming a certain interruption period (e.g. a number of months) and a cost factor that includes the lost economic activity (added value) and the number of affected employees.

If insufficient underlying data is available to estimate the indirect costs from models it is a more practical way to analyse the level of indirect damage by means of surveys. For a flooded area it can be analysed with surveys what the indirect damage categories are what the damage costs are for indirect damages. Eventually this gives information on the ratio between direct and indirect damages. With this ratio it is possible to estimate the indirect damage as a function of the direct damages. Further details on the application of this approach to estimate indirect economic damage to the Lower Mekong Basin are found in Annex 2 to the draft stage 1 evaluation report, entitled “Flood damages and flood risks in the focal areas”.

3.4 Damage models

For consistent decision-making it is desirable to have a more or less standardized approach for damage assessment on a higher aggregation level, such as a river basin or even a complete country. With this in mind, governments in several countries have developed standardized methods and software tools for the estimation of damage due to flooding as well as the risk and cost-benefit calculation.

Examples are the HAZUS methodology developed in the USA (FEMA, 2003) or the standardized damage model developed in the Netherlands (Kok *et al*., 2005). In these approaches the land use data and damage functions have been included in a computer model, so that the damage can be easily estimated if input information for a certain flood scenario is available. Based on this Dutch model a more generic model / tool has been developed under the name of DACA (Damage and Casualties Assessment) and it has also been applied to parts of the Lower Mekong Basin – see Textbox 1.

An automated approach is specifically attractive, when:

- A large number of damage categories and / or a large amount of land use data needs to be processed;
- The underlying data on land use and values of assets is available in GIS format;
- It is expected that a large number of calculations has to be made, so that is efficient to develop on automated approach. This could for example be the case when it is desired to analyze many different situations (e.g. situations with various alternative protection schemes and measures).
- A similar damage function can be used for different areas that are considered in the model, i.e. the land uses and housing types have to be comparable.

Textbox 1 DACA (Damage and Casualties Assessment) and its application to Thailand

As input in the risk-approach for evaluation of infrastructural measures on flood control, a tool was developed that provides insight in the consequences of floods for various user-defined scenarios. The tool, DACA (Damage and Casualties Assessment), is based on the Dutch damage and casualties assessment model 'HIS-SSM'. The assessment takes into account the spatial distribution of land use and its economic value, as well as the characteristics of flooding scenarios. By dividing the assessment over direct damage, production losses and indirect damage, a clear picture of the origin of the damage can be given. Using DACA, decision makers can evaluate land use planning, flood management and mitigation planning against their expected impact on flood damage. Also, DACA has proven to propagate collaboration between governmental agencies and departments due to its standard approach and transparency in methods and data.

Together with the Thai Department of Water Resources, the tool has been tested in a pilot area in Thailand. The province of Chiang Rai includes several rivers and using DACA a damage assessment was done for floods with different return periods (5, 25 and 100 year scenarios). The figure below shows the results of a damage estimate for the study area.

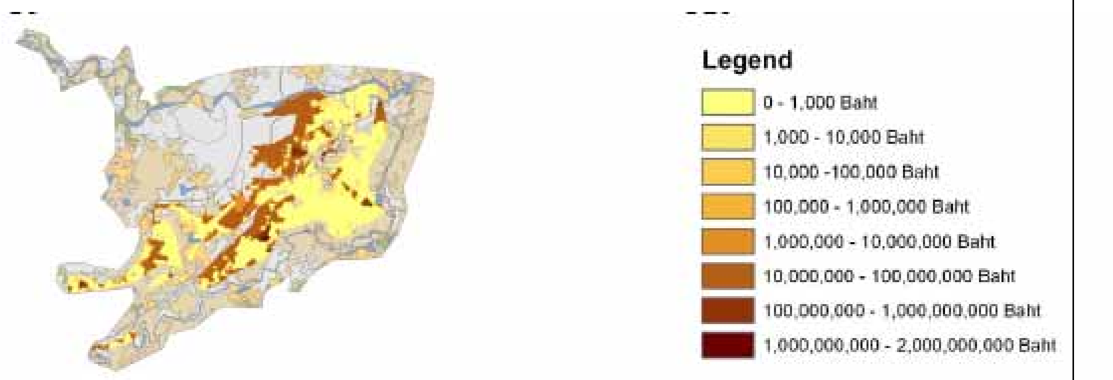

Figure 5: Maps of damage for three flood scenarios

Sources: "Development and Use/Demonstration of DACA in de Lower Mekong Basin" (Anonymous, 2009; Leenders *et al.*, 2009).

DACA has been developed by HKV Consultants and ITC in cooperation with Partners for Water. It is available with the Thai Department of Water Resources or through HKV Consultants.

3.5 Economic and financial issues in damage assessment

Within the context of damage assessment the economic valuation of damages and land use values is important. Without providing final answers some of the main issues are summarized below. Further discussion is included in Appendix 3 and provided in background literature; see for example (Messner *et al.*, 2007).

3.5.1 Financial vs. economic valuation

Various perspectives exist regarding damage appraisal. A first relevant distinction exists between financial and economic valuation. Financial evaluations look at damage from a perspective of a single person or firm, neglecting public affairs and focusing on the actual financial burden that individual or firm has to pay for. Economic evaluations have a broader perspective and want to assess the impact on national or regional welfare, including impacts on intangible goods and services. This broader economic perspective is the appropriate one to apply if calculations of flood damage are to be designed for supporting public policy decisions.

3.5.2 Estimating values of assets

For damage assessments it is important to have insight in the values of the objects and land uses that could be potentially damaged. The question is which economic value to assign.

The basis for valuation is the market price for an object or unit. The economic evaluation of goods and services which are traded in the market is a task that is relatively easy to accomplish. However, in more detailed assessments it could be assessed that several effects could “disturb” the market price and this should be taken into account in damage estimation[5].

Secondly, depreciated values should be applied in order to reflect the value of a good at the time when it is damaged by a flood. Using replacement costs is an overestimation of damage from a broader economic perspective, because replacement usually involves improvements: old goods which are damaged during a flood are usually substituted by new, more productive and better performing goods (Messner *et al*., 2007).

3.5.3 Time value of money

In an economic analysis it is important to consider the value of money over time. For example, a building that is worth US$ 50,000 this year could have a higher price next year.

From a more practical point of view the following is relevant. The (damage) values that are used in a certain damage model could be based on the data collected for a certain year in the past. When one is estimating damages for the current situation it is important to take into account a potential increase in the values and damages. This could be due to economic growth and/or inflation.

3.6 Loss of life and health effects

3.6.1 Introduction

Apart from approaches for the estimation of economic damage that have been discussed above, there are several approaches for the estimation of other damage types that are expressed in different units. These damage types include the loss of life and general health impacts. In this Section existing approaches and literature are briefly summarized for these damage types.

Although the presented approaches and methods are not yet part of standardized methods for damage assessment[6], their inclusion could be relevant for future more detailed investigations.

Finally, it is noted that the loss of life is sometimes expressed in terms of economic damage (e.g. a monetary value or damage sum per fatality). There is no uniform approach for the monetary valuation of loss of life and different approaches will lead to different values. In addition, valuing the loss of life will often lead to many ethical discussions. It is therefore often preferred to assess the loss of life separately and independently from the economic damages.

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[5] Since these ideal conditions are never fulfilled in a real-world market, adjustments are necessary to calculate the ideal ‘shadow price’ of the good under examination. This means market prices must be translated into shadow prices by excluding transfer payments like taxes and subsidies, and by converting monopolistic market prices into competitive market prices.

[6] One exception is the approach for loss of life estimation that is included in the standard model for damage assessment in the Netherlands.

3.6.2 Loss of life

One other very important consequence type concerns the loss of life. In recent years several methods have been developed for the estimation for loss of life, see (Jonkman, 2007). In general the following steps are needed to estimate the loss of life in a certain area:

1) Information regarding the flood characteristics;
2) An analysis of the exposed population and evacuation;
3) An estimate of the mortality amongst the exposed population.

The elaboration of these steps and the level of detail of the analysis depend on the type of flooding studied. Irrespective of the exact application, the output of hydrodynamic flood simulations can be used to estimate the flood characteristics. For large-scale flooding associated with dike breaching, e.g. in the Netherlands or New Orleans the steps 2 and 3 can be elaborated at a relatively rough level of detail. A general estimate of the possibilities for evacuation of the population can be made. In this analysis the effects of warning have to be taken into account. By analysing empirical information from historical floods new mortality functions have been developed. These relate the mortality amongst the exposed population to the flood characteristics. Mortality is defined as the fraction of the exposed population that will not survive a flood event. An example of such a mortality function is presented in Figure 3.5. This function is applicable to areas where the water is rising rapidly, so that people have limited time to find a safe place.

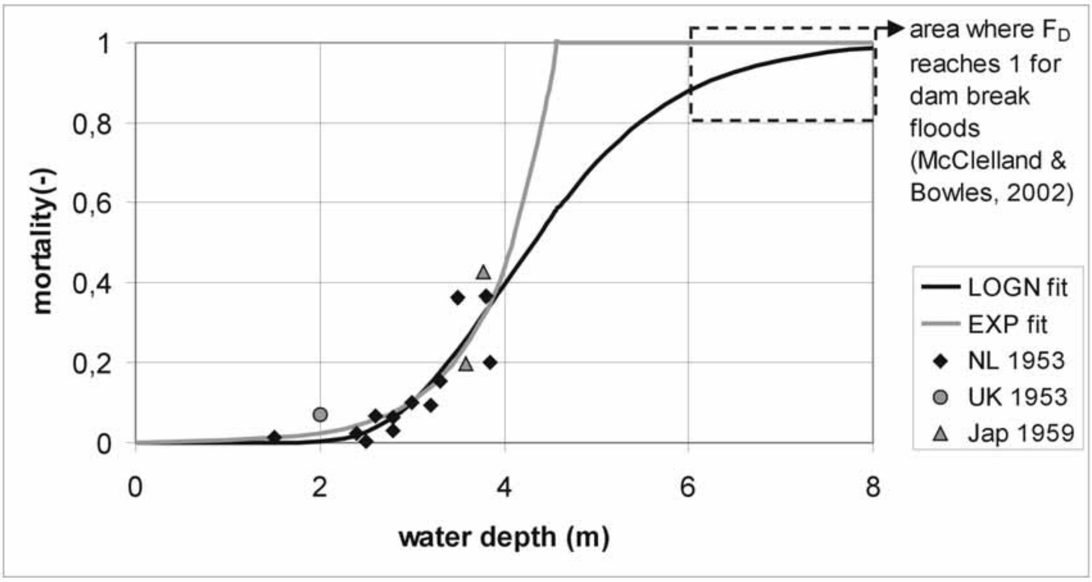


Figure 3.5 Example of a mortality function derived for large-scale flooding in the Netherlands (Jonkman, 2007).

For smaller-scale floods where velocities are more important, criteria have been developed to assess human instability (i.e. toppling) in flood flows. In general so-called depth-velocity products are used to indicate the combination of depth (*h* – [m]) and velocity (*v* – [m/s]) that would lead to a person's instability. Overall, the available studies and experiments show that people lose stability in flows in relatively low depth-velocity products. The obtained critical depth-velocity products for standing range from 0.6 m^2/s to about 2 m^2/s. This means that a flow with 1m depth and a velocity of 1 m/s would most likely lead to instability of most individuals. Further details on human instability are included in Appendix 4.

3.6.3 Health effects and social and environmental impacts

Important non-lethal health impacts of floods are injuries and illnesses. The occurrence of these effects and their importance will highly depend on (amongst others), the general health situation and medical infrastructure in the area affected (before and after the flood), climatic factors, type of flooding (fresh, salt water) and duration of flooding, Thereby there is no standardized approach for “predicting” these health effects. Hajat *et al*. (2004) and Ahern *et al*. (2005) give comprehensive overview of the available information regarding health impacts of floods.

In addition, longer term psychological health effects can occur amongst the population due to flooding. Some evidence exists regarding connections between psychological health effects and post flood mortality, see e.g. (Bennet, 1970).

Flooding will also have adverse effects on the environment and the social system. These damage types are generally analysed by means of qualitative / descriptive methods.

3.7 Presentation of damage assessments results

The results of flood damage assessment can be presented in different ways. Assuming that flood damage is calculated for a given flood scenario, the following presentations are possible:

- The damage number / amount for the flood scenario (in $ or another currency);
- The absolute damage value by category and the distribution of the total damage over the categories;
- To support the damage estimate “underlying” numbers such as numbers of flooded houses, or flooded hectares of farmland could be presented;
- Damage per hectare: indicating the “damage density” in the area.

As the effects of a flood are spatially distributed it could be relevant to present maps that give information on the damages. This is possible by means of geographical information systems (GIS): see Section 2.7. The resolution of these maps and the level of spatial detail depend on the (spatial) scope of the analysis and the data available.

The damage per hectare can be determined precisely if the underlying data (e.g. land use and values) is available at a high spatial resolution. It is also possible to determine the averaged damage per hectare over a larger area. This can be done when damage functions are available for a larger area, e.g. a district.

Presentation example of a damage assessment

As an example a presentation of a damage assessment for a flood scenario in the Netherlands is shown. The flood scenario concerns the flooding of the densely populated province South-Holland due to an extreme coastal flood. An area with in total 1 million inhabitants is flooded in this scenario and the consequences are therefore very large. The total damage for this scenario is estimated with the Dutch standardized damage model and the damage is estimate to be around 23.7 billion Euros.

Table 3.1 gives an overview of the distribution of the total damage over damage categories. The spatial damage distribution for a flood scenario in the Netherlands is given by Figure 3.6, showing the density of damage per hectare. These results are used in flood risk studies and discussions on the revision of the national policy on flood protection in the Netherlands.

Table 3.2 Distribution of damage over damage categories for a flood scenario for South Holland (Jonkman *et al.*, 2008).

Damage Category		Direct damage (mln. EUR)	% of total damage
Residences and inventory		16,000	69%
Commercial and public buildings		2,300	10%
Vehicles		40	0%
Infrastructure		300	1%
Airports		500	2%
Agriculture		1,900	8%
Direct damages due to business interruption		2,700	11%
	Total	23,740	100%

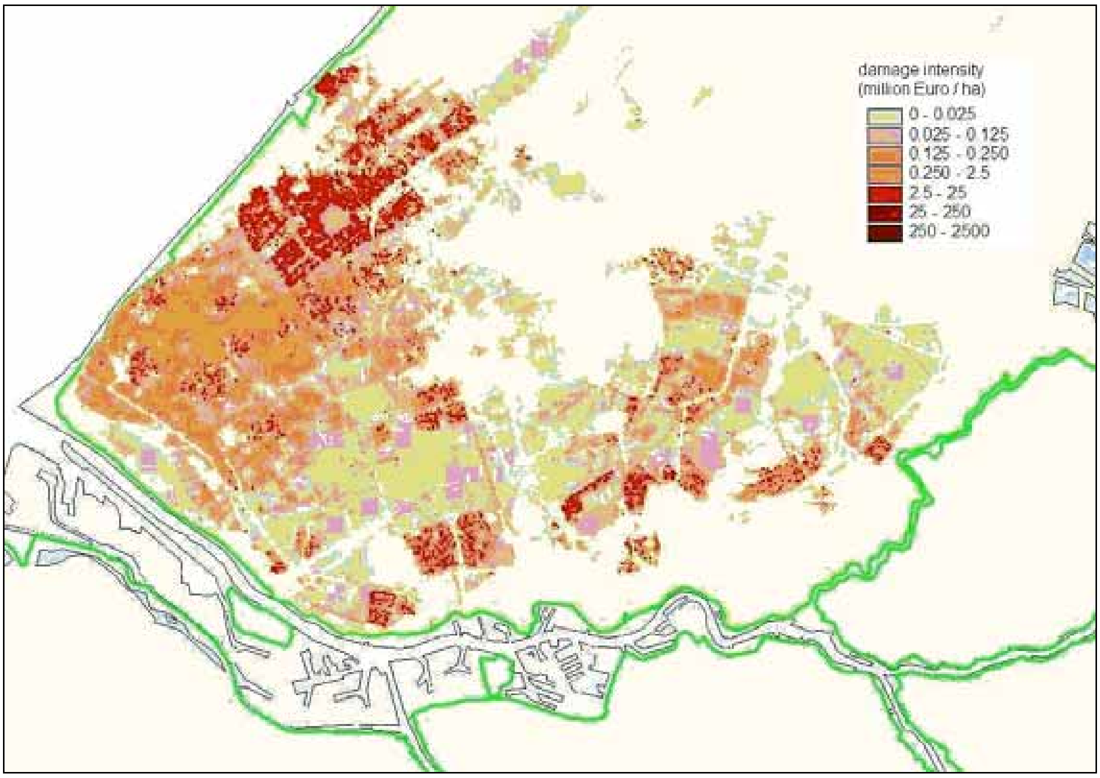


Figure 3.6 Damage intensity per hectare of the flooding of the area South Holland in the Netherlands.

3.8 Data collection

If no damage functions are available it is necessary to collect data for historical flood events to derive damage functions and indicators. The table below gives a general overview of the damage categories, their definition, the type of data and sources that could be utilized to collect data, and a summary of data items that could be collected. The table is based on the presented general classification of flood damages (see Section 3.2.1). As part of the data collection it is also relevant to collect data on benefits of flooding.

The table below could be seen as the desired list of information for several items. In practice a data collection and processing methodology has to be developed that yields the required information, given the availability of secondary data, time and budget constraints. In Section 3.9 it is further elaborated how this approach has been applied in Stage 1 of the FMMP-C2.

Table 3.3 Overview of Flood Damage Data

Category	**Definition**	**Type**	**Source of data**	**Summary of data items that could be collected**
Direct damages				
Loss of life and injuries	Reported number of deaths, injuries and people missing due to the flood	Secondary data	District/Provincial level direct flood damage reports	No. of deaths No. of injuries No. of missing
Damage to properties and infrastructure.	The estimated value of replacement or restoration of an affected structure and inventories in the targeted areas such as houses, schools, offices, commercial & industrial buildings and installations, hydraulic works, energy, transportation, infrastructures and supplies/assets of individuals and businesses			No. of houses collapsed or damaged No. of business collapsed and damaged Km of roads No. of schools/classrooms No. of irrigation schemes Etc. based on the actual indicators that are available in the Provincial & District damage reports
Crop damages	Agriculture land inundated or measure of agriculture production lost, food and seed stocks damaged			Ha of crops destroyed No. of fruit trees destroyed Ha of land damaged/covered in sand Tonnes of expected harvest lost Stocks of produce and seeds lost
Livestock damages	Drowned livestock and loss of income due to distress sale			Dead poultry, dead large and small livestock
Damages to fishery	Damaged aquaculture and fishing gear			Fish/shrimp ponds damaged Fish cages, rafts and traps damaged/lost Boats lost
Damage to paddy	Inundation depth-damage relationships and effect of flooding duration and timing on net benefits	Primary data	Focus Group Discussion	Hypothetical flood damage to paddy in relation to inundation depth and timing of floods
Damage to houses	Inundation depth-damage relationship and house value	Primary data	Household/ business survey	Actual and hypothetical damage to houses as percentage of house value in relation to inundation depth

Category	**Definition**	**Type**	**Source of data**	**Summary of data items that could be collected**
Indirect damages				
Cost of illness	Costs associated with increased incidence of water borne diseases compared to condition of no flood. Includes additional cost of health care that families and individuals spent on flood-related illnesses; and additional expenditures from local government for disease prevention and treatment and for sanitation control during the flood	Primary data	District authorities, line agencies	Amount spent by individuals on flood related health care Loss of labour from flood-related disease Amount spent on drugs, campaigns, care for disease prevention
Cost of temporary relocation and rescue	Costs by local government and NGOs incurred before, during and after the flood	Primary data	District, NGOs	Transport, temporary shelter, provision of food and drinking water, etc.
Income losses	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 of time during high flood water level		Household survey Business survey	Cost of repair/reconstruction of residential structures, including: Hypothetical damages to the residential structures based on flood levels Agricultural assets/incomes, crop losses Livestock losses, fish/shrimp losses Other HH income sources (e.g., home-based businesses, hired labour) Loss of labour days Health costs Damage to business structures, equipment and inventory Losses in revenues and employment Private expenditures for flood protection
Higher cost of living	Due to relocation water, food and fuel has to be purchased that otherwise would be available on the farm			Purchase of food, water, fuel, etc.
Cost of prevention measure	Preventive measures			Sand bags, etc.
Cost of cleaning up	Cleaning houses, shops and other buildings			Mainly labour
Benefits				
Flood benefits	Positive aspects of flooding for agriculture, fisheries and otherwise	Primary data	Focus Group Discussion	Household benefits from fishing the flood waters, fertility and pest control etc. to fields.

3.9 Flood damage assessment in the Mekong basin

3.9.1 Scope and selected areas

In stage 1 of the FMMP several focal areas were selected to investigate in detail the flood damages and risks:

In Thailand:	Lower Nam Mae Kok;
In Lao PDR:	Bokeo province and Lower Se Bang Fai basin;
In Cambodia:	Kratie province, Right Bank Bassac River and Left Bank Mekong River;
In Vietnam:	Upper Se San basin, Plain of Reeds (PoR) and Long Xuyen Quadrangle (LXQ).

The four delta focal areas in Cambodia and Vietnam compose two transboundary areas, one east of the Mekong River and the other west of the Bassac River.

The detail of the assessment is at district level, although part of the data is available at commune level: see *Data collection and surveys* below.

Below, the general implementation of damage assessment is described and results are illustrated for three districts in Cambodia that were analysed as focal areas in the stage 1. These are the districts Koh Andet, Koh Thom and Kampong Trabek. More information on the damage assessments for these districts can be found in the report ”Flood damages and flood risks in the focal areas” Annex 2 to the draft stage 1 evaluation report (Royal Haskoning, 2008).

3.9.2 Approach and methodology

As described in Section 3.3.4, there are basically two approaches for flood damage/ risk assessment: a top-down and a bottom-up one. In the top-down approach historical damage data for an (administrative) area are used to assess the flood damage/ risk in that area. In the bottom-up approach inundation-damage relationships are developed on a per unit (ha, house) basis, and the flood damage/ risk is assessed by applying the per unit risk to the number of units in the concerned area.

For the top-down approach only a limited set of data is needed to determine flood damage, available at government agencies. With these data sets absolute damage curves can be created (see Section 3.3.4), so to the top-down approach is also referred to as the ‘absolute damage approach’.

For the bottom-up approach various data sets and many processing steps are required. It will, among others, result in relative damage curves (see Section 3.3.4), so to the bottom-up approach is also referred to as the ‘relative damage approach’.

In this study both approaches have been followed for damages to Housing and Agriculture; for Infrastructure & Relief only the top-down approach could be applied by lack of adequate spatial information.

The assessment of hydrological hazards (peak discharges and volumes for different return periods) has proven to be possible with accuracy acceptable for risk assessment. The methodology applied is in principle applicable basin-wide. The conversion of hydrological hazards into flood hazards (flooding depth and duration for different return periods) has proven to be more problematic. Limited topographical information and modelling quality or availability hamper accurate flood damage/ risk assessments. The derived flood damage/ risk maps for the focal areas are, therefore, to be considered with due care.

Flood vulnerability assessments have been made for a number of sample districts in the focal areas. These assessments have allowed for the estimate of indirect damages due to flooding in addition to the, generally known, direct damages. Moreover, damage curves could be estimated providing the relation between flood damages and inundation depth and time of flooding in a certain area.

A GIS-based tool has been developed that allows for the calculation of flood damages/ risks by combining flood maps (see Chapter 2) and other available GIS data sets with the derived damage curves. This tool is in principle applicable basin-wide, provided that flood maps are produced and adequate GIS data sets are available.

3.9.3 Damage categories

In the lower Mekong basin the most important damage categories that were analysed as part of Stage 1 of the project are:

- **Infrastructure & Relief**
  Includes facilities, equipment and materials for education, health, irrigation, bank erosion, fisheries, transport, communication, industry, construction, drinking water and sanitation, rescue operations, support and relief.

- **Housing**
  Includes 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 & commercial centres and warehouses.

- **Agriculture**
  Includes rice areas, flower & vegetable areas, other annual crops, perennial crops, large and small livestock and poultry, damaged agro-chemicals and erosion of farm land and housing land.

The importance of these categories varies among the focal areas depending topographical characteristics and existing level of flood protection. The levels of importance in a share of total flood damages are presented in Table 3.4.

Table 3.4 Observed level of important share of damages in the focal areas

Categories	Laos	Thailand	Cambodia	Vietnam
Public infrastructures	3	2	1	1
Housing	2	3	3	2
Agriculture	1	1	2	3

Source: Direct flood damage inventory

Note: Number 1 is the most important share; Number 2 is moderate share, and Number 3 is a small share.

3.9.4 Data collections and surveys

The approach for data collection that was followed in Stage 1 of the FMMP is summarized below. A data collection and processing methodology was designed that could be expected to yield the required data for the focal areas, given the availability of secondary data, time and budget constraints.

Flood damage data is collected annually by various administrations: at province, district and commune level. Also flood levels are measured by governmental agencies. These data have been retrieved by Stage 1 of the FMMP.

Primary and secondary data have been not only been collected at these governmental organisations, but also at households and businesses in order to establish an inventory of flood vulnerability characteristics and direct and indirect flood damages.

Focus group discussions with people living and working in the project areas have been held to provide insight into a range of relevant issues such as the benefits of flooding, traditional coping mechanisms and community resilience.

Surveys have been held to collect and/or validate existing information on *direct damages* for an agreed reference flood; and, to the extent possible, and to document and quantify *indirect damages*_associated with the reference flood event. For this purpose the 2006 flood was selected as this flood can be considered an 'average flood' and as this year was considered recent enough for respondents to remember with an acceptable level of accuracy.

During the Household and Business interviews respondents have been asked to also estimate damages in case the flood water would have reached higher levels than in 2006. During the meeting with Provincial and District authorities flood damages have been collected for as many years as were available in their records.

The sources of data on direct and indirect damages included interviews with the following groups:

- **Provincial and District officials**
  Review and validation of existing data on casualties and direct damages caused by historic flood/erosion events. This is an extensive listing in kind and in monetary terms of damages occurred in the recent past. Damage categories included educational facilities, healthcare facilities and assets, road and transport facilities, irrigation facilities, water supply & sanitation infrastructure, power facilities, and communication infrastructure.

- **Households**
  Collection of data of individual households in the envisaged project areas for a particular reference year in which significant flooding/erosion occurred (2006). Data collection included household characteristics, characteristics of the recent flood(s), losses to residential structures, hypothetical damages to the residential structures in the case the inundation depth would have been higher, agricultural assets/incomes, crop losses, livestock losses, fish/shrimp losses, other HH income sources (e.g. home-based businesses, hired labour) and health impacts.

- **Local businesses (non home-based)**
  Collection of data of individual businesses in the envisaged project areas for a particular reference year in which significant flooding/erosion occurred (2006). Data collection included business data, characteristics of the recent flood(s), direct and indirect damages to business structures, equipment and inventory, impact on revenues and employment, and expenditures for flood protection.

In addition, the field work in each study area included:

- **Baseline flood vulnerability data collection**
  In consultation with local district and/or commune officials and existing databases, data were assembled to document key aspects of flood and erosion vulnerability including: population composition and growth, number of households, household assets, economic activities, poverty incidence, land ownership, land use and cropping patterns, fisheries production, animal husbandry, types of structures and infrastructure. In addition, the baseline captured data on business activities, educational facilities and assets, healthcare facilities and assets, road and transport facilities, irrigation facilities, water supply & sanitation infrastructure, power facilities, and communication infrastructure. This data is to be incorporated into the flood data database, as well as being used in the formulation of flood risk management strategies.

- **Focus groups on community resilience**
  The survey team facilitated focus groups with local leadership, community/ mass organizations and including men and women living in the study area who represent different economic activities and wealth. The groups are used to collect qualitative information on the beneficial and detrimental effects of floods and erosion. A guide for these discussions had been prepared to ensure that the various groups follow the same pattern and that results could be compared and analysed. The focus group discussions covered issues such as the history of flooding in the area, their perception of 'good' and 'bad' floods, benefits of floods for paddy cultivation and fishing, traditional coping mechanisms and strengths and weaknesses of community preparedness and resilience to flooding.

For each of the above-mentioned approaches a survey tool was developed. The tools consist of questionnaires for the first three approaches and a guideline for the focus group discussions. For focal areas where bank erosion is the issue, a revised methodology has been developed to collect data at district level for each relevant river bank Section; no household or business interviews and no focus group discussions were held there. The set of tools consists of:

- Questionnaires for Provincial & District Inventory of direct flood damages/ bank erosion;
- Questionnaires for District Flood vulnerability/ bank erosion baseline database;
- Questionnaires for District flood events/ bank erosion;
- Questionnaires for District Indirect flood/ bank erosion costs;
- Guide for Focal Group discussion;
- Household questionnaire;
- Business questionnaire;
- National Report outline.

These tools have been translated into the local languages as required and spreadsheets for questionnaire analysis were prepared and provided to the survey team, along with a guideline to prepare a national report.

The data from the surveys, interviews, group discussions, field observations, combined with the data in the governmental damage reports, are the basis for the damage functions and damage-probability curves.

Overview of data sources for damage assessment using a GIS

For the absolute approach of flood damage (see Section 3.3.4) the data requirements are lower than for the relative approach. A Geographic Information System (GIS) is required for the relative approach, combining spatial data with tabular data. Figure 3.7 shows the difference schematically for agriculture, housing and infrastructure damage and risk assessments.

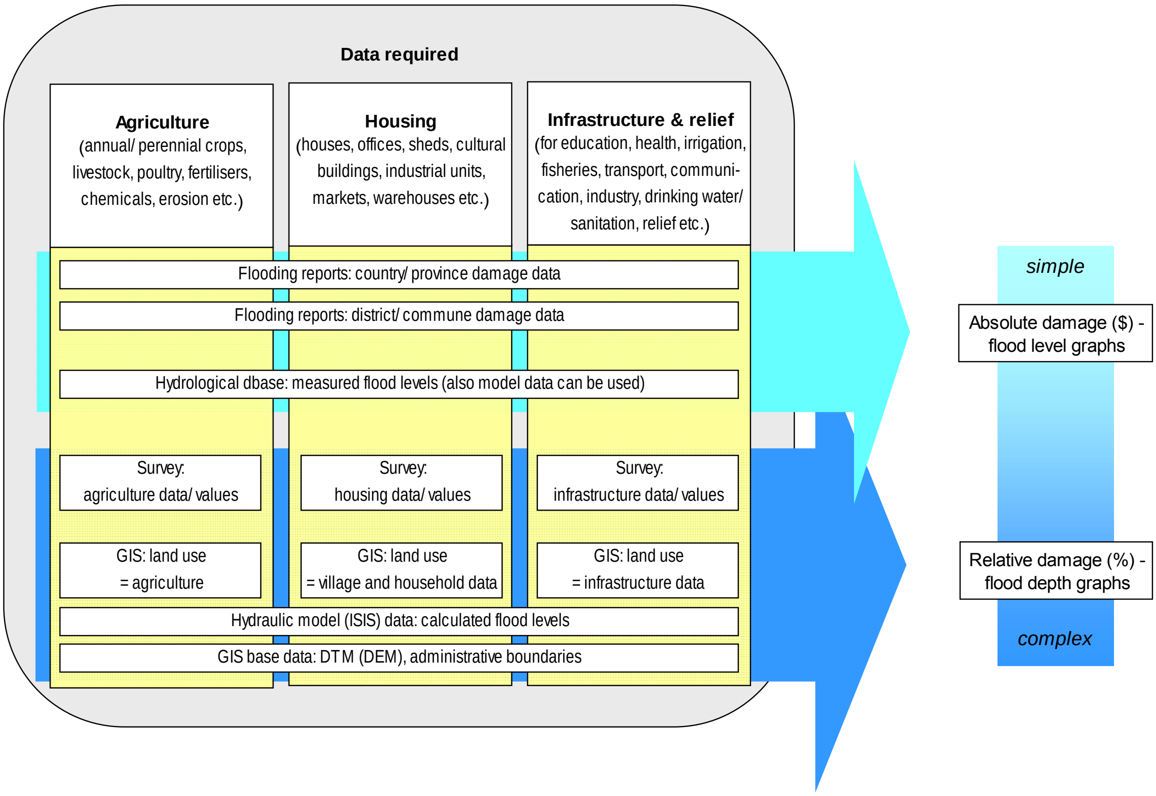


Figure 3.7 The absolute and relative flood damage assessment approaches require different data sets.

Table 3.5 gives an overview of data sources that were used to determine flood damages in the Cambodian focal areas. Maps were produced at both district and commune level, although the commune level results for housing damage were partly based on district-level information (average house values).

Table 3.5 Data sources used for mapping damages in the Cambodian Mekong delta.

Category	**Definition**	**Source**
Information on flood characteristics: Hydrologic and elevation information		
ISIS maximum water levels for different return periods	Max. water levels for different periods in the year (e.g. early flood season, rainy season) and various return periods (e.g. 2, 5, 10, 25 and 100 years)	ISIS hydraulic model (MRC)
Digital Elevation Model (DTM, DEM)	Altitude ground level data for the whole Mekong basin	MRC GIS data
Information on land use and values		
District and commune/ village boundaries	-	MRC GIS data
Village locations and number of households per village	-	MRC GIS data
Paddy coverage (JICA land use map)	Coverage (areas) of early flood rice and rainy season rice cultivation	MRC GIS data, JICA
Average house values per district	-	FMMP-C2 surveys
Damage functions		
'Damage - water depth' curves for housing and rice at district level	Relation (mathematical function) between the local flood level (flooded areas) and the damage on housing or rice cultures	FMMP-C2 surveys

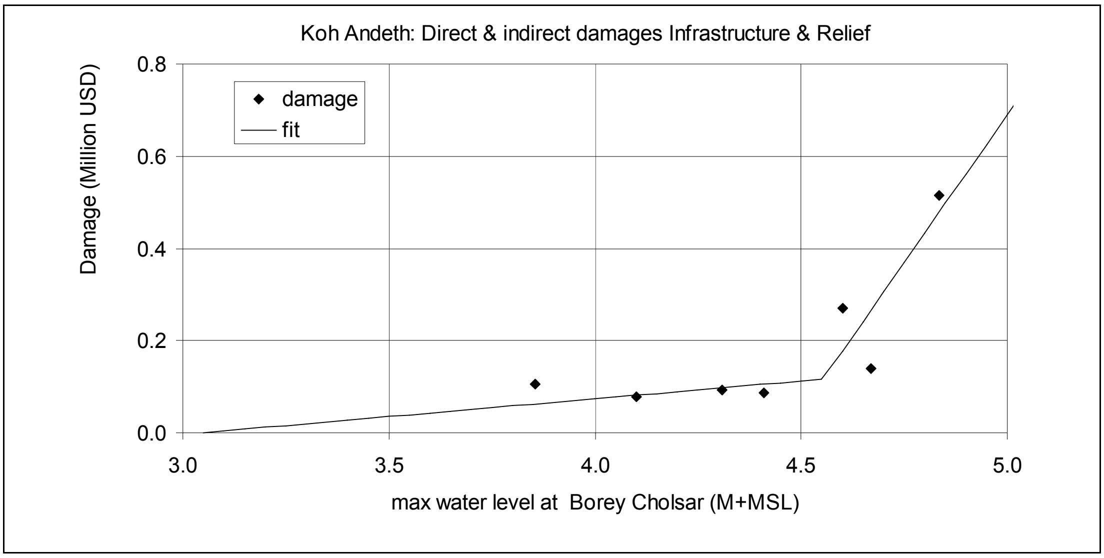
3.9.5 Derivation of damage functions

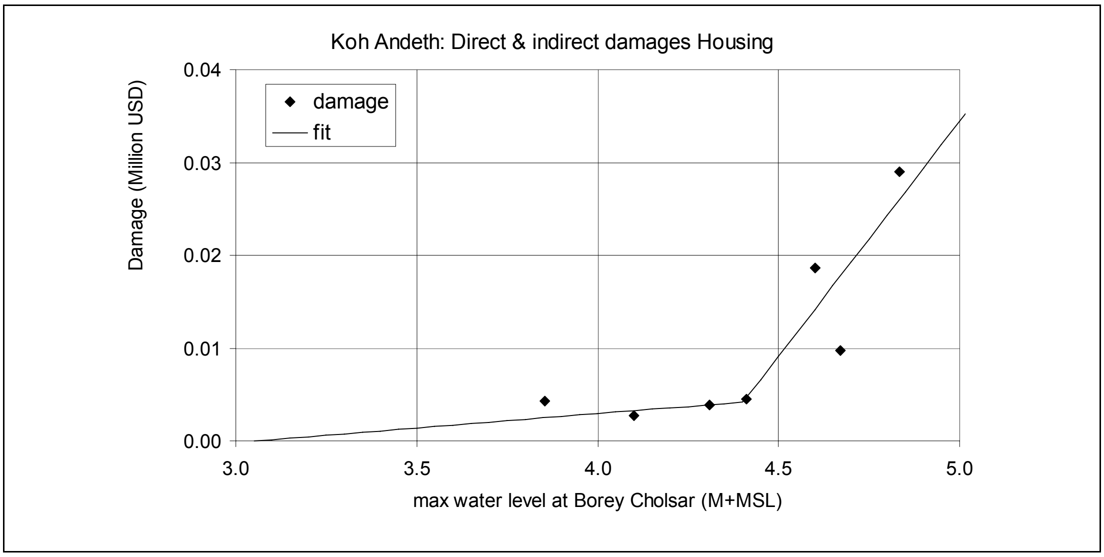
To be able to estimate damage the following information sources have to be combined (also see Section 3.3.2):

a) Information on land use and values;
b) Information on flood characteristics;
c) Damage functions.

The MRC executed a socio-economic survey early 2008 related to flooding in several districts. This survey showed that for some socio-economic aspects (as houses, roads) mainly the maximum annual flood depth is determining the damage. For agriculture there is a distinction between the 'early flood' paddies and the 'rainy season' paddies. Damage to the 'early flood' paddies is mainly caused by the floods up to June - July, while damage to the 'rainy season' paddies is the result of floods up to October.

With the governmental commune data and MRC survey flood damage data of three Cambodian districts the relation between water level and flood damage has been established for infrastructure and relief, housing, and agriculture. Figure 3.8 shows the results for Koh Andeth.





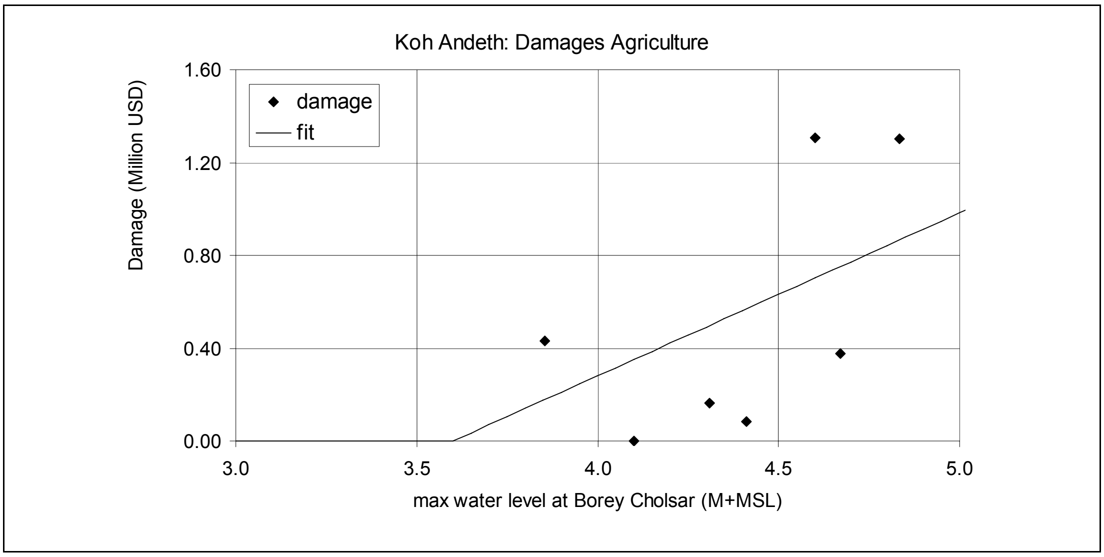


Figure 3.8 District flood damage curves for Koh Andeth.

Damage functions for housing from the household and business survey

In addition to the damage curves derived from the district data damage functions were derived from the household and business survey. It was investigated how the damage in flooded areas was related to the water depth in/around the houses. This approach followed the “relative damage approach” (see Section 3.3.4) and thus the functions include the water depth and the damage fraction. Figure 3.9 shows the derived relative damage function for housing for Koh Andeth.

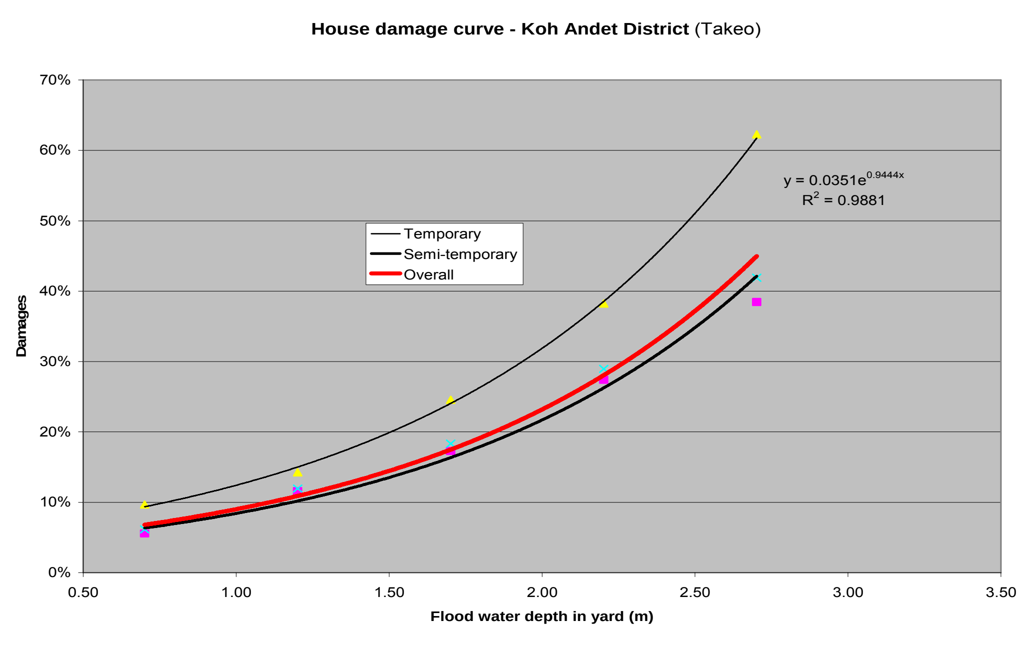


Figure 3.9 Example of damage function for housing, relating housing damage (as % of the total value) to flood depths.

Damage functions for paddy cultivation

Based on information collected during the Focal Group Discussions, damage curves for paddy production in relation to flooding depths in the districts Koh Thom, Koh Andeth and Kampong Trabek have been estimated for early flood paddies and for rainy season paddies. The results are presented in the graphs below, showing three levels of damage, depending on the timing of the flood. For this case the damage depended highly on the moment of flooding during the year. However, for other regions the damage to paddy cultivation could also depend on the duration of the flooding.

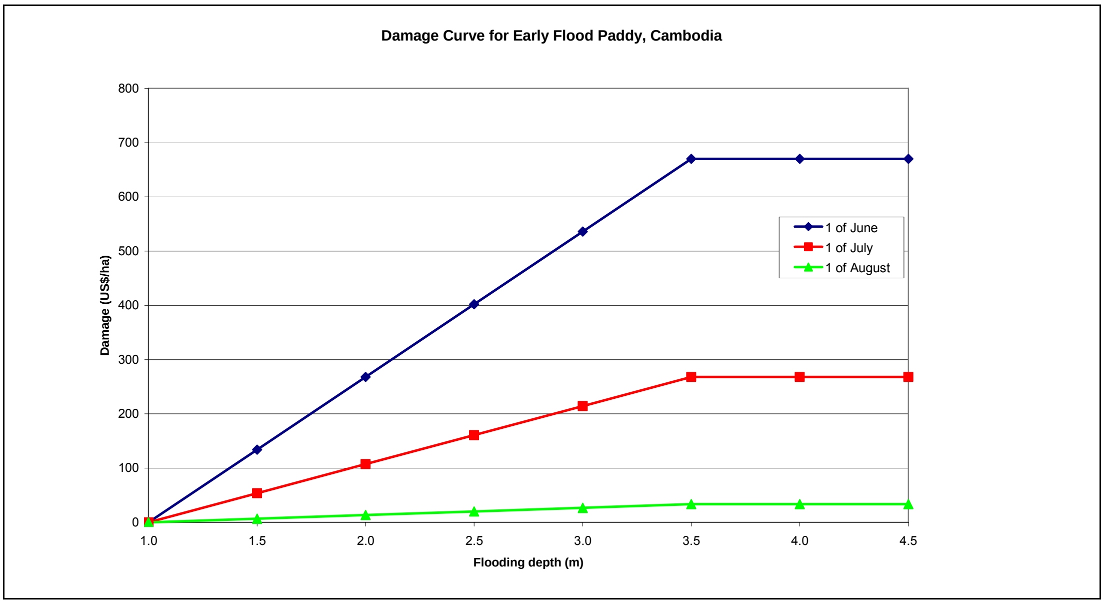


Figure 3.10 Relative flood damage curves for paddies, Cambodia.

3.9.6 Creation of damage maps

Basically two types of damage maps can be distinguished:

1. Damage maps based on absolute damage curves;
2. Damage maps based on relative damage curves.

Figure 3.11 shows the steps to create the maps. The data for creating the damage maps can be combined in several ways, but the map output will be equal to these two types.

Ad 1 Damage maps based on absolute damage curves

Absolute damage curves are created with historic flood damage inventories related to flood levels for a specific area, e.g. a district: see Figure 3.8. The flood level at the time/ date of flooding originates from a gauge station in the district or from a hydraulic model covering that same district. The absolute damage curves are linked to the long-term flood levels from the same gauge station, resulting in a damage probability curve. Damage figures for certain flood return periods are extracted from this curve. A map may show the district boundaries plus the damage value of a certain return period in the district as a ‘pie’, bar chart, colour shading etc.

Ad 2 Damage maps based on relative damage curves

Relative damage curves are created with damage figures related to the flood depths at the damage locations: see Figure 3.9 (housing) and Figure 3.10 (paddies). The damage figures may come from a field survey or may be based on expert knowledge. A land use map may provide the spatial distribution of e.g. paddies. A flood map (see Chapter 2) gives the water depths in an area for a certain return period (based on hydraulic modelling results). By combining the land use map (with e.g. paddies, villages or roads) with the flood map (water depths at specific return period), the areas with ánd paddies ánd certain water depths for different return periods are known. This information can be combined with the relative damage curves, resulting in the damage on paddies. A map shows the damage value of a certain return period in the area as a ‘pie’, bar chart, colour shading etc.

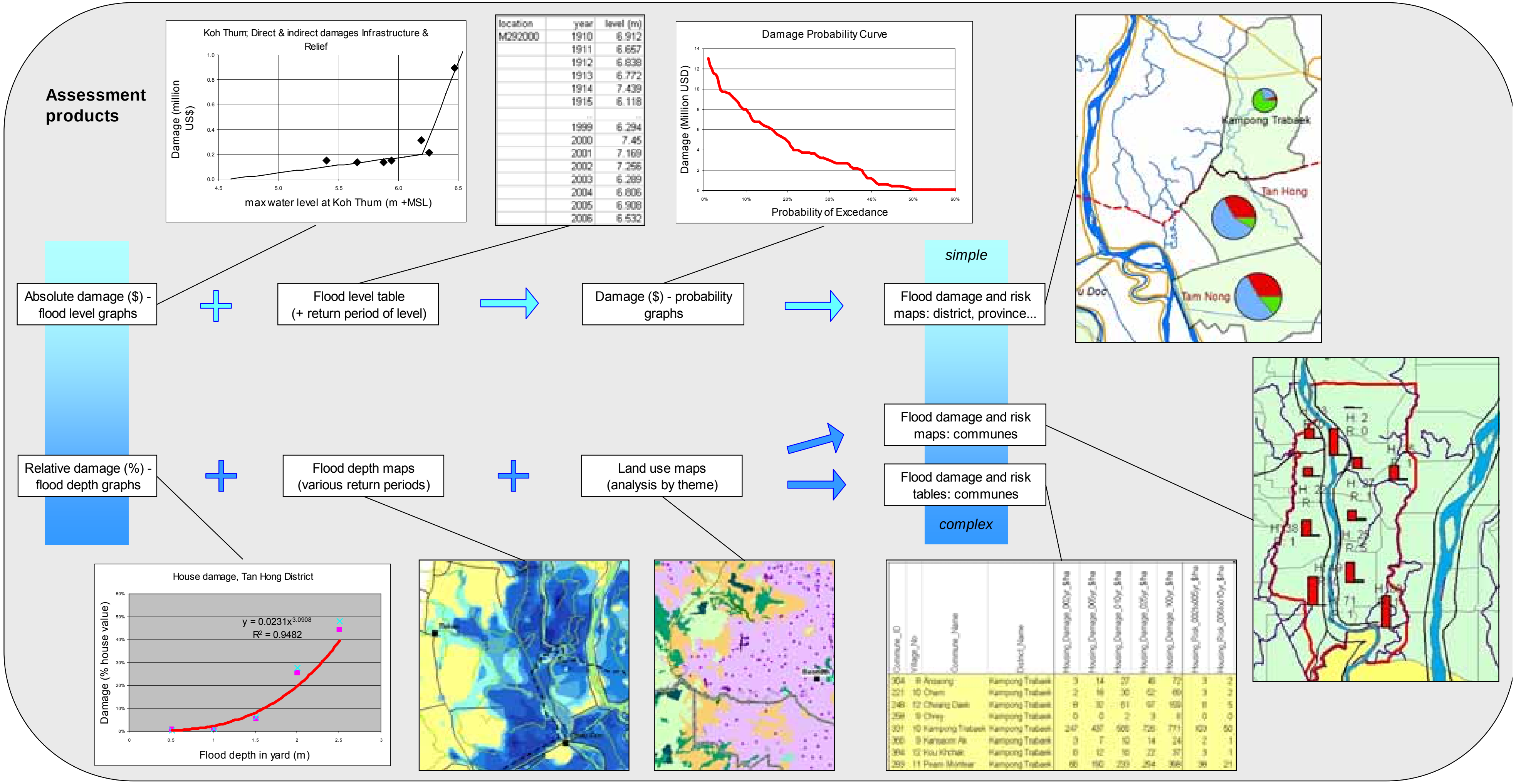


Figure 3.11: Steps (simplified) to create maps based on absolute and relative damage – flood depth curves.

As the 'relative damage curve' method uses spatial information available on maps, the level of detail that may be obtained is higher than with the 'absolute damage curve' method. In both cases care have to be taken with combining information of different detail levels in order to interpret the accuracy of the results correctly.

To come to maps based on relative damage curves, a series of calculations have to be done: both in a spreadsheet and in a GIS. For details on the steps and calculations in the spreadsheet, see the spreadsheet that is included on the CD/DVD with the digital guidelines.

Textbox 2

Example 1: Cambodia, creating a housing damage map based on relative damage curves

The ISIS-based flood or water depth maps can be combined with the village location maps, resulting in known water depths (by return period) for each village. Using house damage curves (see Figure 3.9), knowing district-average house values and having the number of households per village, the housing damage per village and per commune can be calculated (see spreadsheet on CD/DVD). By exporting the data from the spreadsheet to a GIS these results can be displayed on a map.

Example 2: Cambodia, creating a paddy damage map based on relative damage curves

To calculate damages to rice for different flooding return periods, the JICA land use map supplies the areas cultivated with rice. The paddies that are flooded once every two years are considered to be the 'early flood' paddies, while the other paddies (on higher grounds) are considered to be the 'rainy season' paddies. By combining the flood depth maps (by return period) with these paddy maps in a GIS, exporting these GIS data to a spreadsheet and by combining these with the rice damage curves (of e.g. July for 'early flood' rice; see Figure 3.9) in the spreadsheet, the rice damage can be calculated (see spreadsheet on CD/DVD). These results can be exported to a GIS for showing the rice damages on a map with districts or communes: see Figure 3.13.

3.9.7 Results of damage assessments

The damage assessments results of the focal areas in Cambodia have been generated by district using the absolute damage approach. Table 3.6 shows the results for Koh Andet for events with different probabilities. The results can also be shown on maps. Figure 3.12 and Figure 3.13 display the total damage and the damage per hectare for paddies. In addition, the damage values obtained using the absolute method could be mapped.

Table 3.6 Damage data for different return periods for Koh Andet district. Damage is shown in million US $.

	Probability (1/year)			
Damage	1%	5%	10%	50%
Housing	0.05	0.04	0.03	0.00
Infrastructure and relief	1.14	0.75	0.69	0.10
Agriculture	2.15	1.58	1.48	0.35
Total	3.35	2.37	2.20	0.45

By combining the above damage assessments with the estimates of the probability the risk can be assessed, as will be shown in Section 4.5.

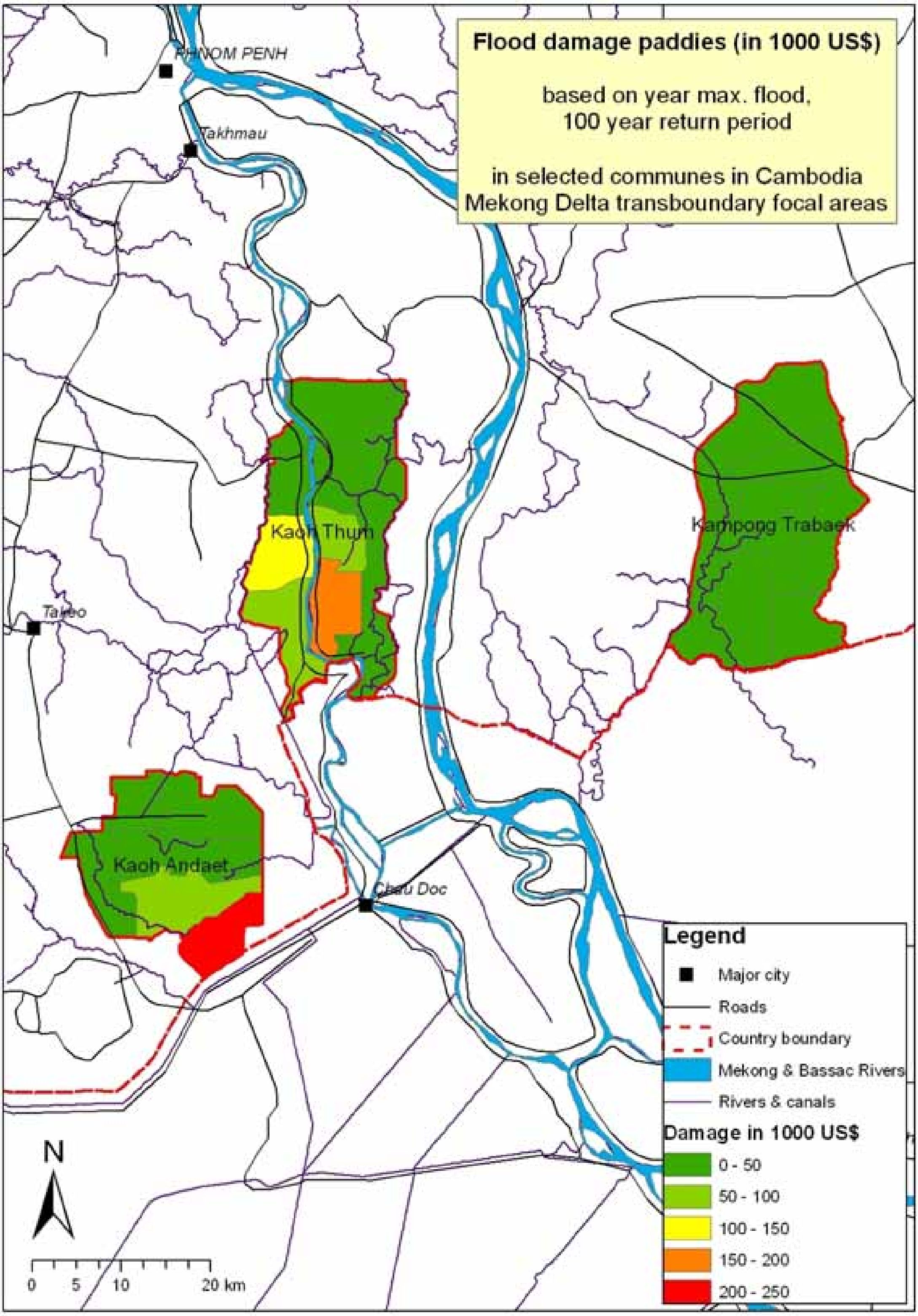


Figure 3.12 Example of a damage map based on relative damage curves, showing total paddy damage in 3 districts and their communes.

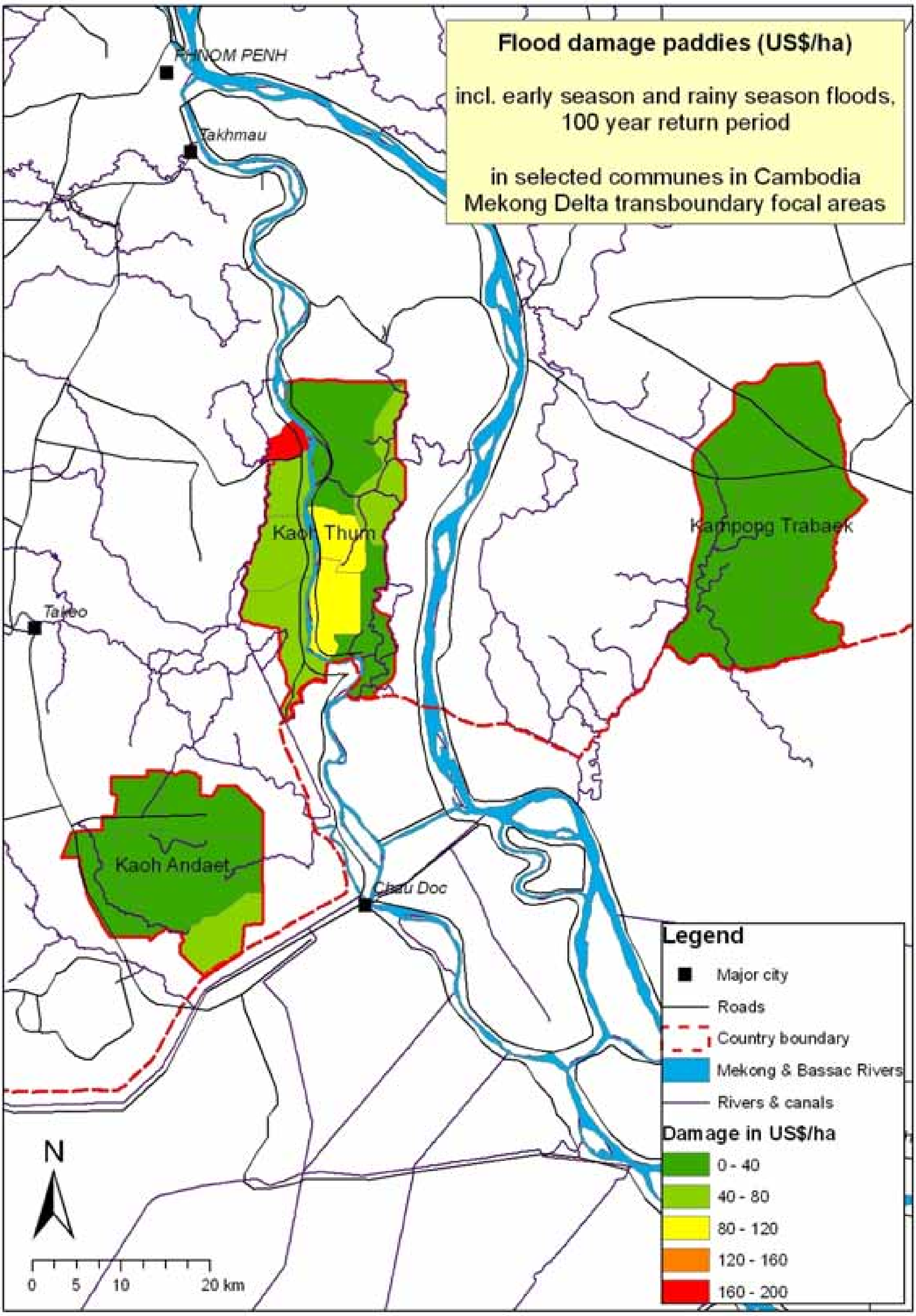


Figure 3.13 Example of a damage map based on relative damage curves, showing paddy damage per hectare in 3 districts and their communes.

CHAPTER 4

FLOOD RISK ASSESSMENT

4 FLOOD RISK ASSESSMENT

4.1 Introduction

In the risk assessment the results of the hazard and damage assessments are combined. This chapter describes the approach for risk assessment (Section 4.2) and several options for presenting the assessment results (Section 4.3). Section 4.4 describes how the results of a risk assessment can be used to evaluate the effects of measures and the level of acceptable risk. The final section demonstrates how the risk is determined for a case study area for the Lower Mekong Basin.

4.2 General approach

Flood risk is generally defined as follows:

$$Risk = Probability \times Damage \qquad (4.1)$$

For example, if an area has a probability of flooding of 1% per year (or 1/100 per year) and the damage is $ 20 million, the risk equals $ 200,000 per year. As this risk number reflects the average expected economic damage per year, it is also referred to as yearly expected economic damage.

In flood risk assessment both the probabilities and consequences of flood events have to be assessed. Figure 4.1 shows conceptually the process of risk determination for a river and it includes the following steps:

1. The starting point is information on the frequency of certain river discharges. This information can e.g. be obtained from historical data or probabilistic analysis of hydrological processes.
2. Next, the relationship between the discharge and the water (flood) depth should be obtained, e.g. by means of a hydraulic model or a stage discharge relationship. These first two steps are described in more detail in Chapter 2 on flood hazard assessment.
3. To assess the flood damage a relationship between the flood characteristics and the level of flood damage is needed, the so-called damage function (see Chapter 3 on flood damage assessment).
4. By combining these steps the return period of a certain damage level can be assessed.

In Section 4.4 this approach is elaborated for areas in the Lower Mekong Basin.

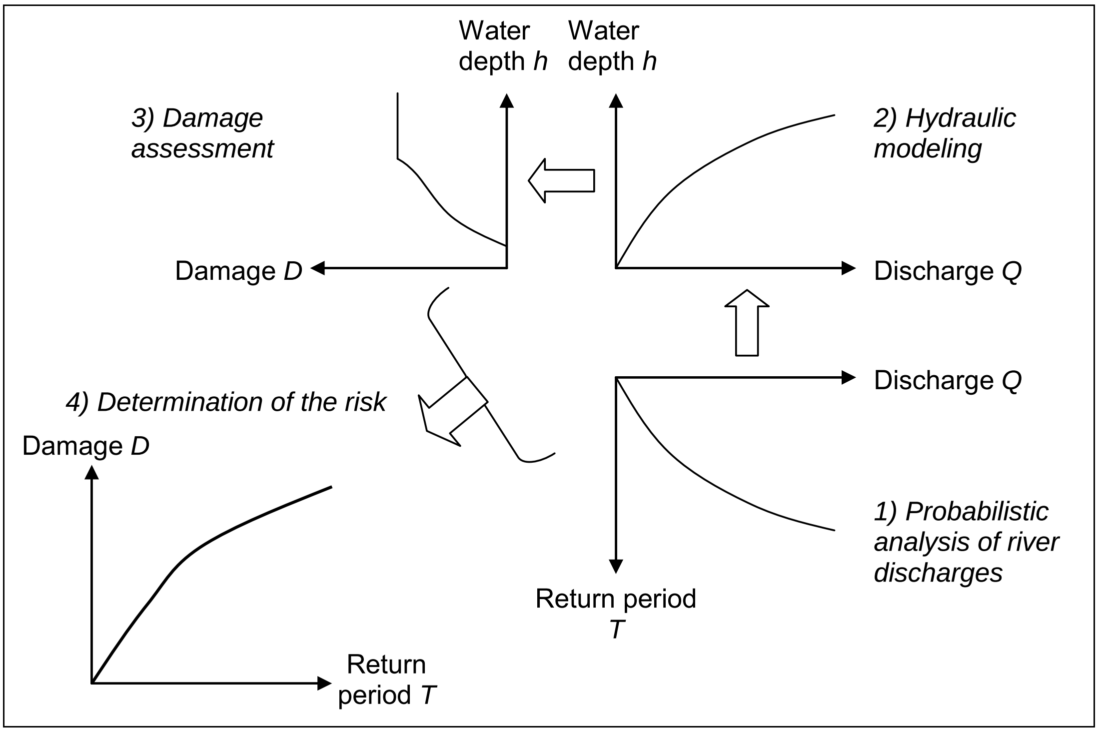


Figure 4.1 Conceptual approach for determination of flood risk.

4.3 Presentation of the results of risk assessments

4.3.1 Economic risk

To estimate the flood risk of an area, information is needed on the probabilities and consequences of flood events that could affect that area. For a full probabilistic analysis a large number of flood events should be analysed with numerical models. This can be done in a so-called Monte Carlo analysis in which a lot of events are numerically simulated. This way the flood hazards and damage values can be determined for all events and they are combined to estimate the risk.

However, usually a practical approach is followed by analysing a limited number of floods which are representative for the spectrum of possible floods. For example, the annual flood, the 1/2, 1/5, 1/10 and 1/100 (read: once per 100) year events could be analysed. For each flood a hydraulic simulation and damage assessment can be made.

Table 4.1 Example of a table that summarizes the damage and probability calculations for a range of flood scenarios.

Return period (year)	2	5	10	100
Probability of exceedance (per year)	1/2	1/5	1/10	1/100
Flood damage ($)	$\text{Damage}_{1/2}$	$\text{Damage}_{1/5}$	$\text{Damage}_{1/10}$	$\text{Damage}_{1/100}$

The flood scenarios can be defined depending on their return period, i.e. the average recurrence interval between the occurrence of two floods with a certain flood level and corresponding damage value. It is also possible to determine the probability of exceedance of an event with certain damage. That is the probability (per year) that a certain damage value will be exceeded. These two metrics can be converted as follows:

Probability of exceedance = 1 / return period (4.2)

This means that the event with a 100 year return period has a probability of exceedance of 1/100 per year.

The relationship between the return period and the damage can be plotted in a graph (see Figure 4.2 – left): the longer the return period, the more extreme the event and the higher the damage. However, with even higher return periods the damage will not keep on increasing exponentially; in fact the expected damages are likely to increase less and less (the curve will 'flatten') as more water on top of a lot of water hardly damages more. Alternatively the relationship between the probability of exceedance and a damage value can be displayed (see Figure 4.2 - right). The events that occur with a low probability and large damages are shown on the left side of this graph.

The figures below are based on the assumption that damages only occur for floods that occur (on average) once per year or with a smaller probability. It is also possible that damages occur multiple times per year in the same area. In that case a certain damage could be exceeded with a frequency that is larger than once per year. For example a certain damage value can be exceeded twice per year. In that case the right figure below could display frequencies that are larger than one. The damage data has to be collected for single events and the frequencies could be analysed from the event data.

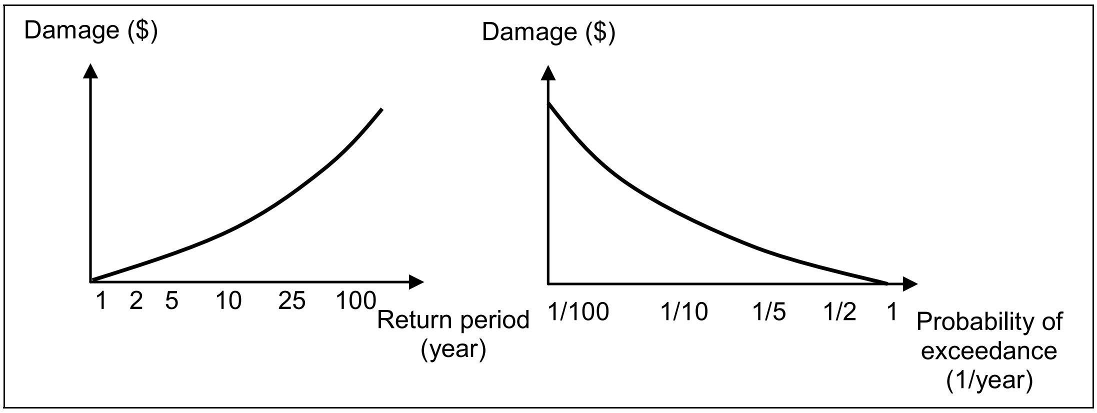


Figure 4.2 Relationship between return period and damage (left) and probability of exceedance and damage (right).

From this information the expected value of damages for an area can be determined, as will be discussed below. The unit of this risk is $/year and it is therefore referred to as expected economic damage. Alternatively the risk / expected damage can be determined for a single unit of land[7], e.g. per hectare. In that case the unit becomes $/(ha x year), i.e. $ per hectare per year. The risk for a whole area is relevant when one wants to know the absolute level of risk and consider risk reduction measures (see also Section 4.4). The risk per hectare is of interest when one wants to compare relative risk values between areas.

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[7] It is preferable to estimate the damage per hectare for the actual surface of land that has been flooded. However, not in all cases the exact size of the flooded area is known and the damage is averaged over a larger administrative area than only the flooded area.

The risk/ expected damage can be determined by calculating the area under the curve that shows the relationship between probability of exceedance and the damage (Figure 4.3). In the figure the risk is found by summing areas A, B, C, D and E. For a more precise estimate also the areas 'a', 'b', 'c', 'd' and 'e' can be approximated by triangles and added to find the total risk.

Note that just multiplying the damages from Table 4.1 with their probability of exceedance would lead to double counting and an overestimation of the damage. Figure 4.3 shows why: by just multiplying Damage$_{1/2}$ with a return period of ½ per year one would 'extend' area E all the way to the y-axis, overlapping partly A, B, C and D. Instead, one should calculate (prob. 1/2 – prob. 1/5) x Damage$_{1/2}$. The same applies to the other damages/ probabilities.

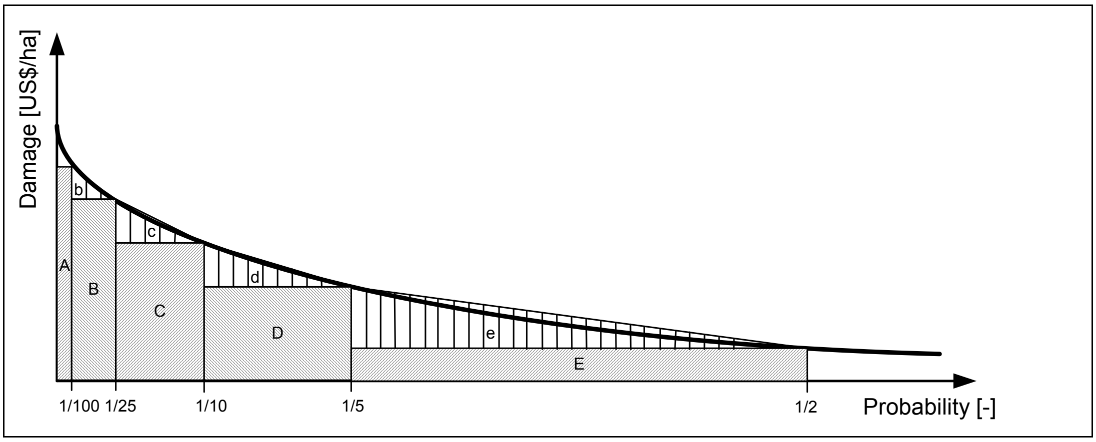

Figure 4.3 The area below the curve, the total risk or expected damage (US$/year), is approximated by summing A, B, b, C, c, D, d, E and e.

When a large number of events with different return periods is known, the stepwise curve will likely approach a continuous curve. In that case the risk / expected value can be approximated by just summing the areas of blocks A, B, C, D and E and the triangles a, b, c, d and e can be omitted.

The general experience is that the events with the highest probabilities (or lowest return periods) form a major part of the risk. Although damages for events with high return periods (e.g. 100 years) can be very high, this effect is often largely compensated by the low probability.

The results of risk calculation can be shown on maps. For example the expected economic damage for different areas can be shown. The advantage of the use of flood risk maps is that they give insight in the spatial distribution of flood risks and thus to the contribution of specific areas to the overall flood risks. This implies that 'hot spots' with the largest contribution to the overall risk level can be easily identified. Also finding the relation with the presence or absence of flood protection works or other flood-related themes can be facilitated by a map. Examples of risk maps for the Lower Mekong Basin are included in Section 4.5.

4.3.2 Risk to life

An important indicator in risk evaluation and decision-making is the risk to life (loss of life). To estimate this type of risk loss of life data and related flood event data are required. The loss of life can be estimated with the approaches described in Section 3.6. Again a table could be made that shows for several events or scenarios the probability of exceedance and the loss of life (similar to Table 4.1).

The risk to life is generally referred to as societal risk. It can be shown in a so-called FN curve, which shows the probability of exceedance of a certain number of fatalities. Both axes are shown at a logarithmic scale, meaning that the difference between two axis-units is a factor 10. Figure 4.4 shows and example of an FN curve[8].

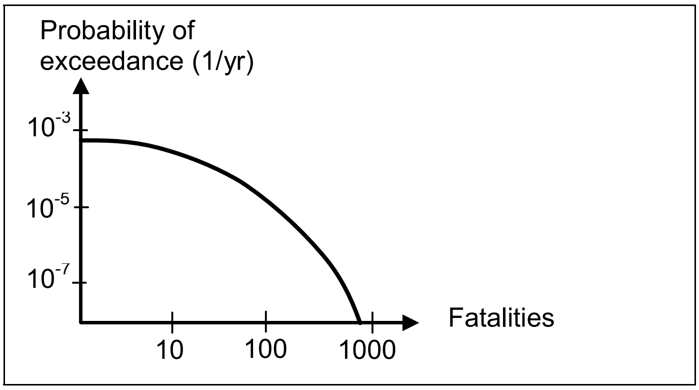

Figure 4.4 Example of a FN curve.

In addition the individual risk of flooding (death of a person) can be calculated. The individual risk due to flooding can be compared to individual risks for other activities, e.g. the risks of traffic or disease. These results can be used as input for decision-making; see Section 4.3 for further details.

4.4 Risk reduction measures and risk evaluation

4.4.1 Effects of measures on the risk

The results of a flood risk assessment could be very useful to evaluate the effects of measures. Basically there are two types of measures:

1. Measures to reduce the probability of flooding;
2. Measures to reduce the consequences of flooding.

Figure 4.5 gives an overview of possible measures and schematically shows the effects of these measures on risk. It assumes that measures to reduce the probability will completely eliminate the damage up to a protection level with a certain probability of exceedance. In that case floods with larger probabilities (smaller return periods) will be controlled and will not cause any damage. This is for example the case when dikes or embankments are built to provide protection to an area up to a certain protection level, e.g. for a 50 year return period.

Measures to reduce the consequences, e.g. adaptation of land use and buildings, will reduce the consequences of an event for a given return period. Measures can be combined, so there will be a combined reduction in risks.

Finally, compensation and insurance are also often mentioned as measures to reduce the consequences. However, these measures do not reduce the total damage, but imply only a financial reallocation of the flood damage.

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[8] A FN curve is very similar to the curve that shows the probability of exceedance of a certain damage value. The difference is that the damage value (in this case loss of life) is shown on the horizontal axis of the FN curve.

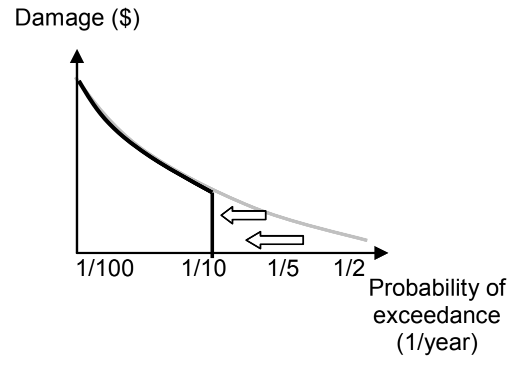
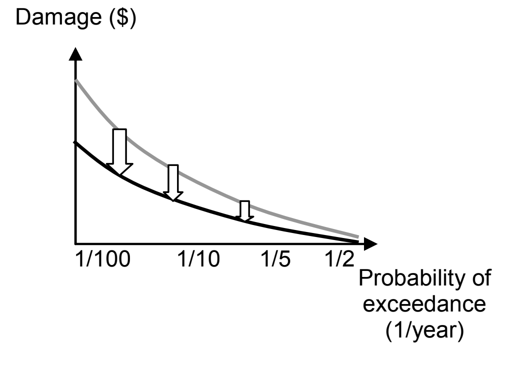
Measures to reduce flooding probability: - Strengthening of dikes and embankments - River widening ("room for rivers") - Retention and emergency storage	Measures to reduce flooding consequences: - Land use planning - Secondary flood defences - Flood proof buildings (e.g. raising)
	

Figure 4.5 Effects of measures on flood risk.

4.4.2 Basics of cost-benefit analysis

In order to evaluate whether a certain measure achieves enough risk reduction, a cost - benefit analysis can be carried out. A project should result in an increase of economic welfare, i.e. the benefits generated by the project should exceed its costs (or disbenefits). Further information on cost - benefit analysis in the context of flood management is given in (Penning Rowsell and Chatterton, 1977) or the guidelines for cost-benefit analysis (CBA) developed in the UK (MAFF, 1999, 2000) and Australia (BTRE, 2001).

Every effect of an investment project can be systemically estimated and, wherever possible, given a monetary value. The cost - benefit analysis gives an overview of distribution effects, alternatives and uncertainties, since an overall assessment by politicians and others requires complete information. This requires that all relevant effects, also the intangible effects, are taken into account. However, in the analysis of the costs and benefits of projects in practice, the analysis is often narrowed to tangible monetary effects.

In such a 'limited' cost - benefit analysis the economic benefits of an activity are compared with the costs of the activity. If the benefits are higher than the costs, the activity is attractive (it generates an increase in economic welfare). If the benefits are lower, the activity is not attractive. In flood management this means that the costs of measures for increasing the safety against flooding (e.g. dike strengthening of flood proofing) are compared with the decrease in the yearly expected economic flood damage. In the cost figure different types of costs have to be included: costs of investment (fixed and variable) and the costs of maintenance and management. As said, the benefits are represented by the reduction of the expected economic damage.

A project or measure is attractive according to the cost - benefit analysis if:

$$I < \Delta E(D) \tag{4.3}$$

where: I = investment in project / measure [$/yr]
ΔE(D) = reduction of expected economic damage [$/yr]

The reduction of the risk / expected economic damage can be calculated with:

$$\Delta E(D) = E(D)_0 - E(D)_N \tag{4.4}$$

where: $E(D)_0$ = expected economic damage in the original situation [\$/yr]
E(D)N = expected economic damage after measures/ project completion [\$/yr]

The expected economic damage can be determined with the approach outlined in Section 4.2.

The change in the expected damage value due to different types of measures can be determined according to the principles presented in Section 4.3.1.

The above approach works if both the investments and the benefits can be expressed in monetary units for the same unit of time (e.g. \$/yr). In many cases investments in flood risk reduction are one-time costs, e.g. a dike construction project, whereas the benefits are expressed per year. In that cases the benefits have to be discounted over the life time of the project to determine the net present value of the costs and benefits. The following general formula can be used for that:

$$NPV = \sum_{1}^{n} \frac{B_i - C_i}{(1+r')^t} \tag{4.5}$$

where: NPV = net present value [\$]
Bi = benefits in year i [\$]
Ci = costs in year I [\$]
t = time [year]
r’ = reduced interest rate [-]

The reduced interest rate r’ is generally used for discounting and it equals the economic growth minus the inflation. When one assumes an infinite time horizon the discount factor approximates 1/r’ and the net present value of the benefits becomes ΔE(D)/r’.

4.4.3 Economic optimisation

A specific form of the cost - benefit analysis is the economic optimisation. This approach is applicable to determine an optimal level of protection when the investments in the protection and the risk are dependent on the level of protection. This is for example the case for flood prone areas that are protected by dikes. In that case the decision problem becomes the choice of the height and thus the choice for the protection level that the dikes provide.

The economic optimisation was applied to flood protection systems by the Delta Committee in the Netherlands. This Committee investigated possibilities for new safety standards after a major flooding caused enormous damage in the Netherlands in 1953.

According to the method of economic optimisation, the total costs in a system are determined by the sum of the expenditure for a safer system and the expected value of the economic damage. In this economic optimisation the incremental investments in more safety are balanced with the reduction of the risk. The investments consist of the costs to strengthen and raise the dikes. In a simple approach it is assumed that flooding could only occur due to overtopping of the flood defences. Thereby each dike height corresponds to a certain probability of flooding (the higher the dikes the smaller the probability of flooding) and an associated damage. By summing the costs and the expected damage or risk, the total costs are obtained as a function of the safety level. A point can be determined where the total costs are minimal, the so-called optimum: see Figure 4.6. In the optimum the corresponding dike height is known. Because the statistics of the water levels is also known a corresponding protection level in terms of a probability can be defined.

The approach has been applied after the Dutch 1953 storm surge to determine an optimal safety level for the largest flood prone area, South Holland (van Dantzig, 1956). Eventually these results have been used to derive safety standards for flood defences in the Netherlands. For coastal areas protection has been chosen with exceedance probabilities of 1/4,000 per year and 1/10,000 per year. For the Dutch river areas the safety standards were set at 1/1,250 per year and 1/2,000 per year.

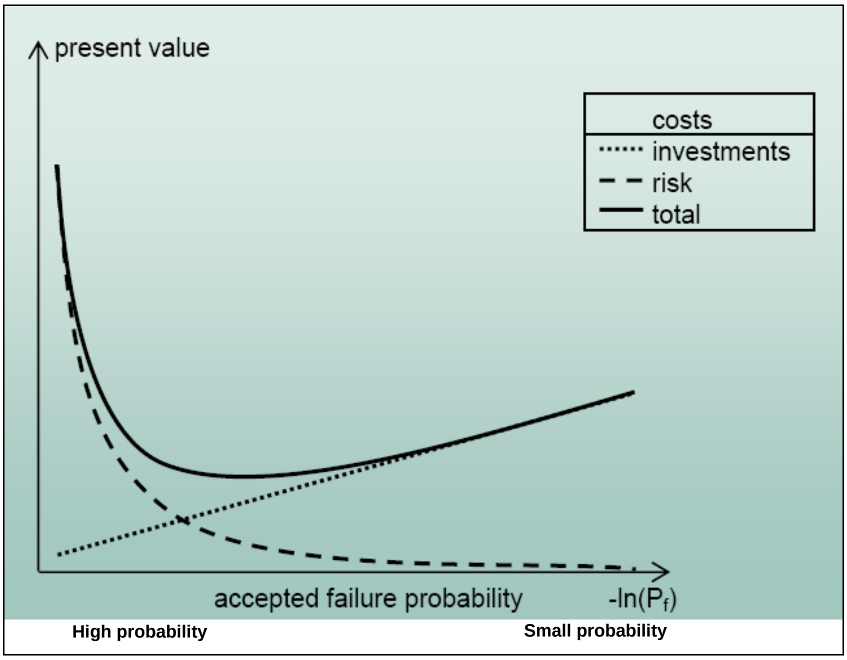


Figure 4.6 Principle of economic optimization.

The economic optimisation can also be applied to other types of problems at various scales. For example, the optimal level of raising a house can be determined while taking into account the additional costs of raising the building, the damage to the structure in case of flooding and the probabilities of several water levels that would lead to flooding.

4.4.4 Risk evaluation for loss of life

The estimates of risk to life can be included in risk evaluation and decision-making. It is possible to define certain standards that indicate the acceptable level of individual or societal risk (see Section 4.3.2 for definitions). More information on this topic is found in (Vrijling *et al.*, 1998; Jonkman *et al.*, 2009), but a summary of the main concepts is given below.

For individual risk a threshold level can be set to indicate the tolerable risk due to a certain activity, for example a probability of death of 10^{-5} per year. If the actual calculated risk is higher (e.g. 10^{-4} per year) the situation is not acceptable and risk reduction measures are necessary.

For societal risk a limit can be determined by means of a limit line in the FN curve (see Figure 4.7). The limit line shows that an event with larger consequences is acceptable only with a smaller probability. The calculated risk can be compared with the limit line. If the calculated risk is below the limit line the situation is acceptable. If the calculated risk is above the limit line the situation is not acceptable and additional measures are needed.

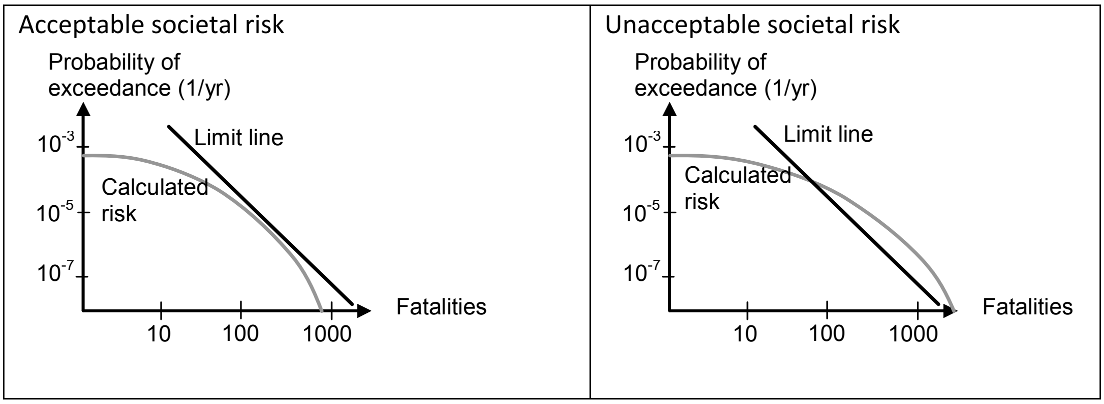


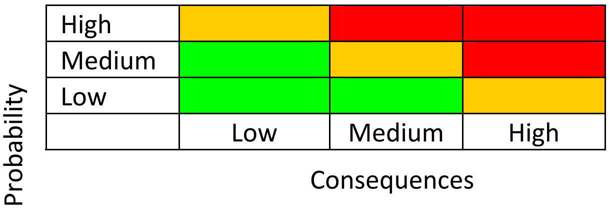
Figure 4.7 Societal risk and limit line.

The above concepts for limits for individual and societal risk are currently explored in the Netherlands where new safety standards are developed that are also based on risk to life. However, there are no other (known) examples of countries that use this type of safety standard for flooding.

4.4.5 Risk matrix

A tool to evaluate the risk is the risk matrix (see below). It gives a ranking of the probability (vertical axis) and consequences (horizontal axis). Based on the magnitude of probability and consequences a certain risk can be ranked to be acceptable (green), unacceptable (red) or subject to further discussion on acceptability (orange). In order to categorise the consequences, different consequence types (economic damage, loss of life, environmental or social impacts) can be taken into account.

The choice of the boundaries between the categories is an arbitrary choice. The outcomes of risk assessment can only provide information on the level of risk and not on the acceptability.



High	🟧	🟥	🟥
Medium	🟩	🟧	🟥
Low	🟩	🟩	🟧
	Low	Medium	High

Consequences

Probability

Figure 4.8 Structure of a risk matrix.

4.5 Risk assessment for the Lower Mekong Basin

4.5.1 Introduction and approach

In this section the results of the risk assessment are presented. This means that the results of the flood hazard analyses (Chapter 2) and damage assessments (Chapter 3) are combined. The benefits of flooding are not discussed in detail here, but could be relevant in an overall evaluation.

Figure 4.9 outlines the approach that was followed in the project to estimate the risk. From the time series output of the ISIS hydraulic model (graph upper left), the probability of occurrence of different water levels can be analysed (upper right). On the other hand the relation between flood level or flood depth and damage (lower left) is known. By combining the damage with the flood probability the damage probability curve can be established (lower right).

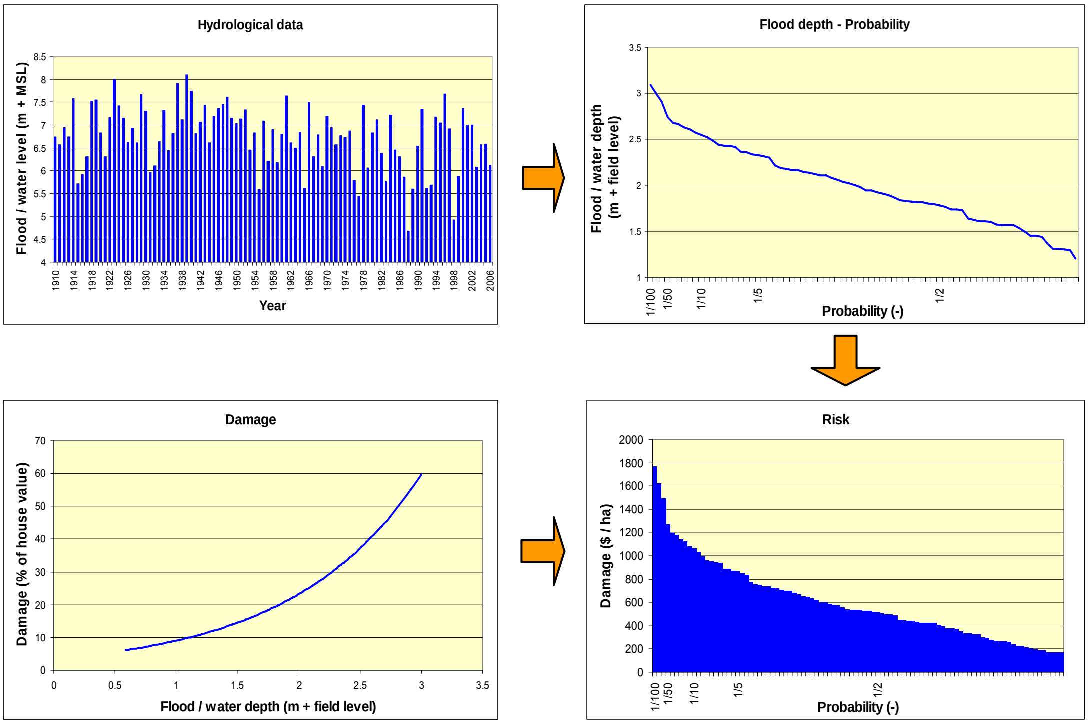


Figure 4.9 Approach for estimation of the risk.

It is illustrated below which results were obtained with this approach for three districts in Cambodia that were analysed as focal areas in the stage 1. These are the districts Koh Andet, Koh Thom and Kampong Trabek.

4.5.2 Results of risk assessment

As part of the risk assessment the floods that occurred between the years 1910 and 2006 were simulated. The damage curves from Section 3.8 were used to estimate the damages for these flood events. By combining these results the following probability damage curve was obtained. From the figure it can be seen that Koh Andaet has the largest damage for most return periods, especially for events with a relatively large probability of exceedance (40% - 60%). The Koh Tum district has the lowest overall risk curve.

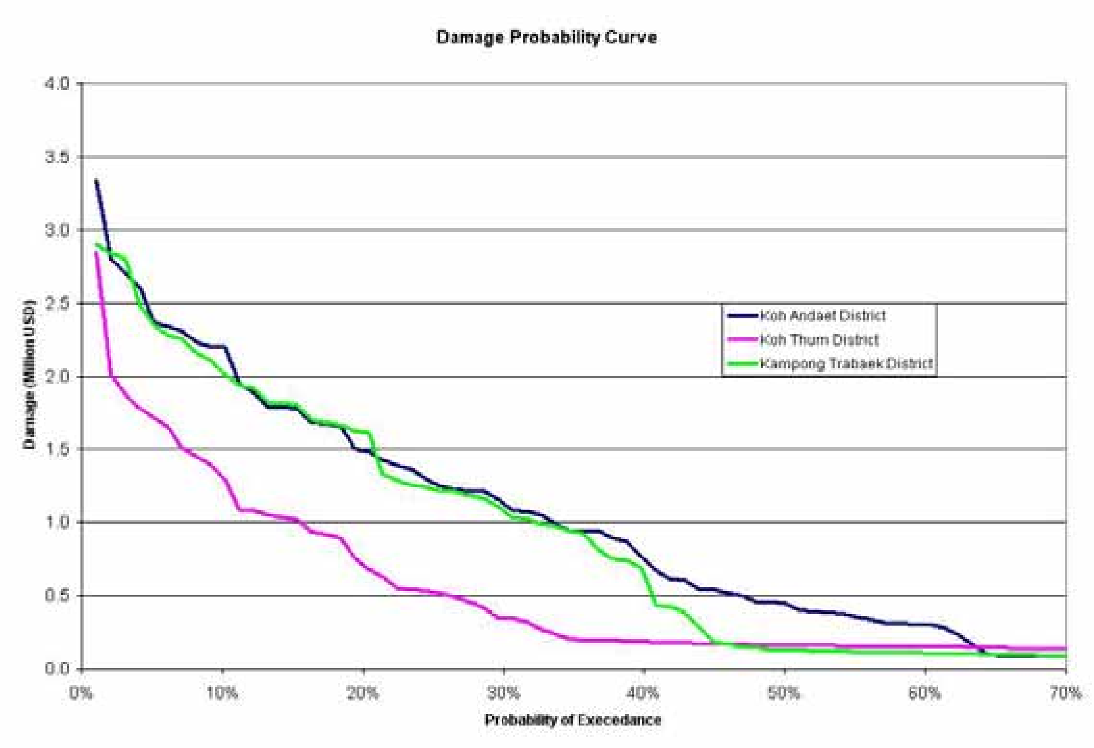


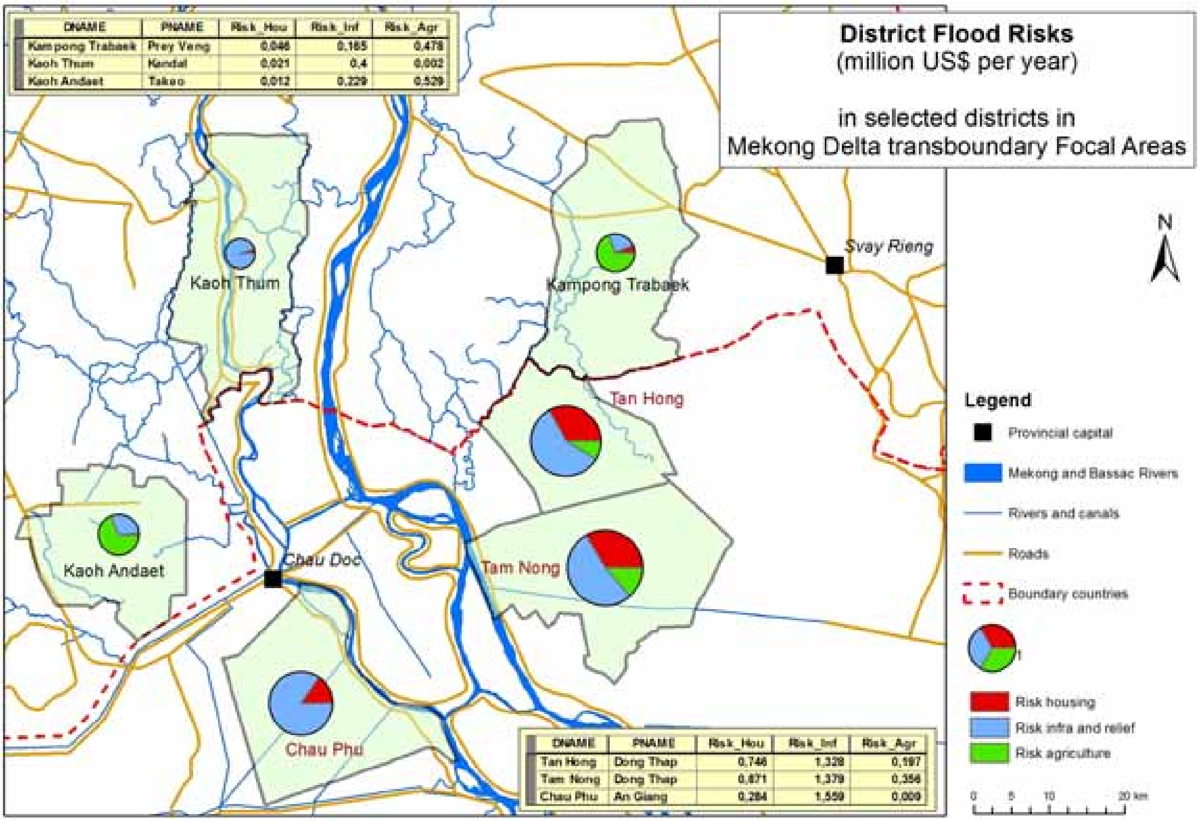
Figure 4.10 Probability damage curve for three Cambodian districts.

From this information the risk/ yearly expected value of the damage for the three districts could be derived by estimating the area under the probability damage curve (see explanation in Section 4.3.1). Table 4.2 shows both the absolute expected value and the expected value per square kilometer. From these results it becomes clear that Koh Andaet has the highest risk value.

Table 4.2 Results of risk calculations for the three focal areas in Cambodia.

District	Expected economic damage (million \$/yr)	Expected economic damage per hectare (million \$/(km^2*yr)
Koh Andeth	0.77	0.0022
Koh Thom	0.42	0.0009
Kampong Trabek.	0.69	0.0014

The results of the risk calculations can also be visualized. Figure 4.11 shows the results for the average flood risk calculations for the focal areas in Cambodia and Vietnam. The size of the circle shows the magnitude of the risk for the district and within the circle the distribution over the three damage categories (housing, infrastructure & relief, agriculture) is shown. It becomes clear that the distribution over the damage categories varies between districts. For Koh Andat and Kampong Trabek the largest part of the risk is determined by the category agriculture. For Koh Thom the largest part of the risk is for the category infrastructure.



DNAME	PNAME	Risk_Hou	Risk_Inf	Risk_Agr
Kampong Trabaek	Prey Veng	0,046	0,165	0,478
Kaoh Thum	Kandal	0,021	0,4	0,002
Kaoh Andaet	Takeo	0,012	0,229	0,529

DNAME	PNAME	Risk_Hou	Risk_Inf	Risk_Agr
Tan Hong	Dong Thap	0,746	1,328	0,197
Tam Nong	Dong Thap	0,871	1,379	0,356
Chau Phu	An Giang	0,284	1,559	0,009

Figure 4.11 Flood risks by district for selected areas in Cambodia and Vietnam.

The figure shows clearly that the risk values on the Vietnamese side are much higher. This is due to the fact that the Vietnamese areas are more densely populated.

CHAPTER 5

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5 REFERENCES

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APPENDICES

APPENDIX 1 APPROACH TO FLOOD DAMAGE AND RISK ASSESSMENT IN EUROPE

In this Appendix the European Union's Flood Directive is presented, along with preliminary studies and guidelines produced by EXCIMAP and FLOODsite, and the Dutch DACA approach to show how flood damage and flood risk are handled in Europe.

In 2007 the European Parliament and the Council of the European Union promulgated Directive 2007/60/EC[9] on the assessment and management of flood risks. This directive compels the 27 member states of the European union to (preliminarily) assess their flood risks (by 2011), prepare flood hazard and flood risks maps (by 2013), and to prepare flood risk management plans (by 2015).

The Flood Directive introduces a number of key principles, which could be relevant and applicable also for other regions or river basins:

- Member States shall, for each river basin or the portion of an international river sub-basin lying within their territory, undertake a preliminary flood risk assessment in accordance with an assessment of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity, taking into account as far as possible issues such as the topography, the position of watercourses and their general hydrological and geo-morphological characteristics, including floodplains as natural retention areas, the effectiveness of existing manmade flood defence infrastructures, the position of populated areas, areas of economic activity and long-term developments including impacts of climate change on the occurrence of floods.
- In the case of an international river basin or sub-basin which is shared with other Member States, Member States shall ensure that exchange of relevant information takes place between the competent authorities concerned.
- Flood risk management plans shall take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, environmental objectives, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure.
- Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin.
- Flood risk management plans may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event.
- In the interests of solidarity, flood risk management plans established in one Member State shall not include measures which, by their extent and impact, significantly increase flood risks upstream or downstream of other countries in the same river basin or sub-basin, unless these measures have been coordinated and an agreed solution has been found among the Member States concerned.
- Member States shall make available to the public the preliminary flood risk assessment, the flood hazard maps, the flood risk maps and the flood risk management plans.
- Member States shall encourage active involvement of interested parties in the production, review and updating of the flood risk management plans.

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[9] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32007L0060:EN:NOT

EXCIMAP

In order to carry out the tasks set by this directive, a large number of European countries organised themselves into the European Exchange Circle on Flood Mapping EXCIMAP. In 2007 they produced the Handbook on Good Practice for Flood Mapping in Europe[10], which focuses on the first steps required by the Directive.

Flood maps are to indicate the geographical areas which could be covered by flood waters from all natural sources at several levels of probability. The effect of floods is always the same: water and or sediments in unwanted places outside the normal water course. The Guideline distinguishes between: (i) river flooding in flood plains, (ii) sea water flooding, (iii) mountain torrent activity or rapid run-off from hills, (vi) flash floods in Mediterranean ephemeral water courses (wadi's), (v) groundwater flooding, (vi) lake flooding.

Flood maps can show flood extent according to: (i) probability classes, (ii) historic events, (iii) flood depth, (iv) flow velocity, (v) flood propagation, and (vi) degree of danger. These maps can be used for: (i) land use planning and management, (ii) water shed management, (iii) hazard assessment, (iv) emergency planning and management, (v) planning of technical measures, and (vi) overall awareness building.

For flood risk management, flood maps are useful tools in answering questions such as: (i) where is the greatest risk? (ii) where should investments be targeted? (iii) which investments may have the highest cost effectiveness?

Flood hazard maps

Flood hazard maps need to be prepared for low, medium and high probabilities of occurrence. For each probability the extent, inundation depth or water level, and where appropriate the water velocity should be indicated. These maps are to be prepared using hydraulic models, statistical analysis and observations.

Flood danger maps indicate a degree of danger by combining information on probability level, flood depth, velocity and debris content. These maps are not required by the Flood Directive, but are used in some member countries for land use planning.

Flood event maps record historical flooding and can be seen as a first approach to flood hazard maps. The can be used in awareness raining, for follow-up of flood hazard assessment, for the calibration of models, and an emergency management and planning tool.

Flood vulnerability maps

Flood vulnerability maps show the assets at risk: (i) population, (ii) assets and economic activity, and (iii) potentially affected installations causing pollution. For the Netherlands such maps have been prepared on a provincial level and are available for the public and specialised services[11].

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[10] http://ec.europa.eu/environment/water/flood_risk/flood_atlas/index.htm

[11] www.risicokaart.nl

Flood risk maps

The EU Flood Directive defines 'flood risk' as 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.

These maps should therefore indicate: (i) the number of inhabitants potentially affected, (ii) the type of economic activity potentially affected, (iii) installations which might create incidental pollution, and (iv) other information such as high content of transported sediments and debris and other significant sources of pollution.

Risk may be calculated as:

$\text{Risk} = C * Ph$
where: C = potential adverse consequence and Ph the probability of the hazardous process.

This way, risk is expressed as a potential loss in a particular area or unit area (ha) within a given time period (one year):

$C = V * S * E$
where: V, S and E are vulnerability parameters:
V = value of element at risk (in monetary terms or human life)
S = susceptibility: damage effect on element at risk (as a function of magnitude of hazard; e.g. depth-damage and damage-duration curves (factor ranging from 0 to 1)
E = exposure: the probability of the element at risk to be present while the event occurs (factor ranging from 0 to 1)

FLOODsite[12] is a research oriented project supporting the member states in complying with the requirements stipulated in the EU Flood Directive and runs from 2004-09. FLOODsite covers the physical, environmental, ecological and socio-economic aspects of floods from rivers, estuaries and the sea. It considers flood risk as a combination of hazard sources, pathways and the consequences of flooding on the “receptors” – people, property and the environment. The FLOODsite consortium includes 37 of Europe's leading institutes and universities and the project involves managers, researchers and practitioners from a range of government, commercial and research organisations, specialising in aspects of flood risk management. FLOODsite research is being integrated through decision support technologies, uncertainty estimation and pilot applications for river, estuary and coastal sites in Belgium, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Spain, and the UK.

FLOODsite has prepared a discussion paper[13] reviewing the flood damage evaluation methods applied in the UK, the Netherlands, the Czech Republic and selected German States. Based on this review, a guideline for flood damage evaluation has been prepared[14]. The final outcome of the project will include modelling tools and a “flood knowledge map”, in which persons, organisations and pilot projects can be located.

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[12] www.floodsite.net

[13] Meyer, V.(2005): National flood damage evaluation methods

[14] Messner, F. *et al*. (2007): Evaluating flood damages: guidance and recommendations on principles and methods

Dutch Damage and Casualties Assessment Tool[15]

Traditionally flood defence planning focused on safety standards, such as dike design levels or reservoir volumes required to ensure predefined protection levels for population and economy. Protection of the community against floods with a frequency of once in 1,250 years and more is a good example, as is the case with the flood protection law of the Netherlands. However, this approach neglects the amount of valuables protected by a defence system and, hence, disregards the efficiency of flood protection measures. While economic costs of alternative flood defence options are usually considered in the decision-making process, the benefits of flood protection in the form of prevented damages should be taken into account too.

The new paradigm for flood risk management includes the economic analysis of costs and benefits of flood protection and mitigation measures. Here, not only the safety of a defence system and its associated costs are considered, but also the damages to be expected in case of its failure. As a consequence of the application of cost-benefit and risk analysis, safety standards could better be adjusted to the specific circumstances, because it could turn out that the costs of ensuring an overall safety standard considerably exceed the benefits in some areas.

Usually there are two integral parts in the state-of the-art ex ante estimation of flood damages. Firstly, the flood hazard needs to be determined by means of exposure indicators, using flood parameters like expected inundation area and depth, velocity and flood duration. Secondly, the expected damage needs to be estimated. For this all valuable property located within the endangered area, i.e. the damage potential, needs to be quantified. The expected damage is then calculated by using depth-damage-functions showing the total damage of the properties (buildings, cars, roads, etc) or its relatively damaged share as a function of inundation depth.

Depending on whether the functions relate to the absolute damage or the damage share, they are called absolute or relative depth-damage functions. Over the past decades a variety of methods for the ex-ante estimation of flood damages emerged. According to their scale and goal, these methods can be roughly divided into three categories: macro-, meso- and micro-scale analyses. Macro-scale analyses consider areas of inter/national and should provide decision support for national flood mitigation policies. Meso-scale analyses deal with research areas of regional scale, i.e. river basins or coastal areas. Here, the planning level refers to large-scale flood mitigation strategies. The aim of micro-scale analyses is the assessment of single flood protection measures on a local level.

In the Netherlands a standard method for flood damage and casualties assessment has been developed and used since 1999 (HIS-SSM). It is used to assess the change of risk following national and regional decisions on water management measures in the Netherlands. Moreover, from 2007 onwards all Dutch water-projects of national importance must be evaluated using this tool. It is also used in the production of the Dutch flood vulnerability maps mentioned in Section 3.7.

The Damage and Casualties Assessment Tool (DACA) is a GIS-based application in which land use, inundation depth-damage functions per land use and maximum damage values of each land use are combined with a model-generated flood hazard. This is in line with the ‘bottom-up approach’ or ‘relative approach’ described in Section 3.3.4.

In parallel with the FMMP-C2 project, HKV Consultants carried out a pilot project with the Thai Directorate of Water Resources to test the applicability of the DACA approach in Thailand.

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[15] Based on: Messner, F. and Meyer, V. (2005)

APPENDIX 2 APPROACHES FOR THE ASSESSMENT OF STRUCTURAL DAMAGE TO BUILDINGS

An important source of economic damage is the structural damage to buildings. Figure 5.1 shows how economic damage is connected to structural damage. The level of structural damage caused by the flood will be determined by the flood actions (or loads) and the building resistance (or strength) (Kelman and Spence 2004). The degree of structural damage depends on the intensity and magnitude of the flood actions, i.e. hydrostatic and hydrodynamic forces, and on the building's resistance to flooding. The next step is the economic valuation of the physical damages. To convert the structural damage to economic estimates insight in the building's pre-disaster market value and the replacement cost is required. Apart from damage to the structure, the damage estimation in monetary terms will also include damage to the inventory of the structure.

In the earlier presented damage functions the economic damage estimate is directly related to the flood characteristics. However, for some applications it could be relevant to have insight in the degree of structural damage. The level of structural damage is also important for human safety and loss of life as buildings are important shelters during flood events.

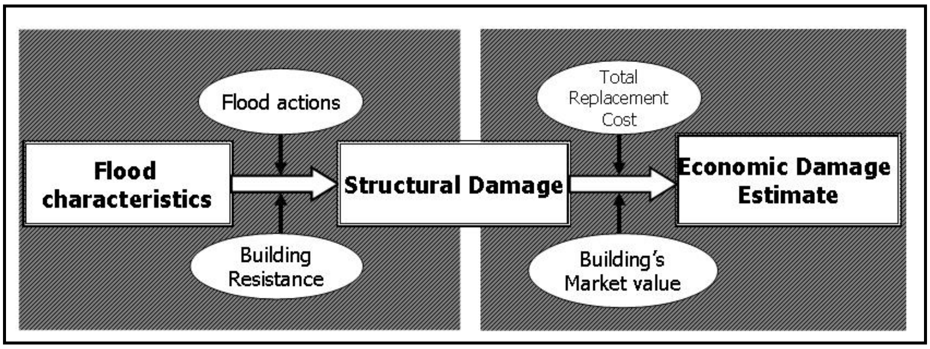


Figure 5.1 Scheme of structural flood damage analysis.

Especially flow velocity is an important factor for building damages as it determines the hydrodynamics loads. Several models have been developed that relate the physical damage to houses to the combination of flood depth and flow velocity. As an example Figure 5.2 presents the damage criterion from brick and masonry houses (Clausen, 1989). In combination with input from flood simulations, such criteria can be used to develop flood risk maps that exhibit different levels of expected damage. Other researchers have investigated building vulnerability. Kelman (2002) and Kelman and Spence (2004) investigated physical vulnerability of residential properties in coastal areas and added the influence of rise rate. Roos (2003) developed a comprehensive probabilistic model for collapse of buildings, which takes into account two failure modes that can lead to partial or full collapse of a building. These are 1) the scour of foundations and 2) the failure of walls. The model of Roos considers hydrostatic and hydrodynamic loads, as well as the impacts of waves and pounding debris. Also the strength (resistance) of the building type is considered. A general weakness of these 'collapse of buildings' models concerns their limited practical validation. Most of the presented relationships are based on theory or scale model tests.

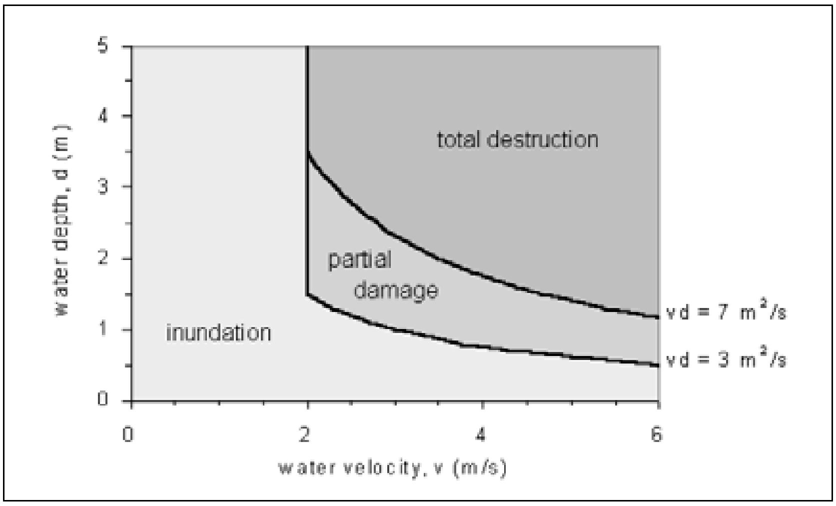


Figure 5.2 Damage criterion for brick and masonry houses proposed by Clausen, figure from (Karvonen *et al*., 2000).

In general the advantage of the above approach is that the actual flood conditions (depth, velocity) are taken into account. A related disadvantage is that a lot of detailed (GIS) data is needed to relate the local flood conditions to the vulnerability of an individual building.

The degree of damage will also be highly dependent on the type of structure that is affected. For example wooden houses will have a different damage pattern than concrete or brick houses. Measures and construction techniques, e.g. building houses on poles, will also affect the degree of structural damage. Therefore it is not recommended to directly transfer existing models and relations for structural damage to other regions and housing types without a detailed assessment of building types and their vulnerability.

APPENDIX 3 FUNDAMENTAL ISSUES IN ECONOMIC EVALUATION

There exist different rationales of the evaluation. Financial evaluations look at damage from a perspective of a single person or firm, neglecting public affairs and focusing on the actual financial burden that individual or firm has to pay for. Economic evaluations have a broader perspective and want to assess the impact on national or regional welfare, including impacts on intangible goods and services. This broader economic perspective is the appropriate one to apply if calculations of flood damage are to be designed for supporting public policy decisions.

Several principles of economic evaluation need to be considered in order to conduct a comprehensive flood damage evaluation study in a consistent way. The most important principles as regards the economic evaluation of flood damage are specified in the following sections. The application of the principles of economic evaluation is crucial for an appropriate examination of flood damage, and the use of their results in flood risk analysis. Therefore, It is essential to follow these principles as closely as practicable.

Economic point of views

Economic aspects of flood damage evaluation and analysis require a determination of flood damages to the national economy. There is no matter of who would pay for the damages and who would receive the benefits (if any) as result from the flood.

The analyst has to point out the flood damages in a view point of the society as a whole. To reflect a view point of the society, the economic and/or shadow prices of good and services - opportunity cost are used in estimating flood damages and benefits. Thus, anything that reduces national income is a damage and anything that increases national income is a benefit.

In an economic damage study, depreciated values should be applied in order to reflect the value of a good at the time when it is damaged by a flood. Using replacement cost is an overestimation of damage from a broader economic perspective, because replacement usually involves improvements: old houses/goods which are damaged during a flood are usually substituted by new, more productive and better performing ones.

Apply economic prices for evaluation of damages

The economic evaluation of goods and services which are traded in the market is a task that is relatively easy to accomplish. However, according to economic theory several rules need to be considered to identify the ”correct“ value. As stated in most economic textbooks, the value of a market good corresponds to its scarcity price. And a scarcity price emerges in the context of an ideal competitive market with many competing actors involved and without government intervention. Since these ideal conditions are never fulfilled in a real-world market, adjustments are necessary in order to calculate the ideal “shadow price“ of the good under examination. This means, real world market prices must be translated into shadow prices by excluding all kind of transfer payments like taxes and subsidies and by converting monopolistic market prices into competitive market prices.

Time value of money

To simplify the idea, we take the following example: if we have $100 today and lend it to someone or put it in a bank, we expect to be paid interest for the use of the money (say 10% per year). It means that from $100 today we will get $110 in one year later or in another words, the value of $100 today worth $110 next year.

In economic analysis the economist compares value of money at a different time instead of the amount of money. To do this the economist uses discounting technique for converting value of money to a specific time/date . There are some key converting factors often used in economic analysis as presented bellow:

Compounding factor

The factor is used to determine future value (FV) of a present amount (PV) at the end of nth period at the interest rate of *i*:

$$FV = PV\,(1 + i)^{n}$$

Compounding factor for 1 per annum

It is used to calculate the future accumulated value (FV) at the end of nth period at an interest rate of *i* with a sequence of equal payments (A).

$$FV = A\,\frac{(1 + i)^{n} - 1}{i}$$

Capital recovery factor

It is used to calculate the amount of each payment (A) at the end of each n period to recover the present amount (PV) with the interest rate of *i*:

$$A = PV\,\frac{i\,(1 + i)^{n}}{(1 + i)^{n} - 1}$$

Net Present Value (NPV)

Net Present Value is the present worth of the incomes stream generated by an investment. It can be calculated by:

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+i)^{t}}$$

where: B = benefit; C: cost of investment and annual cost
T = time from year 1 to year n; and i: discount rate

Constant price

Flood damage evaluation is carried out in a specific year (say 2007) but the cost and damages were pricing at the time it occurred (say 2000, 2001, etc.). It is therefore economist has to convert nominal damage value to constant/fixed value at the time doing the analysis by deflating the current pricing value of damage in the past years.

Constant or fixed price refers to a value from which the overall effect of a general price inflation has been removed. Where current prices are adjusted for general inflation, it is assumed that inflation will affect the prices of the inputs and outputs at same extent, such that prices retain the same general relationship to each other. Using constant prices ensures that the past and future costs and benefits of the identified alternatives are estimated in the same units as the costs and benefits measured at the time of evaluation for decision.

APPENDIX 4 ANALYSIS OF HUMAN INSTABILITY IN FLOOD FLOWS

For smaller-scale floods where velocities are more important, loss of stability (i.e. toppling) for people in flood flows can be an important reason of death. Criteria have been developed to assess this. These can be used to assess the flood risks at a local level. Different series of experiments have been undertaken (Abt *et al*., 1989; Karvonen *et al*., 2000). For the available test data Figure 5.3 shows the combinations of depth and velocity that resulted in instability. Overall it shows that people lose stability in flows with limited depth-velocity products. The obtained critical depth-velocity products range from 0.6 m^2/s to about 2 m^2/s. The differences in the reported test results can be related to test circumstances (bottom friction, test configuration) or personal characteristics (weight, length, clothing). Further background information regarding human instability is given in (Jonkman and Penning-Rowsell, 2008).

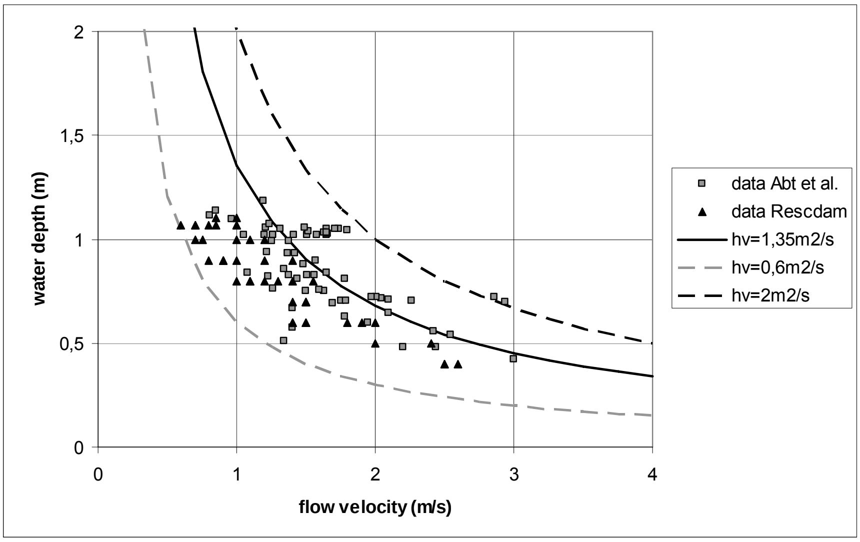


Figure 5.3 Observations from experimental series regarding the combination of water depth and flow velocity that resulted in instability.

Based on such tests criteria have been developed that show different levels of danger as a function of water depth and flow velocity. An example of such a criterion is shown in Figure 5.4. A distinction is made between three zones with different levels of danger. The above criteria can be used to determine risk zones for certain flood conditions.

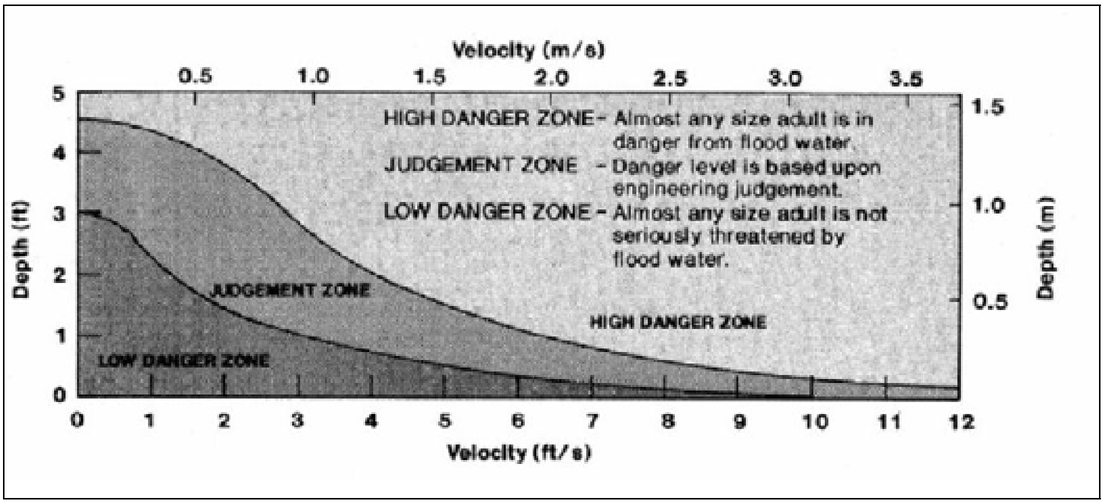


Figure 5.4 Criteria for danger to people in flood flows (USBR, 2001).

Finally, indirect flooding effects (e.g. on local food supply) and longer term health impacts (e.g. diseases) can also contribute to loss of life. However, there are no quantitative approaches to directly estimate the effects of these processes on the loss of life. It is expected that the processes will be dependent on the area that is affected and the social and economical conditions.

APPENDIX 5 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.

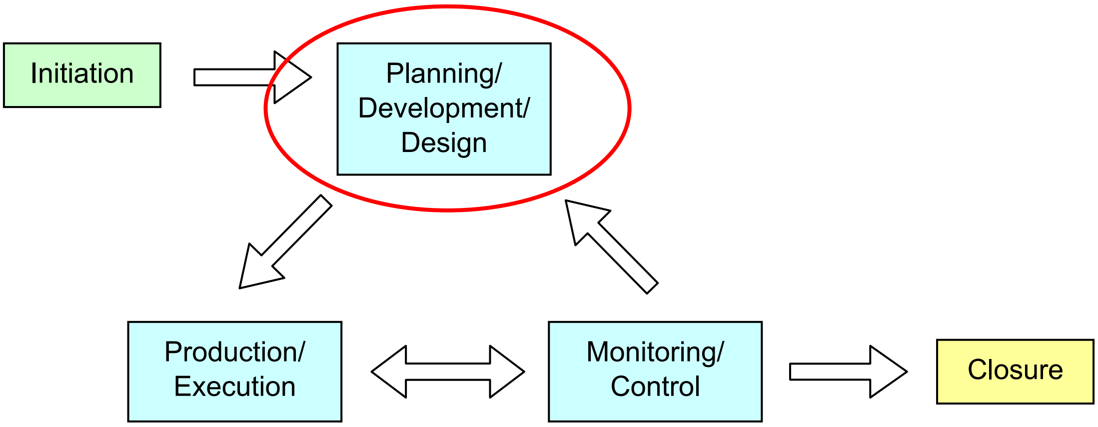


Figure 5.5 The phases of an engineering project.

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.

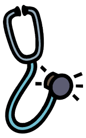
The five stages of Phase 2 contain the following:

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.

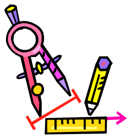
c) Preliminary design

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



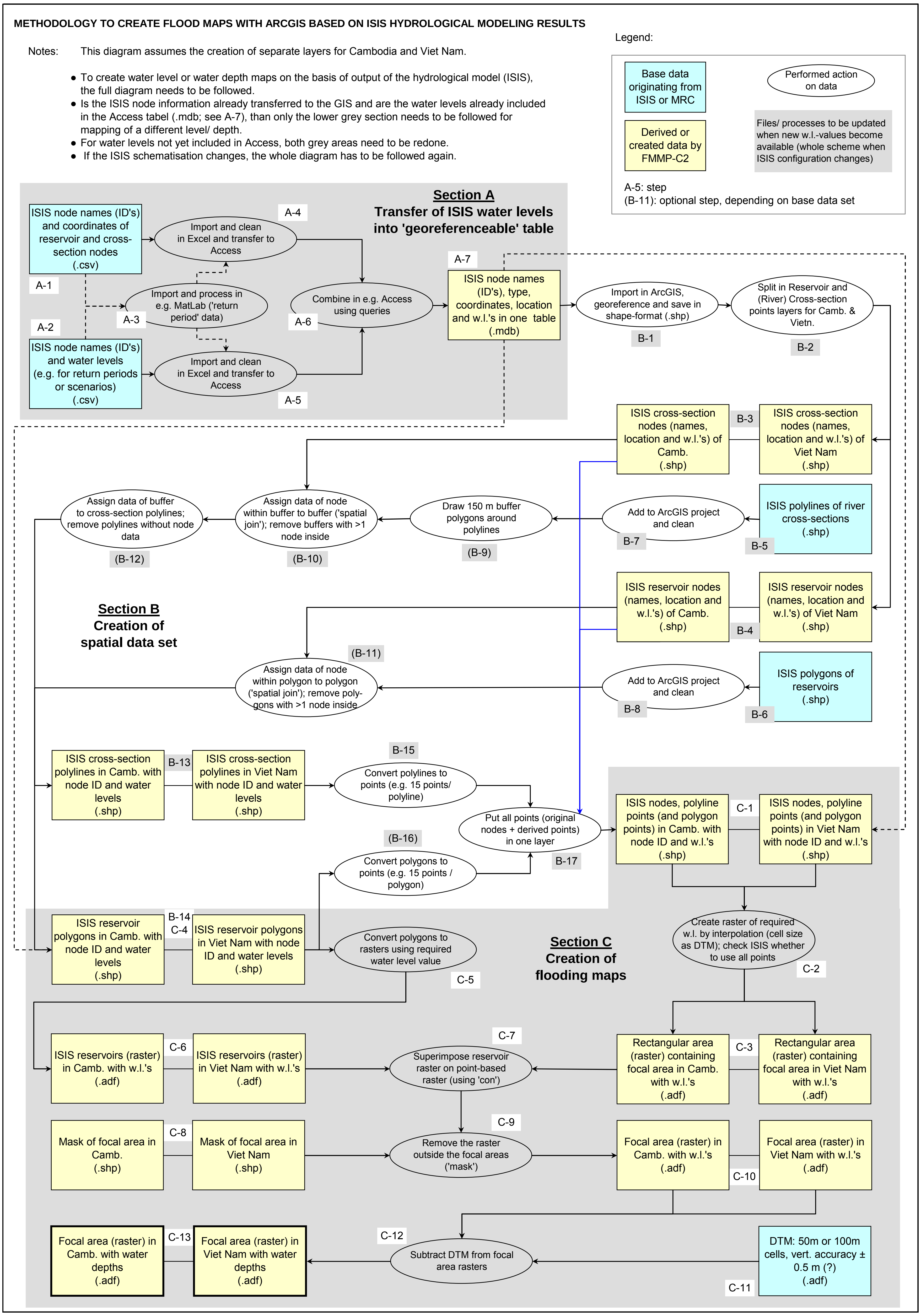
During the final design stage the detailed architectural and engineering drawings (the blueprints) of all physical components of the project are produced. Virtually all design problems must have been resolved before the end of the final design stage. Sufficient detail must be provided by the drawings 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:

APPENDIX 6 FLOW CHART TO CREATE FLOOD MAPS WITH A GIS



METHODOLOGY TO CREATE FLOOD MAPS WITH ARCGIS BASED ON ISIS HYDROLOGICAL MODELING RESULTS

Notes: This diagram assumes the creation of separate layers for Cambodia and Viet Nam.

- To create water level or water depth maps on the basis of output of the hydrological model (ISIS), the full diagram needs to be followed.
- Is the ISIS node information already transferred to the GIS and are the water levels already included in the Access tabel (.mdb; see A-7), than only the lower grey section needs to be followed for mapping of a different level/ depth.
- For water levels not yet included in Access, both grey areas need to be redone.
- If the ISIS schematisation changes, the whole diagram has to be followed again.