MEKONG RIVER COMMISSION
MRC
FOR SUSTAINABLE DEVELOPMENT

Best Practice Guidelines for Flood Risk Assessment

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

May 2010
Final Report, Volume 3A

Deltares
Enabling Delta Life Delft Hydraulics

ROYAL HASKONING

UNESCO

Mekong River Commission

Flood Management and Mitigation Programme

Structural Measures and Flood Proofing in the Lower Mekong Basin

Best Practice Guidelines for Flood Risk Assessment

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TABLE OF CONTENTS

1 INTRODUCTION ... 3
1.1 Guide to the reporting structure of the Flood Management and Mitigation Programme - Component 2, Structural Measures and Flood Proofing ... 3
1.2 Best Practice Guidelines for Integrated Flood Risk Management ... 4
1.3 Concepts of Flood Risk Assessment in the Best Practice Guidelines ... 4
1.3.1 Flood risk and flood risk management ... 4
1.3.2 Flood risk assessment ... 5
1.4 Basis of the Flood Risk Assessment Guidelines ... 7
1.5 Use of the Flood Risk Assessment Guidelines ... 7
1.6 The Best Practice Guidelines and project phases/stages ... 8

2 FLOOD HAZARD ASSESSMENT ... 11
2.1 Introduction ... 11
2.2 Classification of type of flood ... 11
2.3 Tributary flood hazard assessment ... 15
2.3.1 General ... 15
2.3.2 Flood hazard derived from rainfall extremes ... 15
2.3.3 Example of flood hazard derived from rainfall extremes ... 18
2.3.4 Flood hazard determined from observed flows ... 23
2.3.5 Flood hazard derived from regional flood statistics ... 26
2.4 Mainstream flood hazard assessment ... 28
2.4.1 General ... 28
2.4.2 Data collection ... 28
2.4.3 Database development and conduct of field visits ... 30
2.4.4 Data validation and processing ... 31
2.4.5 Hydrological hazard assessment in terms of flood peak water levels and flood volumes ... 31
2.4.6 Flood hazard assessment ... 32
2.4.7 Example: Mekong near Nakhon Phanom (Thailand) ... 33
2.5 Combined flood hazard assessment ... 37
2.5.1 General ... 37
2.5.2 Data collection ... 38
2.5.3 Database development and conduct of field visits ... 39
2.5.4 Data validation and processing ... 39
2.5.5 Hydrological hazard assessment ... 39
2.5.6 Flood hazard assessment using a hydraulic model ... 41
2.5.7 Example: combined floods in the lower Xe Bang Fai River Focal Area (Lao PDR) ... 42
2.6 Flood Hazard Assessment in the Mekong Delta ... 51
2.6.1 General ... 51
2.6.2 Data collection and conduct of field visits ... 51
2.6.3 Database development ... 53
2.6.4 Hydrodynamic model development ... 54
2.6.5 Flood hazard assessment ... 58
2.7 Flood hazard mapping ... 58
2.7.1 General ... 58
2.7.2 Transfer of modelling results (A) ... 59
2.7.3 Creation of spatial data (B) ... 60
2.7.4 Creation of flooding maps (C) ... 62
2.7.5 Data sources ... 64

3 FLOOD DAMAGE ASSESSMENT 69
3.1 Introduction 69
3.2 Classification of flood damages and benefits 69
3.2.1 Flood damages 69
3.2.2 Flood benefits 71
3.3 General approach to economic damage assessment 72
3.3.1 Scope of the analysis and level of detail 72
3.3.2 Direct damage assessment 73
3.3.3 Damage functions 74
3.3.4 Relative and absolute damage assessments 76
3.3.5 Assessment of indirect damages 77
3.4 Damage models 78
3.5 Economic and financial issues in damage assessment 79
3.5.1 Financial vs. economic valuation 79
3.5.2 Estimating values of assets 79
3.5.3 Time value of money 80
3.6 Loss of life and health effects 80
3.6.1 Introduction 80
3.6.2 Loss of life 81
3.6.3 Health effects and social and environmental impacts 81
3.7 Presentation of damage assessments results 82
3.8 Data collection 83
3.9 Flood damage assessment in the Mekong River Basin 86
3.9.1 Scope and selected areas 86
3.9.2 Approach and methodology 86
3.9.3 Damage categories 87
3.9.4 Data collection and surveys 87
3.9.5 Derivation of damage functions 92
3.9.6 Creation of damage maps 95
3.9.7 Results of damage assessments 96

4 FLOOD RISK ASSESSMENT 103
4.1 Introduction 103
4.2 General approach 103
4.3 Presentation of the results of risk assessments 104
4.3.1 Economic risk 104
4.3.2 Risk to life 106
4.4 Risk reduction measures and risk evaluation 107
4.4.1 Effects of anti-flooding and flood preparation measures on risk 107
4.4.2 Basics of cost-benefit analysis 108
4.4.3 Economic optimisation 110
4.4.4 Risk valuation for loss of life 111
4.4.5 Risk matrix 111
4.5 Risk assessment for the LMB 112
4.5.1 Introduction and approach 112
4.5.2 Results of risk assessment 113

5 REFERENCES 117

APPENDICES

Appendix 1 Approach to Flood Damage and Risk Assessment in Europe
Appendix 2 Approaches for the Assessment of Structural Damage to Buildings
Appendix 3 Fundamental issues in Economic Valuation
Appendix 4 Analysis of Human Instability in Flood Flows
Appendix 5 The Best Practice Guidelines and Project Phases/Stages
Appendix 6 Flow Chart to Create Flood Maps with a GIS

LIST OF FIGURES

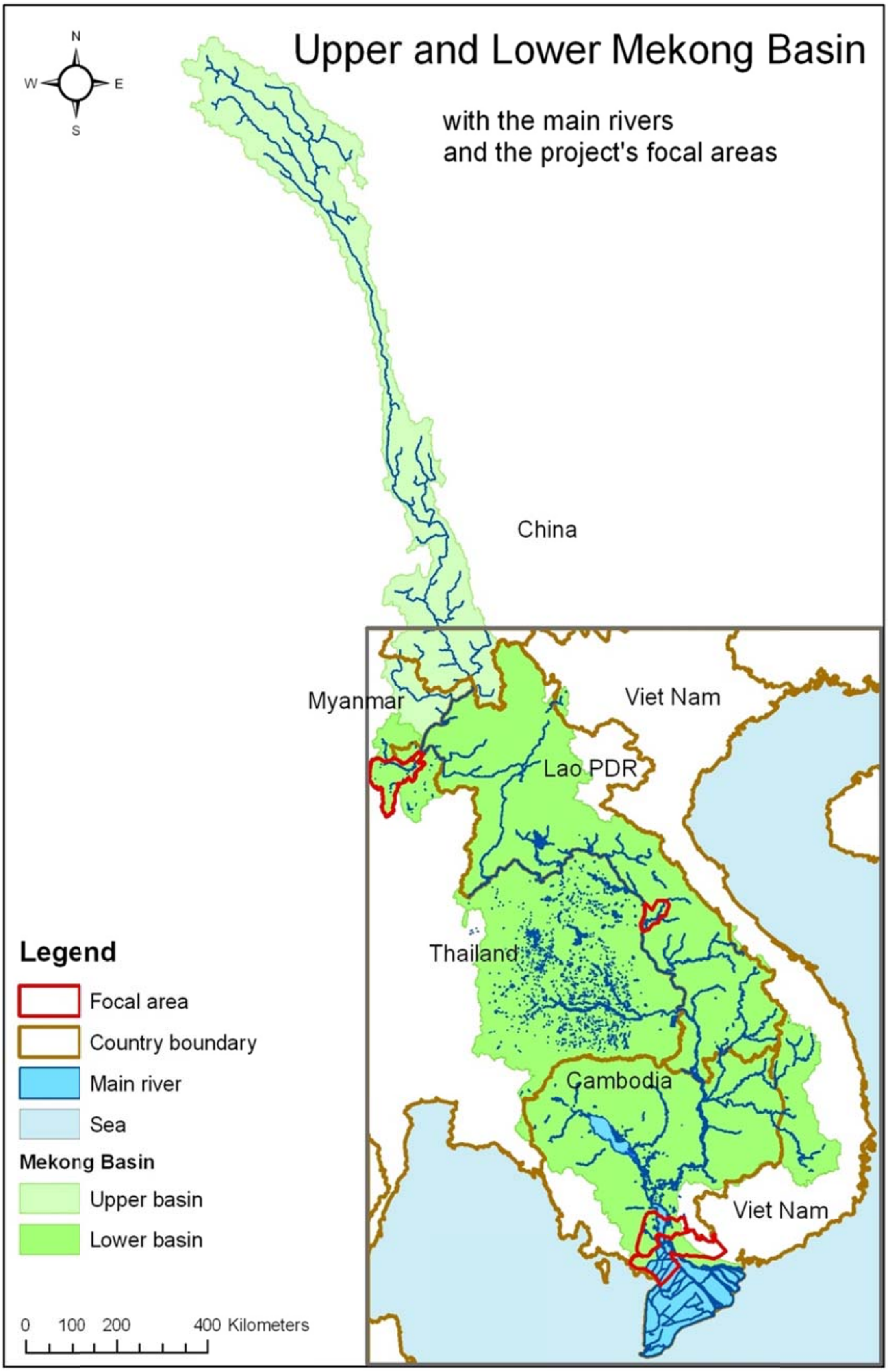
Figure 1-1 General scheme for flood risk management. 5
Figure 1-2 General scheme for flood risk assessment. 6
Figure 1-3 Scheme for flood risk assessment used in the FMMP-C2. 6
Figure 2-1 The sub-basins or sub-areas in the Lower Mekong River Basin. Letters refer to the countries in which these sub-basins are found (M= Myanmar, T = Thailand, L = Lao PDR, V = Viet Nam, C = Cambodia). 12
Figure 2-2 Overview of flood types in the Mekong River. 13
Figure 2-3 EV1 and GEV-fit to annual maximum daily rainfall at Pleiku for the years 1927-2006. 19
Figure 2-4 Depth-duration-frequency curves for Pleiku. 20
Figure 2-5 A 2-hour-design rainstorm diagram for the Upper Se San River derived from measures used for Pleiku. 21
Figure 2-6 Principles of the Clark Unit Hydrograph method, shown in various diagrams that are related to each other. 22
Figure 2-7 Hypothetical scatter plot of data points and fitted regression line showing the relationship between flood volumes and flood peak water levels. The red arrow in the Figure shows the deviation from the regression line for a single observation. 25
Figure 2-8 TCEV-distribution of the ratio of the T-year return period event to the mean annual flood for the pooled regional sample (Upper part of LMB, from Adamson, 2007). 27
Figure 2-9 Fit of the GEV function to annual maximum daily discharge of the Mekong River at Nakhon Phanom. 33
Figure 2-10 Peak water level discharge-Flood volume relation at Nakhon Phanom. 34
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). 35
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 most closely reflect the grid combinations. 35
Figure 2-13 Example of scaling of an observed hydrograph to make it suitable for serving as one of the grid points in Figure 2-12. 36
Figure 2-14 Derived frequency curve for maximum annual water levels at a location in the Mekong River floodplain just downstream of Nakhon Phanom. 37
Figure 2-15 Development of the flood simulation matrix for combined floods. 41
Figure 2-16 Hydrological map of Lower Xe Bang Fai River basin. 42
Figure 2-17 Impression of the 3-D grid for peak discharge and flood volume in the Mekong River (at Nakhon Phanom) and flood volume in the Xe Bang Fai River (at Mahaxai). The blue dots only show the 'outer side' of the grid; the full grid contains 90 such dots. 44
Figure 2-18 Scaling of an observed hydrograph for the Xe Bang Fai River at Mahaxai. 45

Figure 2-19 GEV-fit to marginal distributions of annual maximum discharge and flood volume at Mahaxai (Xe Bang Fai River). 46
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 lines. 47
Figure 2-21 Xe Bang Fai River hydraulic model with boundary conditions. 48
Figure 2-22 Derived frequency curve for maximum annual water levels at a location in the floodplain of the Xe Bang Fai River. 49
Figure 2-23 Flood depth and extent map of the Lower Xe Bang Fai River, for a return period of T = 100 years. 50
Figure 2-24 Hydraulic infrastructure of the Mekong Delta. 52
Figure 2-25 The schematisation of the Mekong Delta using the hydrodynamic delta model (ISIS) involves a large number of hydraulic nodes downstream of Kratie, next to floodplain 'reservoirs and river cross-sections. 53
Figure 2-26 Annual maximum water discharges at Stung Treng, 1910-2006. 55
Figure 2-27 Annual flood volumes at Stung Treng, period 1910-2006. 55
Figure 2-28 Seasonal hydraulic inflow to the Tonle Sap Lake, estimated from 1910-2006, with recorded data for 1997-2004. 56
Figure 2-29 Average monthly flow regime of the Mekong River at Stung Treng and of the Tonle Sap Lake as percentage of the annual totals. 56
Figure 2-30 Water level map, based on interpolation of ISIS nodes. 58
Figure 2-31 Water depth map, generated from a water level map subtracting the DTM (ground) levels. 58
Figure 2-32 Depiction of how water or flood depth is obtained by subtracting the ground level (DTM) from the water level (hydraulic simulation + GIS interpolation). 59
Figure 2-33 Example of ISIS data imported into Access, with node information and water levels for different scenarios, various return periods (probabilities), and different periods of the year. 60
Figure 2-34 ISIS schematization. ISIS calculates with (among other data) reservoir nodes (+) and cross-section nodes (dots). A spatial component of ISIS contains cross-sections (blue lines) and reservoirs (purple polygons). 61
Figure 2-35 Example of a raster, with the reservoir raster (angular areas) superimposed on the point-based raster. 63
Figure 2-36 Example of a flood depth map, here in the Mekong Delta for a flood with a return period of 25 years. 64
Figure 3-1 General approach to damage estimation, with the relationship between land use and flood depths used to calculate damages. 73
Figure 3-2 Example of a stage damage function for houses in the Netherlands (Kok et al., 2005). Note that the curves for building damage and contents show these as percentages of the total damage. 75
Figure 3-3 Schema of structural flood damage analysis. 76
Figure 3-4 Absolute and relative damage approaches. 77
Figure 3-5 Example of a mortality function derived for large-scale flooding in the Netherlands (Jonkman, 2007). 81
Figure 3-6 Damage intensity per hectare of the flooding of South Holland province in the Netherlands. 83
Figure 3-7 The absolute and relative flood damage assessment approaches require different data sets. 91
Figure 3-8 District flood damage curves for three categories of damages in Koh Andet District in Cambodia. 93
Figure 3-9 Example of a damage function for housing, relating housing damage (as % of the total value) to floodwater depths. 94
Figure 3-10 Relative flood damage curves for rice paddies, Cambodia. 95

Figure 3-11: Steps (simplified) to create maps based on absolute and relative damage – flood depth curves. 97
Figure 3-12 Example of a damage map based on relative damage curves, showing total damage to rice paddy fields in 3 districts and their communes in Cambodia. 99
Figure 3-13 Example of a damage map based on relative damage curves, showing damages to rice paddy fields per hectare in 3 districts in Cambodia and their communes. 100
Figure 4-1 Conceptual approach for determination of flood risk. 104
Figure 4-2 Relationship between return period and damage (left) and probability of flooding and damage (right). 105
Figure 4-3 The area below the curve, the total risk or expected damage (for example, in USD/year), can be approximated by summing the areas of the rectangles, A, B, b, C, c, D, d, E and e. 106
Figure 4-4 Example of an FN curve. 107
Figure 4-5 Effects of measures on flood risk. 108
Figure 4-6 Principle of economic optimisation. 110
Figure 4-7 Societal risk of fatalities due to flooding and the limit line of acceptable harm. 111
Figure 4-8 Structure of a risk matrix. 112
Figure 4-9 Approach for estimation of the risk. 112
Figure 4-10 Probability damage curve for three Cambodian districts. 113
Figure 4-11 Flood risks by district for selected areas in Cambodia and Viet Nam. 114

LIST OF TABLES

Table 2-1 Overview of flood types per sub-area (sub-basin) 14
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. 19
Table 2-3 Short duration rainfall (mm) at Pleiku derived from daily rainfall extremes. 20
Table 2-4 Computation of design storm ordinates for 15 min intervals. 21
Table 2-5 Parameters of the GEV distribution fitted to annual maximum daily discharge of the Mekong River at Nakhon Phanom and discharges (m^3/s) for selected return periods. 34
Table 2-6 Average monthly and annual flow (MCM) of the Xe Bang Fai River at Mahaxai and Mekong River at Nakhon Phanom. 42
Table 2-7 GEV-parameters, flood peak discharges and flood volumes (June-November) for distinct return periods in the Xe Bang Fai River at Mahaxai. 44
Table 2-8 Overview of water level monitoring stations at coastal boundaries in Viet Nam. 57
Table 3-1 Classification of flood damages. 69
Table 3-2 Distribution of damage over damage categories for a flood scenario for South Holland province in the Netherlands (Jonkman *et al*., 2008). 83
Table 3-3 Overview of Flood Damage Data 84
Table 3-4 Observed rank share of damages in the focal areas 87
Table 3-5 Data sources used for mapping damages in the Cambodian Mekong Delta. 90
Table 3-6 Damage data for different return periods for Koh Andet District. Damage is shown in million USD. 96
Table 4-1 Illustrative summary of damage and probability calculations for a range of flood scenarios. 104
Table 4-2 Results of risk calculations for the three focal areas in Cambodia. 113


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

ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler (Acoustic Doppler Profiler); an instrument used to measure the velocity of water across an entire water column
ArcGIS	ArcGIS is a complete software system for designing and managing solutions through the application of geographic knowledge
ARF	Area Reduction Factor (hydrology)
BCM	Billion Cubic Meters
BDP	Basin Development Planning
BPG	Best Practice Guidelines
CBA	Cost Benefit Analysis
d/s	Downstream
DACA	Damage and Casualties Assessment project for the Lower Mekong Basin using the HIS-SSM for assessing damages and casualties
DEM	Digital Elevation Model (see also DTM), is a digital model or 3D representation of a terrain's surface created from terrain elevation data
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 of the USA
FHA	Flood Hazard Assessment
FMM	Flood Management and Mitigation
FMMP-C2	Flood Management and Mitigation Programme, Component 2 (MRC)
FN curve	Societal risk is usually defined as the relationship between the probability of a catastrophic incident, expressed as the average frequency with which it can be expected to occur, and its consequences. It is usually represented as an F-N curve in which F is the annual frequency and N represents the number of casualties.
FRA	Flood Risk Assessment
FV	Future Value (economic analysis)
GEV	Generalised Extreme Value distribution (hydrology)
GIS	Geographic Information System
HAZUS	Software model used for risk assessment analysis of potential losses from floods, hurricane winds and earthquakes (by FEMA)
HH	Household(s)
HIS-SSM	Hydrological Information System: a damages and casualties assessment module
HYMOS	An 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 the 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 of water in open channels and estuaries
IUH	Instantaneous Unit Hydrograph (hydrology)

JICA	Japan International Cooperation Agency
LMB	Lower Mekong (River) Basin
LMD	Lower Mekong Delta
LXQ	Long Xuyen Quadrangle (Viet Nam)
MCM	Million Cubic Meters
MRC(S)	Mekong River Commission (Secretariat)
MRB	Mekong River Basin
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 the greatest weight to nearby points by calculating overlapping areas in Voronoi/Thiessen polygons (see also IDW)
NPV	Net Present Value (an economic term)
PDR (Lao)	(Lao) People's Democratic Republic
PoR	Plain of Reeds (Viet Nam)
PV	Present Value (an economic term)
RFMMP	Regional Flood Management and Mitigation Programme
RID	Royal Department of Irrigation
RR	Rainfall Ratio (hydrology)
SBF	Xe Bang Fai River (Lao PDR)
SCS-CN	Soil Conservation Service (USA) Curve Number method (hydrology)
SWAT	Hydrological model: 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 (UNESCO)
USA	United States of America
UTM	The Universal Transverse Mercator is the geographic coordinate system, which uses a 2-dimensional Cartesian coordinate system to give locations on the surface of the Earth
VRSAP	The "Vietnam River Systems and Plains" model is a hydro-dynamic model to simulate mainly one-dimensional hydrodynamic river flow or quasi two-dimensional flow on floodplains
WUP	Water Utilisation Programme
WUP-A	Water Utilisation Project Component A: Development of Basin Modelling Package and Knowledge Base

GLOSSARY

Attribute data	Also known as "count" data.
Areal rainfall	Rainfall in a specific area expressed as an average depth of liquid water over the area; the average rainfall over the specific area calculated on timescales on a storm, seasonal, or annual basis.
Backwater	The rise in surface elevation of flowing water upstream from and as a result of an obstruction to flow. The difference between the observed stage and that indicated by the stage-discharge relation is reported as backwater.
Best Practise Guidelines	Best Practice Guidelines are guidelines, describing methods or techniques that have consistently shown results superior to those achieved with other means, and that are used as a benchmark. Best Practice Guidelines are also interpreted guidelines describing processes of developing and following a standard way of doing things that dedicated organizations can use.
Colmatage	The natural deposition of particles suspended in water on land areas, usually on river floodplains and deltas, coastal lowlands, and flooded meadows.
Convective rainfall	Occurs when rain particles form in the active updraft of a cumulonimbus cloud, grow primarily by the collection of cloud droplets (i.e., by coalescence and/or riming) and fall out not far from their originating updraft.
Damage curve	The functional relationship between inundation characteristics (depth, duration, flow velocity) and damage for a certain category of risk.
Design rainstorm	A critical rainfall event that is used for assessing the flood hydrograph of a certain return period.
Direct damage	All harm which relates to the immediate physical contact of floodwater to people, property and the environment. This includes, for example, damage to buildings, productive assets, loss of crops and livestock, loss of human life, immediate and immediately foreseeable and calculable health impacts to the population in the flooded area and ecological harm.
Double mass test	A statistical test that is used to check the consistency of many kinds of hydrologic data by comparing date for a single station with that of a pattern composed of the data from several other stations in the area.
Exposure	A measure of the people, assets and activities threatened by a flood hazard.
Flashiness	Term reflects the frequency and rapidity of short term changes in streamflow, especially during runoff events.

Flood control	A structural intervention to reduce a flood hazard.
Flood damage	Damage to people, property and the environment caused by a flood. It includes direct as well as indirect damages.
Flood damage map	Map of the predicted flood damage.
Flood damage risk (= Flood risk)	The combination or mathematical product of the probability of the flood hazard and the possible damage that it may cause. This risk can also be expressed as the *average annual possible damage* or *expected damage*. If it is expressed in a financial measure, it is the expected net present value using economic valuations with different measurement assumptions.
Flood hazard	A flood that may *potentially* result in damage. A hazard does not necessarily lead to damage.
Flood hazard map	Map of the predicted or documented extent/depth/velocity of flooding with an indication of the flood probability.
Flood proofing	A process for preventing or reducing flood damages to infrastructure, buildings and/or the contents of buildings located in flood hazard areas.
Flood risk management	Comprehensive activity involving risk analysis, and both identification and implementation of risk mitigation measures.
Flood risk management measures	Actions that are taken to reduce the probability of flooding or the possible damages due to flooding or both.
Flood risk map	Map of the predicted extent of different levels/classes of *average annual possible damage* due to flooding.
Hydrograph	A time series of water levels at a fixed location. For floods, it shows the rise and fall of flood waters and the peak water level height of the flood.
Hydrological hazard	A hydrological event (discharge) that may result in flooding.
Hydraulic roughness	Is the measure of the amount of frictional resistance water experiences when passing over land and channel features.
Hydrodynamic load	The pressures that result from water flowing against and around a rigid structural element or system. The pressures are functions of velocity, direction of flow relative to the object, object geometry, and object surface roughness characteristics.
Hydrostatic load	The pressure at any water depth due to hydrostatic pressures.
Hyetograph	A graphical representation of the distribution of rainfall over time.
Indian 1954	A geodetic datum first defined in 1954 and used by MRC for the

	Mekong River Basin.
Indirect damage	All non-direct damage which relates to the disruption of economic activity and services due to flooding including impacts on the non-flooded areas.
Integrated flood risk management	The approach to flood risk management that focuses on the full chain of a meteorological hazard leading to flood damages and considers combinations of structural and non-structural solutions to reduce that damage.
Meteorological hazard	A meteorological event (storm) that may result in a hydrological hazard and, eventually, in flooding.
Monte Carlo analysis	A computer sampling technique often used for simulating long term events based on statistical probabilities, testing a series of multiple random events by drawing random samples from a data set.
Non-staggered grid	A grid for which vector variables and scalar variables are stored at the same locations.
Orographic effect	Occurs when an air mass approaches a mountain range and is rapidly forced upward, causing any moisture to cool and create precipitation in the form of rain or snow.
Unit hydrograph (UH)	The hypothetical unit response of a watershed (in terms of runoff volume and timing) to a unit input of rainfall. It can be defined as the *direct runoff hydrograph* resulting from one unit (e.g., one cm or one inch) of *effective (net) rainfall* occurring uniformly over that watershed at a uniform rate over a unit period of time.
Raster	Defines values for pixels occupying a particular rectangular area of the plane, not necessarily including (0, 0).
Rating curve	A rating table or curve is a relationship between stage (water level) and discharge at a cross section of a river.
Reach	Any length of a stream between any two points.
Resilience	The ability of a human social system (at the level of community or society) to cope with the damaging effect of floods.
Return period	Recurrence time, average time interval between subsequent events in which conditions are exceeded. When designing a structure, the return period is usually larger than the projected lifetime, because, for instance, if both would equal 50 years, the structure would have a 64% probability of failure during its lifetime. In statistical analysis an event with a return period of N years is likely, on average, to be exceeded only once every N years.
Routing	A technique used to predict the changes in shape of water as it moves through a river channel or a reservoir.

Saint Venant equations	The shallow water equations in its unidimensional form are a set of hyperbolic partial differential equations that describe the flow below a pressure surface in a fluid (sometimes, but not necessarily, a free surface).
Scour	Washing away of the bed/bank material under the action of current and wave.
Serial and cross correlation	The existence of serial correlation in a time series will affect the ability of the test to assess the site significance of a trend; and the presence of cross-correlation among sites in a network will influence the ability of the test to evaluate the field significance of trends over the network.
Spatial data	Data or information that identifies the geographic location of features and boundaries on Earth, such as natural or constructed features, oceans, and more. Spatial data is usually stored as coordinates and topology, and is data that can be mapped. Spatial data is often accessed, manipulated or analyzed through Geographic Information Systems.
Spot height	The height of the highest point in a given area expressed in feet or meters above sea level, as marked on topographical charts. These are indicated by black dots with adjacent numerals.
Susceptibility	The opposite of resilience: the inability of a human social system (at the level of community or society) to cope with the damaging effect of floods.
(N-year) synthetic series	Simulated long term event-related data series.
Vulnerability	The potential damage that flooding may cause to people, property and the environment.

REFERENCE SYMBOLS FOUND IN THE TEXT

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

A. Type of text/content; and
B. Project stages within the five consecutive project phases.

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

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

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

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

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

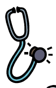
iv) Applications and Guidelines
Methodology and theory adapted/applied to the Lower Mekong River Basin (LMB), including guidelines. The guidelines are applied in one of the five project stages described below (B).

B) Project Stage Symbols: A project usually consists of five phases (see Section 1.6). FMMP-C2 covers only the second phase: Planning/Development/Design. This phase can be subdivided into five stages:

a) Preliminary/pre-feasibility study stage

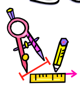
b) Feasibility study and overall planning stage

c) Preliminary design stage



d) Detailed design and detailed planning stage

e) Construction/bid documents stage



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

Sometimes more than one symbol may apply to a section.

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

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

The Mekong River Commission (MRC) implemented Component 2 on Structural Measures and Flood Proofing of the Flood Management and Mitigation Programme (FMMP) between September 2007 and January 2010 under a consultancy services contract between the Mekong River Commission Secretariat (MRCS) and Royal Haskoning, working in association with Deltares and UNESCO-IHE. The work comprised three periods, an Inception period and two Implementation periods. During each period, the consultants delivered a series of outputs and discussed them with the MRC, the National Mekong Committees, and line agencies of the four MRC Member Countries. A portion of Component 2 - on 'Roads and Floods' - was implemented by the Delft Cluster under a separate contract with the MRC. Component 2 included five Demonstration Projects which are presented separately.

The consultancy services contract for Component 2 requests, in general terms, four main products in addition to a Final Report. The reports produced as of the completion of Component 2 (FMMP-C2) 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 Viet Nam*[1]
Volume 4	**Project development and Implementation Plan**
Volume 5	**Capacity Building and Training Plan**
Demonstration Projects	
Volume 6A	*Flood Risk Assessment in the Nam Mae Kok Basin, Thailand*
Volume 6B	*Integrated Flood Risk Management Plan for the Lower Xe Bang Fai Basin, Lao PDR*
Volume 6C	*Integrated Flood Risk Management Plan for the West Bassac Area, Cambodia*
Volume 6D	*Flood Protection Criteria for the Mekong Delta, Viet Nam*
Volume 6E	*Flood Risk Management in the Border Zone between Cambodia and Viet Nam*

This report is **Volume 3A** in the above series.

[1] Developed by the Delft Cluster

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

1.2 Best Practice Guidelines for Integrated Flood Risk Management

The MRC Secretariat has developed Best Practice Guidelines (BPG) for Integrated Flood Risk Management under FMMP-C2 to provide policy-makers, managers and FMM professionals in the MRC and Member Country line agencies with a common standard to apply in:

- Policy formulation;
- Strategy and planning for policy implementation;
- Project design and evaluation;

for flood risk management in the Lower Mekong Basin (LMB).

Each Member Country of the MRC already has its own policy and set of legal frameworks that guide or regulate the planning, evaluation and implementation of flood risk management that complement the BPGs.

The BPGs do not attempt to summarise 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 provide an information resource/tool that can be adapted to each country and project context.

The basis of flood risk management in the LMB is proper assessment of the manageable risks. The Best Practice Guidelines for flood risk assessment (BPG for FRA) in the LMB offer one set of guidelines.

1.3 Concepts of Flood Risk Assessment in the Best Practice Guidelines

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 with its adverse 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, 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 adverse consequences in case of an event.

(Integrated) Flood risk management is an approach to identify, analyse, evaluate, control and manage flood risks in a given river system. Figure 1-1 presents a general scheme for flood risk management consisting of four components.

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

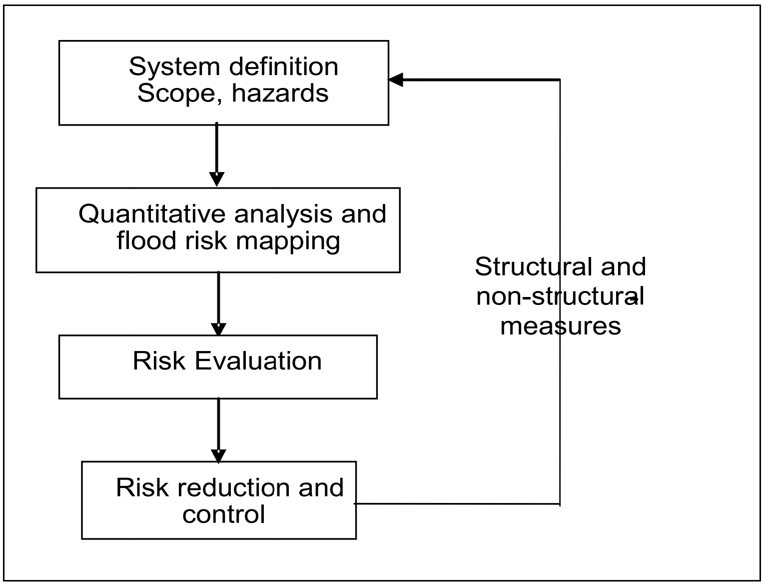


Figure 1-1 General scheme for flood risk management.

This general scheme focuses on minimisation of flood risks to an acceptable level. The approach could also be used to assess the overall hydrological performance of the system (e.g. minimisation of drought, maximisation of water quality and ecological quality). In such cases, the approach can focus on multiple objectives: not only to minimise the risk, but also to maximise the performance of the water system.

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

1.3.2 Flood risk assessment

The identification and mapping of flood risks requires several types information collected in several steps. Figure 1-2 presents a general scheme for flood risk assessment, consisting of four components:

1) **Flood System definition and collection of basic data** (e.g., basic data on elevation of the terrain and water flows).
2) **Flood hazard analysis** of the occurrence of flooding. This step includes an analysis of meteorological events that may eventually lead to flooding combined with data on the hydrological hazard characteristics of the respective watershed (peak flood discharges, volumes). The results can be eventually displayed by means of flood (hazard) maps.
3) **Vulnerability and damage assessment** in the areas prone to flooding based on socio-economic data and a vulnerability/damage model.

4) **Risk determination and flood risk mapping** combining the results of the flood hazard analysis, (the probability of a certain hazard) with the results of the damage assessment. These results can be displayed in risk maps, graphically, or numerically in ways that offer insight into the expected annual damage.

These steps are presented in separate sections in this report.

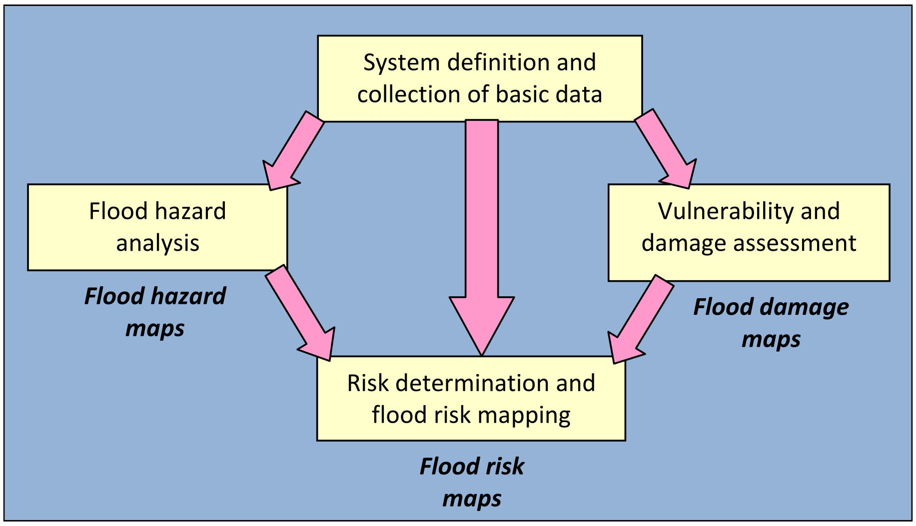


Figure 1-2 General scheme for flood risk assessment.

The FMMP-C2 project uses a variation on this scheme that is shown in Figure 1-3. The figure indicates how meteorological information is combined with watershed and river information to determine hydrological and flood hazards. Damages can be determined by combining data for the possibility of floods with data on the vulnerability to damage of the affected area. When the return period data for different flood events are included, the probability of a certain type of damage -- i.e., the risk – can be determined. The figure also indicates how crisis management can reduce the risk at the final stage.

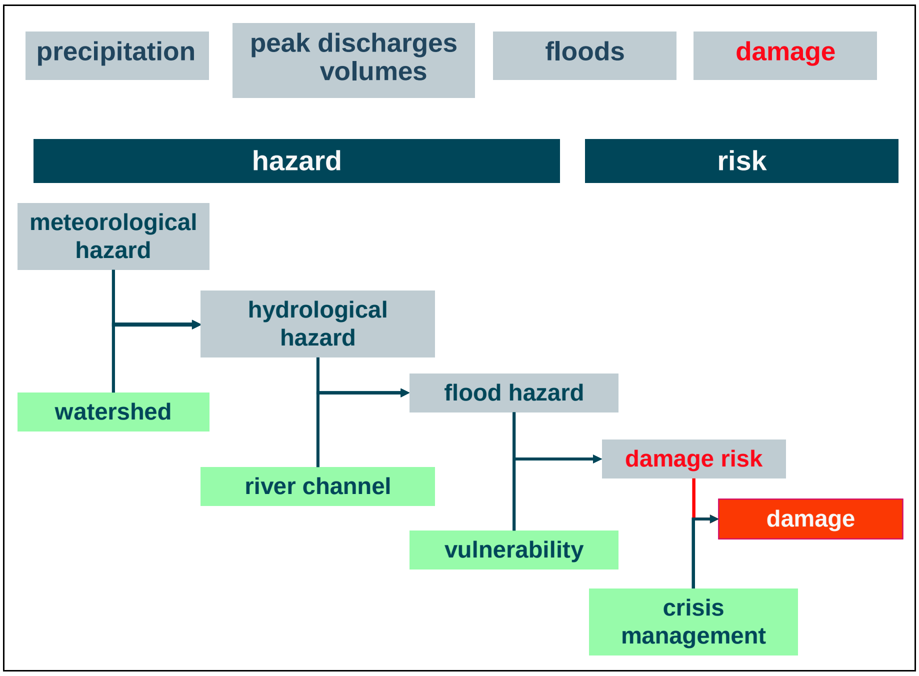


Figure 1-3 Scheme for flood risk assessment used in the FMMP-C2.

1.4 Basis of the Flood Risk Assessment Guidelines

The Best Practice Guidelines in the area of Flood Risk Assessment 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; and
3. experience in flood risk assessments in the LMB focal areas during Stage 1 of the FMMP-C2.

During Stage 1 of the FMMP-C2, a flood damage data collection and processing methodology was designed for the LMB focal areas that takes into account the availability of secondary data as well as time and budget constraints. Survey teams collecting secondary and primary data offered feedback on the feasibility of the methodology along with consultants. Both concluded that the methodology was feasible and suitable for use in the MRC Member Countries and that the damage data collected could be used for estimating flood risks. (For details on the FMMP-C2 damage data collection, see Annex 2 to the Stage 1 Evaluation Report.)

The details and results of these methodologies applied for the assessment of the flood hazards in the LMB focal areas were presented in Annex 1 of the Stage 1 Evaluation Report and were updated in Stage 2.

The guidelines for flood risk assessment have been tested and amended during Stage 2 of FMMP-C2, especially through the demonstration projects. The methodology was also discussed in regional training courses.

1.5 Use of the Flood Risk Assessment Guidelines

Who should use the "Best Practice" guidelines and for what purpose?

The four target groups for these guidelines are:

1. Policy makers who will participate in the development of the flood risk management strategies at national and/or regional levels.

2. Regional and/or basin planners who should be aware of the impact of development scenarios on flood risks and who should apply flood risk management as an essential component of Integrated Water Resources Management. The IFRM BPG for Basin Development Planning (BDP) is also relevant to this category of planners.

3. Flood risk management related project designers, for structural or non-structural projects. They can use these guidelines to estimate field level flood benefits and costs to input in project analysis as described in the Best Practice Guidelines for IFRM Planning and Impact Assessment.

4. Participants in multilateral discussions on transboundary flood risk related impacts.

The BPG for FRA provides a set of methodologies for assessing:

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

These guidelines combine theory and practice with specific emphasis on flooding in the LMB. This document follows the general scheme for flood risk mapping (Figure 1-2). Section 2 describes the process of analysing flood hazards. Section 3 presents the tools for flood damage and vulnerability assessment. Section 4 shows how flood risk can be determined and displayed. Each section is comprised of four sub-sections. These present:

- Principles, concepts and terminology;
- Selected models (for defining and quantifying hazards, consequences or risks);
- Proposed approaches for the LMB; and
- Examples of results from Stage 1 of the Mekong FMMP-C2.

These guidelines can be adopted as part of a consistent and uniform approach to flood risk assessment in the LMB. These guidelines do not fully present all of the details of the methods and models in risk assessment, but focus, instead on the principles and offer an overview of the steps that need to be followed for a complete risk assessment.

Precise elaboration and application of risk assessment depends on many factors: objectives and scope of the assessment, available data and local conditions (e.g., hydrology, land use). For example, there are several types of flooding in the LMB: tributary floods, main stream floods, or floods in the floodplains (see Section 2.2). Each type of flooding is associated with particular processes such as flood duration or flow speed. These, among other factors, affect the flood hazard analysis.

1.6 The Best Practice Guidelines and project phases/stages

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

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

The Best Practice Guidelines are almost exclusively applicable to Phase 2: Planning/ Development/Design. This phase, its stages and the associated symbols used in the guidelines are elaborated in Appendix 5 and are presented briefly, above, in the report introduction.

CHAPTER 2

FLOOD HAZARD ASSESSMENT

2 FLOOD HAZARD ASSESSMENT

2.1 Introduction

There are 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 (of available measures) in place. In order to choose the appropriate protective measures, policy makers must have a clear understanding of the processes of flooding involved. Some of the key questions to start with are:

- What types of floods occur?
- From where does the water come and to where does it flow?
- What quantities of water are involved?
- Which factors influence water flows?
- What is the frequency of flooding?

This type of analysis is referred to as "flood hazard assessment". This chapter presents the basic guidelines in flood hazard assessment for the Mekong River Basin (MRB). Section 2.2 presents a classification list for the different types of flood events in the MRB. This classification is relevant because the different types require different guidelines. Sections 2.3 - 2.6 present the guidelines that are applicable to estimating flood hazard for each of the different types of flooding that are listed in Section 2.2 along with examples of their use for selected "focal areas" in the MRB.

Section 2.7 describes flood hazard mapping, following the assessment procedures.

2.2 Classification of type of flood

A classification of floods is used as applied by the MRC in the Lower Mekong River Basin (LMB), including:

- Tributary floods,
- Main stream floods,
- Combined floods,
- Floods in Cambodian Floodplain, and
- Floods in the Mekong Delta.

The LMB is divided in sub-basins numbered from 1 to 10 (see Figure 2-1). Figure 2-2 offers an overview of the location where different flood types occur in the LMB.

The flood types are described in detail as follows.

Tributary floods occur in the steep sloped upper reaches of the basins. They are generally flash floods, caused by intense rainfall after a long rainy period and forcing the catchment to respond quickly. Flash floods are short lived, rise and fall rapidly and have high flow velocities. The effects of flash floods, when accompanied by landslides, are equivalent to dam break waves. Further downstream, in the middle sections of tributaries the flashiness reduces, but flood levels are not affected by backwater from the Mekong, as 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 peak water levels responsible for the maximum water levels. Flood volumes are important for measuring flood duration. Mainstream floods occur at a number of locations along the Lower Mekong River all the way from Chiang Saen to Kratie.

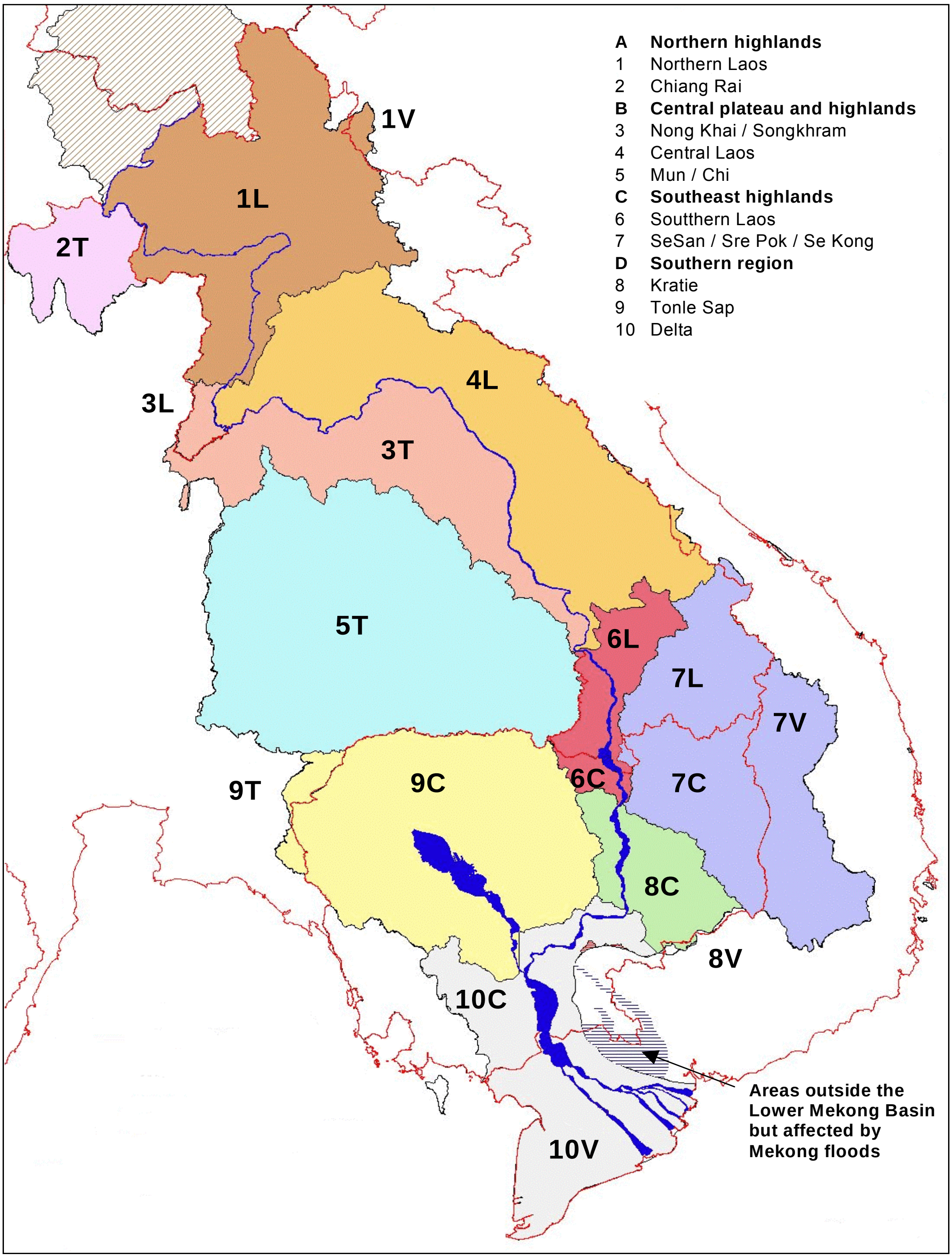


Figure 2-1 The sub-basins or sub-areas in the Lower Mekong River Basin. Letters refer to the countries in which these sub-basins are found (M= Myanmar, T = Thailand, L = Lao PDR, V = Viet Nam, C = Cambodia).

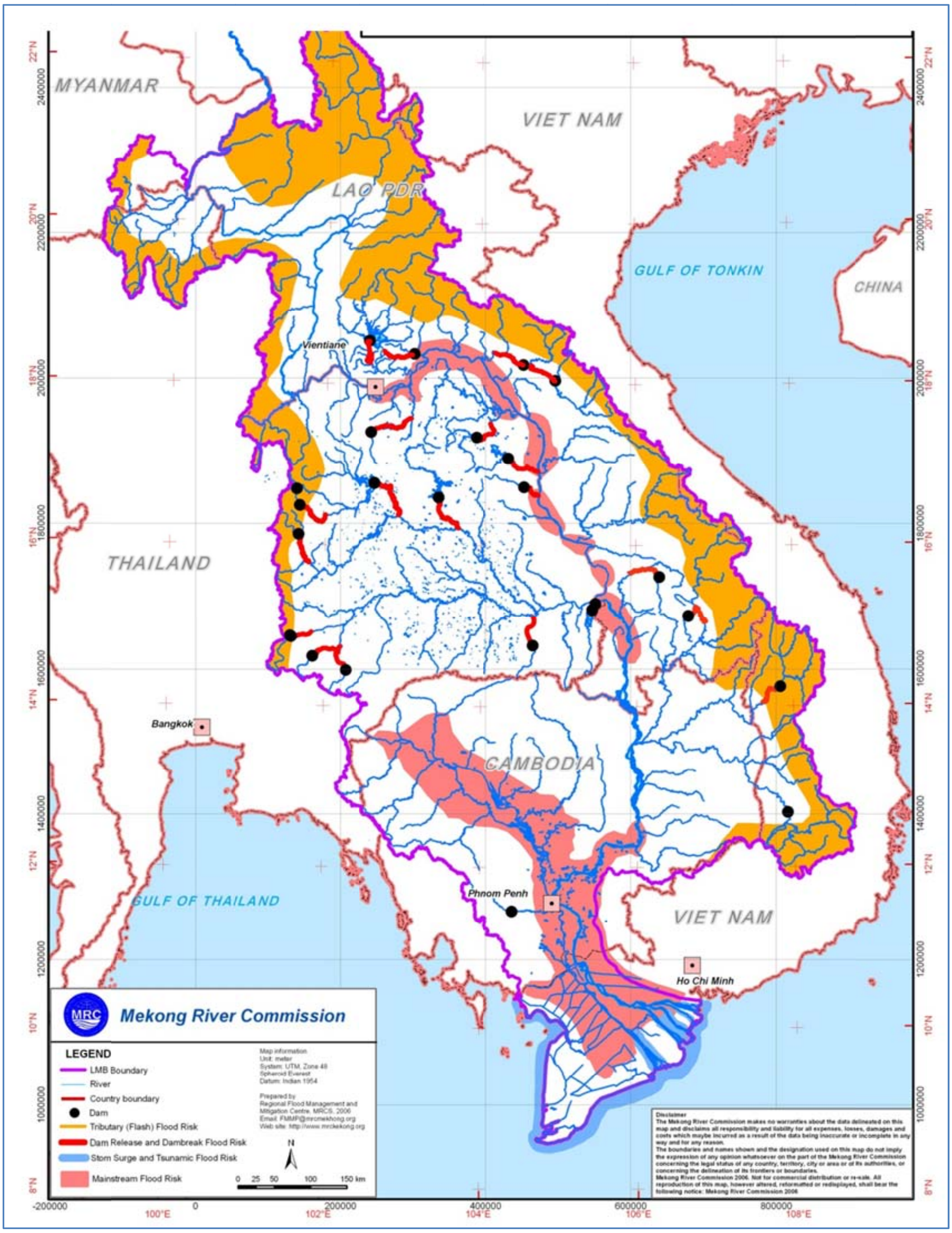


Figure 2-2 Overview of flood types in the Mekong River.

Combined floods are floods in the downstream sections of tributaries, where the flood level is determined by a combination of tributary flow and water levels in the Mekong River that back up the tributary levels and impede drainage. When water levels in the Mekong River are high, backwater may flow into the tributaries. These floods are not short term like flash floods; they may continue for weeks. In the shallow areas along the Mekong River downstream of Vientiane, several lower reaches of tributaries face this type of flooding.

Floods in the Cambodian floodplain occur along the Mekong downstream of Kratie to Phnom Penh and include flooding around the Tonle Sap Lake and the Tonle Sap River that flows into and out from the Tonle Sap Lake.

Floods in the Mekong Delta occur in the Mekong and Bassac Rivers and their floodplains, including the areas of *colmatage* canals that divert and control the flow from and to the rivers. In the Mekong Delta water levels rise slowly due to storage in the Tonle Sap Lake and in the Mekong River floodplains. Flooding here is recognised 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 downstream are essentially the result of upstream and lateral inflow and downstream water levels of the sea.

Table 2-1 offers an overview of flood hazards of these different types of floods in the sub-areas of the LMB.

Table 2-1 Overview of flood types per sub-area (sub-basin)

Sub-area	Type of flood	Issue	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, Xe 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
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 flood hazard assessment

2.3.1 General

Flood hazard assessment procedures rely on hydrological monitoring infrastructure in order to provide measurement data, yet such monitoring capacity on the tributaries of the Mekong is currently limited. Only a limited number of basins are equipped with rainfall and water level recorders. In most locations only daily rainfall data are available. The water level gauging network and the monitoring intervals are usually inadequate to properly describe flash floods. Often, only daily water levels are measured and this is unsuitable for flash flood analysis. Flow discharge measurements usually cover only the lower stages and occasionally include flood data. Dependent on data availability one of the following three procedures is feasible for estimating flood hazards:

1. **Flood hazard derived from rainfall extremes.**
   This method is recommended for small basins when little or no historic data is available on flows. It starts with the specification of the meteorological hazard is terms of design rainstorms of desired return periods. The design rainstorms data are adjusted to net rainstorm data and plotted on design discharge hydrographs for the required location using appropriate unit hydrograph and hydrologic routing techniques to arrive at the hydrological hazard measure. Finally, the flood hazard is determined by transforming the peak level data of the discharge hydrographs into water levels by means of flow simulation techniques using a hydraulic model.
2. **Flood hazard derived from observed flows.**
   When a homogeneous water discharge data series (of >15 years) is available for a specific river reach, the hydrological hazard can be derived from a statistical analysis of annual flood peaks and flood volumes. A hydraulic model of river and floodplain can then be used to convert the hydrological hazard into a flood hazard. Data from representative flood hydrographs, covering the full spectrum of flood peak and flood volumes, can be converted into water level data using this hydraulic model. Water level and flood volume data can be used in a Monte Carlo procedure to derive the frequency of different water levels as a function of time and space. A Digital Elevation Model (DEM) can then be used to generate flood hazard maps.
3. **Flood hazard determined from regional flood statistics.**
   The distribution of annual flood peak can also be obtained from regional flood statistics, when available, if the average annual flood peak is known. For streams without water level recorders and discharge measurement equipment, this value may be estimated from basin characteristics.

2.3.2 Flood hazard derived from rainfall extremes

The method of using rainfall extremes for the assessment of the flood hazard includes the following steps:

1. Collection of relevant information;
2. Development of a database and conduct of field visits;
3. Determination of the design rainstorms for different return periods;
4. Plotting of design rainstorm information on design hydrographs; and
5. Use of design hydrographs to determine design levels.

These steps are elaborated below.

Step 1 Collection of relevant information

Data required for flood hazard assessment includes:

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

Step 2 Database development and field visits

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

There are a number of procedures for preparing data for use in models. For example, rainfall data in weekends is often suspect since there may be no monitoring staff available. Thorough validation, correction and completion procedures should be applied to improve the reliability of the data. Since the flood hazard assessment relies heavily on quality rainfall data, available records have to be thoroughly reviewed to assure their quality. Graphical and tabular comparisons are often useful in preparing the data. In some cases, data from the nearest neighbour (i.e., closest monitoring stations) can be used for cross checking purposes and to fill in missing data. A double mass analysis can also be used. Standard textbooks offer detailed explanations of these procedures.

In this data collection and validation process one or more field visits is essential to validate collected information and to assess its quality. Experts should visit key rainfall monitoring stations to review their monitoring practices and. Interviewing residents and officials on the extent of historic floods, land use patterns and construction. The field visits can also be used for collection of additional data or establishment of a (temporary) monitoring program to check on the validity of the data.

Step 3 Determination of the design rainstorms for different return periods

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. Time concentration is defined as the travel time required for a drop of water to travel from the uppermost part of the catchment to the outlet. Tc is a measure that expresses the time delay between rainfall and flood runoff.

2. Determine the basin rainfall from point rainfall data for the smallest available interval if applicable.

3. Develop intensity (or depth)-duration-frequency curves for specific rainfall return periods of 2 to 100 years, for durations of 5 minutes to 24 hours. If no short interval rainfall data is available, short duration rainfall intensities can be derived from daily rainfall data. In such cases, Extreme Value Type 1 (EV1) or Generalized Extreme Value (GEV)-distributions can be

fitted to the observed distribution of annual maximum daily rainfall, and the rainfall for selected return periods can be estimated. These values should be adjusted to 24 hr values by applying a correction factor of 1.12. 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).

4. Apply the Rainfall Ratio Method 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. Thus, 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: RR_D = rainfall ratio for conversion of 24 hr rainfall into D hr rainfall
D = rainfall duration (hours)

5. In case of single point rainfall, the point rainfall data needs to be adjusted for the variability of rainfall over the area (spatial distribution). This can be done through the application of an Areal Reduction Factor (ARF). The ARF is a function of the basin area (A) and rainfall duration (D) and can be derived through statistical processing of single point rainfall data. For example in the case of convective rainfall in Cambodia for durations less than or more than 8 hours and where A is measured in $km^{2,}$, the ARF is given as follows:

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

6. 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 = j^{th} incremental intensity (mm/hr)
$R_{A,D}$ = areal rainfall of duration D

7. The incremental intensities can then be arranged around the highest intensity (peak value). The graphical 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. Another option to determine the design rainstorms is by using 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 data is then a necessity.

8. Repeating the above step for required return periods yields a set of hyetographs.

Step 4 Using the design storm to determine the design hydrograph

The conversion of design rainstorm into a design hydrograph involves the following steps:
1. Determination of the net rainfall by estimating rainfall losses, to be distributed among the ordinates of the hyetograph;
2. Development of a unit hydrograph of the basin up to the location for which the flood hazard assessment is undertaken, and
3. Convoluting the net hyetograph to the design hydrograph using the unit hydrograph developed under the previous activity.

Rainfall losses are considered not contributing to the flood hazard. One of the methods used to determine rainfall losses is the Soil Conservation Service Curve Number method (SCS-Curve Number method or SCS-CN), applied to wet antecedent soil moisture conditions. This method requires information on soil types, land use and condition of the land. The SCS-CN method is extensively described in hydrological textbooks (e.g., Viessman, 1989).

To develop a unit hydrograph of the basin it is recommended that use is made of the Clark method. Clark's method requires estimation of three basin parameters for the derivation of unit hydrograph and is based on the concentration time Tc, on the routing of a time-area diagram with a time base equal to the concentration time Tc, and on a simulation of channel storage through a linear reservoir.

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

The above procedure is applicable to relatively small catchments, roughly up to 1,000 km^2. With some modification, this procedure can also be applied to larger areas. For larger areas, the calculations should use a segmented approach. This will transform excess rainfall into runoff to allow spatial variation in the excess rainfall and runoff characteristics. In making these calculations, the basin up to the location of interest can be divided into segments and the rainfall-runoff transformation can be applied to each segment. The hydraulic output of each segment is then added 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 Using design hydrographs to determine 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 the river and floodplain, and the estimated or calibrated hydraulic roughness. The calculations should take into account existing flood protection measures and include planned protection works for investigation of alternatives, since these measures may cause future water levels to rise in areas further upstream.

2.3.3 Example of flood hazard derived from rainfall extremes

To demonstrate how the above procedure works, a hypothetical basin on the Upper Se San River near Pleiku, Viet Nam can be used as an example. For the calculations, we assume that only daily rainfall series are available. For the development of a design storm calculation, the following parameters have also been assumed:

- Basin area of 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 those at Pleiku with an orographic adjustment factor of 1.25.

Daily rainfall series data for Pleiku (monitoring station 140703) are available for the years 1927-2006, though with some gaps. After validation and homogeneity tests, EV1 and GEV distributions have been fitted to the annual maximum rainfall of the monitoring station. The results are shown in Table 2-2 and in 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

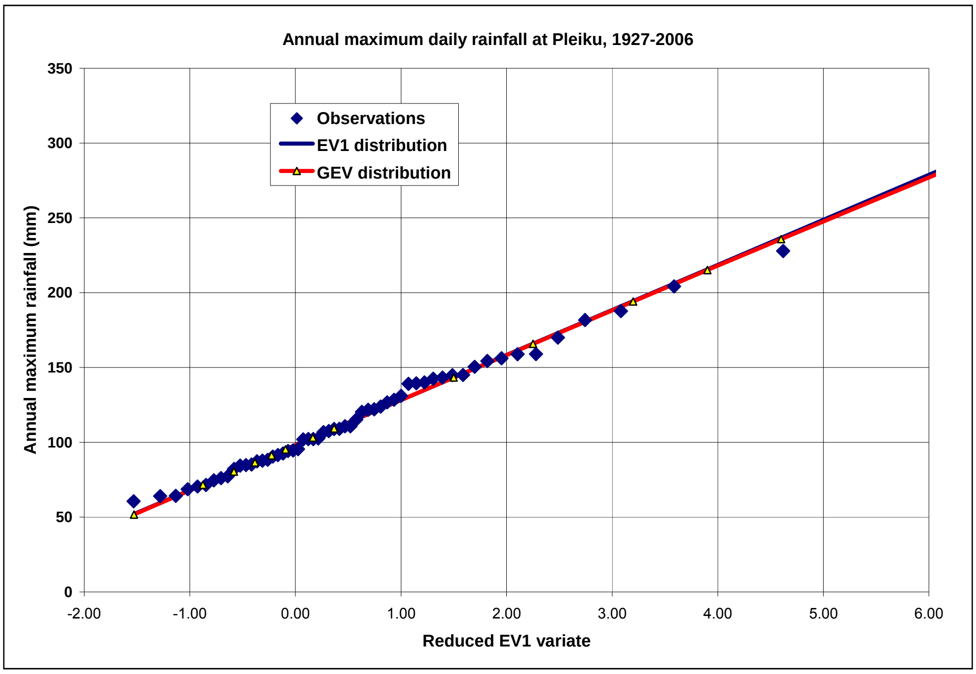


Figure 2-3 EV1 and GEV-fit to annual maximum daily rainfall at Pleiku for the years 1927-2006.

The depth-duration-frequency curves have been derived for intervals of 5 min to 24 hrs starting from the daily rainfall extremes for return periods (T) of 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 for the T = 50 year design storm is shown in Table 2-4. The result is presented in Figure 2-5. It is derived 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 should be tested, once the basin Unit Hydrograph is derived. This procedure is to be repeated for other selected return periods that will be used in the flood hazard assessment.

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

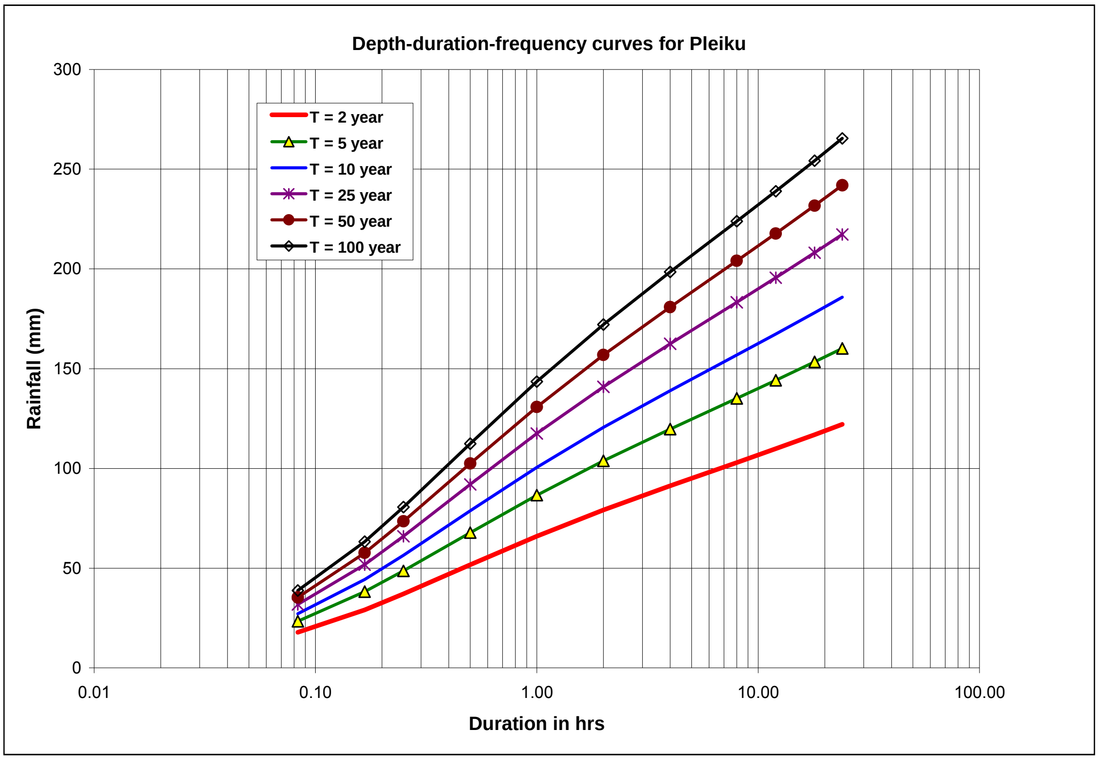


Figure 2-4 Depth-duration-frequency curves for Pleiku.

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

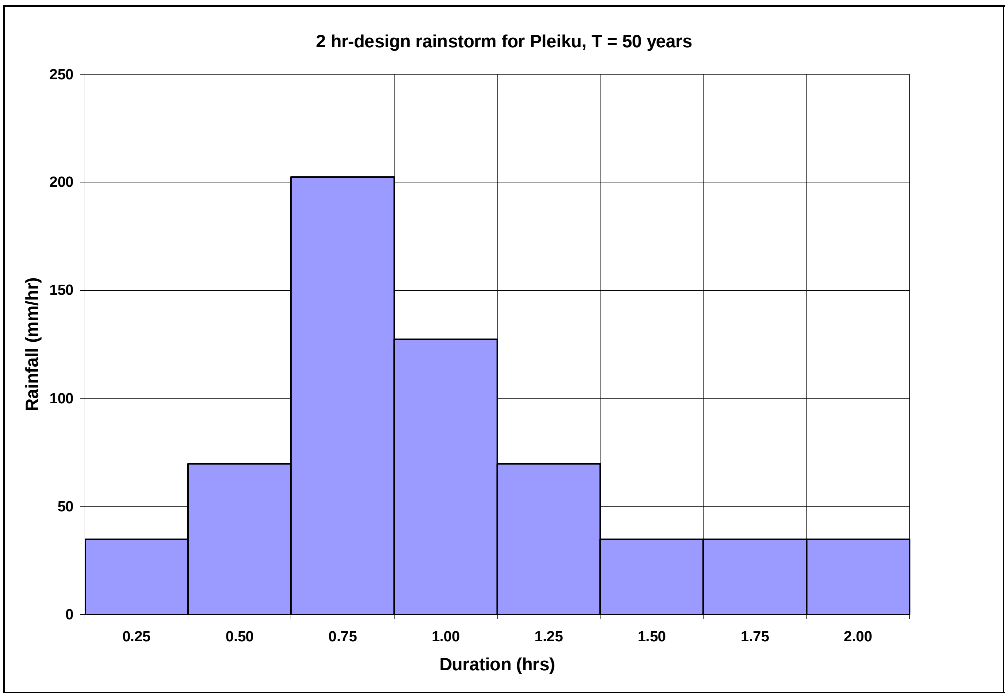


Figure 2-5 A 2-hour-design rainstorm diagram for the Upper Se San River derived from measures used for Pleiku.

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 is useful. Next, the Unit Hydrograph of the basin is determined for which the Clark Method can be used. This 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. In the diagram of the hypothetical basin, isochrones representing points of equal travel time to the segment outlet (downstream basin limit) can also be constructed. (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 catchment if only translation and no deformation takes place of an instantaneous unit supply of rain. Flow paths, slopes and hydraulic roughness determine the speed of water outflow and these characteristics are easy to obtain from a Digital Elevation Model (DEM) or a topographic map. In addition to the concentration time, plotting of the time area diagram requires estimating a water recession coefficient, k, for routing. Note that the output from the reservoir is representative for the instantaneous unit hydrograph (IUH). In order to develop the Unit Hydrograph, the IUH data must be transformed into a Unit Hydrograph (UH) of the required interval by multiplying with observed rainfall depths. The two parameters, Tc and k, can also be obtained from observed rainfall and discharge hydrographs.

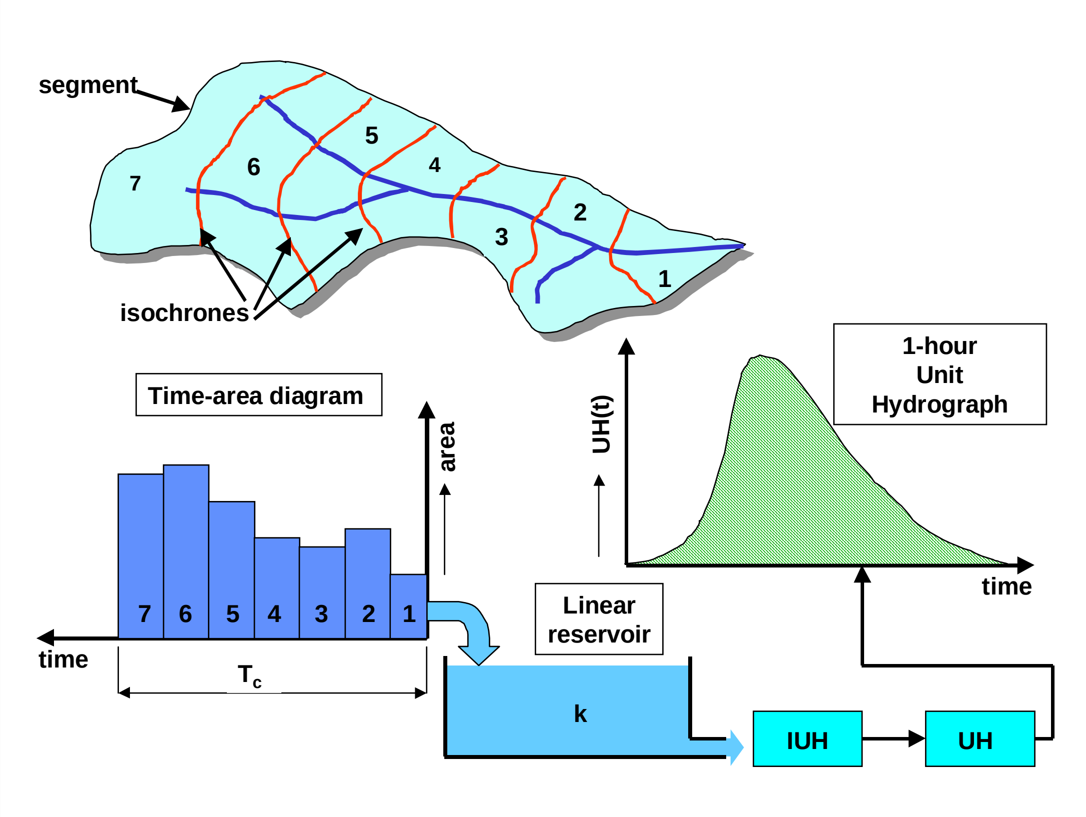


Figure 2-6 Principles of the Clark Unit Hydrograph method, shown in various diagrams that are related to each other.

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 method is only applicable when drainage conditions and infrastructure are constant and are not expected to change. If conditions are not constant, the time of concentration can be determined from physical features of the catchment segment such as length and slope. The recession coefficient, k, can be calculated from the surface runoff hydrograph by measuring the slope of the curve in the area where it descends (the area of flood water recession). The Unit Hydrograph can be used to generate the excess hyetograph and the data can then be used to calculate the design flood for the selected return periods. Using these results, it is possible to generate a frequency distribution of the floods resulting from the selected rainfall duration (equal to the time of concentration).

It is to be verified whether storms of shorter or longer duration lead to higher peak discharges. The height of the peak discharge relative to storm duration is dependent on the intensity distribution in the rainstorm and the way the losses are distributed over the rainfall ordinates.

The data for frequency distribution of flood peak can be transformed to design flood levels through calculations using measurements of backwater. If upstream water storages are significant, then the full flood hydrograph should take the entire hydraulic network into account, using realistic initial values for the storage capacities.

2.3.4 Flood hazard determined from observed flows

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

1. Collection of relevant information;
2. Database development and field visits;
3. Assessment of the hydrological hazard in terms of flood peak water levels and flood volumes;
4. Conversion of selected flood hydrograph data to flood level data using a hydraulic model;
5. Flood hazard assessment by means of a Monte Carlo sampling procedure, interpolating between the simulated water levels based on samples from the flood peak water levels and volume distributions; and
6. Preparation of flood maps by selection of flood levels, durations etc. of the same return period.

Step 1 Collection of relevant information

The required data for this type of flood hazard assessment does not differ much from the one above. (See Step 1 in the procedure described in Section 2.3.2.) Here, emphasis is on several factors in the hydrometric (water measurement) network layout and operations. These include sampling and measurement procedures, monitoring station and equipment maintenance, gauge ranges and re-settings, available water level data series, stage-discharge data and assumed discharge ratings with extrapolation procedures and discharge series data.

Step 2 Database development and field visits

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

Thorough validation, correction and completion procedures (filling in missing data) should be applied to improve the reliability of the water discharge data. This requires inspection of all hydrometric monitoring stations relevant to assessment of the hydrological hazard and validation of the data from key stations. Flood marks should be levelled and discussed with local residents. Sometimes there is lateral water inflow. In such cases, when rainfall data are used to determine the lateral inflow, the rainfall network should be inspected as part of the validation procedure. The hydraulic infrastructure and flood protection works should also be inspected on field visits, to ascertain their capacity and operations in times of floods and to determine their impact on the shape of the hydrograph curves as a result of water storage and/or backwater. Construction in the basin, which can affect the hydrograph (specifically the peak value), should be quantified.

Screening of historical water levels involves inspection of the historical patterns of hydrographs, comparison with hydrographs at nearby monitoring stations, stage relation curve analysis to identify outliers and shifts in gauge locations, and comparison of hydrographs with hyetographs to detect anomalies in the rainfall – runoff process. Special attention should be paid to differences between instantaneous peak water levels and maximum daily average water levels. The latter information is generally only available in the databases. The peak values of the hydrographs should later be adjusted in case of differences between instantaneous peak water levels and maximum daily average water levels.

Stage relation curves describing the relation between water levels and discharges at gauging stations may be applied to fill in gaps in the data of a station (with appropriate time shifts to account for flood wave celerity). 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 taking into account flood protection works in and downstream of the river section.
The next step is to apply the discharge rating to the water level data series in order to compute the discharge data series. A comparison is made with the series in the database. Discharge hydrographs at neighbouring monitoring stations can be compared graphically and the consistency of the data can be verified by means of water balances and double mass analysis. Similar comparisons with data at neighbouring monitoring stations can be used to validate peak values. Finally, peak values should be examined, graphically, statistically and using documents on drainage conditions to spot possible trends indicating problems in the data and other anomalies. Data should be corrected to eliminate these trends and anomalies.

Special attention should be paid to the variability of the discharge ratings at locations where there have been morphological changes in the river bed. The variation in water levels for particularly high discharges over the years should be calculated and then applied to assessing the additional uncertainty in water levels for the specific discharge rating used in the model.

Step 3 Assessment of the hydrological hazard

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

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

2. For flood volumes:
   - Selection of data from 20 to 25 of the largest recorded floods;
   - Derivation of a regression line that shows the relationship between flood peak discharge (Q) and flood volumes (V) as V = f(Q) and its scatter (the deviation from the fitted line), or “standard error”, (Se). The regression line gives the “average” or “expected” value of the flood volume, for given values of the flood peak. The expected flood volume increases in relation to the increasing flood peak. Note that the relationship is not perfectly described by the fitted line. There is some scatter (volumes above and volumes below the expected values of the fitted line). Figure 2-7 offers 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. It can be used (in step 3) to take the effect of the 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 until N days after the peak water level). For each flood assign the time of Qmax (the peak discharge of the flood) as the initial time (t) such that t=0. Then, determine for the range of times (t = -M, …, t=0, ..., t=N) the water discharge for each time relative to Qmax (=Q/Qmax). Repeat the procedure for all other selected peak discharges (for the different return period floods).

Then, apply a frequency analysis on Q/Qmax for each time measurement (t = -M, ..., t=0, ..., t=N). The result will be a distribution function of Q/Qmax for each time at which measurements are taken. Thus, for any give probability, p, of (non-)exceedance the value of Q/Qmax will be known for all time at which measurements are taken. Connection of these values yields the (dimensionless) hydrograph for p. In this manner, for a variety of p-values, hydrographs can be generated for use in the next step.

3. For creation of a flood peak water level-flood volume matrix for use in hydraulic simulations:
   - Selection of flood peaks of return period 2, 5, 10, 25, 50 and 100 years;
   - Determination of a range of flood volumes for the selected flood peak values, based on the scatter plot data around the flood volume (V) - flood peak discharge (Q) regression line relationship, V = f(Q). For each selected peak value (the different return period floods), we can generate a very low (R-1.96 Se), a low (R-Se), medium (R), high (R+Se) and very high flood volumes (R+1.96 Se) – R being the mean of the flood volumes - by scaling of the representative flood hydrographs to the flood peak value of selected return periods. This results in 30 (6 return periods x 5 flood volumes = 30) hydrographs;
   - Adjustment of flood hydrographs for differences between daily average flow maxima and instantaneous peak flows;
   - Lateral water inflows, assumed to be relatively small, can be defined as a percentage of the selected flood hydrograph measurement.

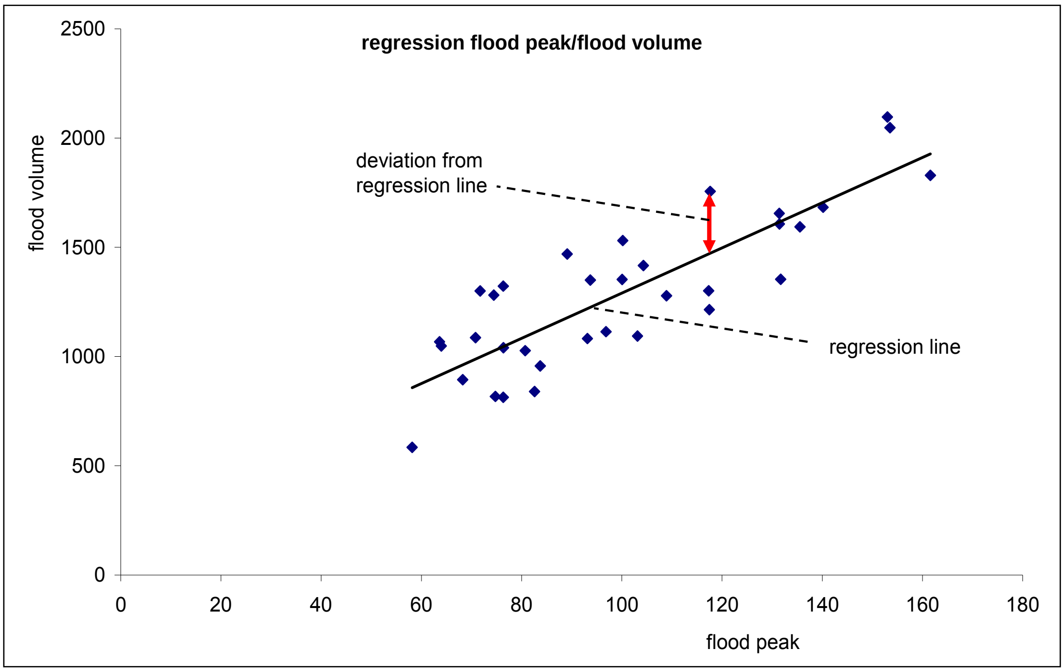


Figure 2-7 Hypothetical scatter plot of data points and fitted regression line showing the relationship between flood volumes and flood peak water levels. The red arrow in the Figure shows the deviation from the regression line for a single observation.

Step 4 Conversion of flood hydrographs to flood levels using a hydraulic model

There are a number of options of hydraulic models for use in converting flood water data into flood levels. An accurate hydraulic model is needed for the river and floodplain being analysed. The model's boundaries should be chosen in accordance with the hydrometric network equipment and the boundaries of the area of analysis. It is suggested using a one-dimensional (1D) – two-dimensional (2D) hydraulic model, where rivers are represented as 1D and the floodplain as 2D, both derived from a DEM. This approach has clear advantages over a quasi-2D approach, which is a 1D model with storage cells for the floodplain, where the need to make qualitative assumptions or estimates on the connection between the river and floodplain introduces subjectivity. The 1D-2D model has also advantages over a full 2D model, since narrow rivers cannot be properly represented in the 2D model. Any selected model should be calibrated for river and floodplain conditions representing the base case. Special attention should also be given to the position of the river bed in comparison with possible river bed shifts due to natural or human induced morphological developments.

The 30 selected hydrographs are subsequently routed in the model through the river and floodplain system, and the water levels are computed as functions of time and space which are placed in a database for use in a Monte Carlo simulation procedure for flood hazard assessment. These simulations can be repeated to test the results of construction plans that are under consideration, after adjustment of the hydraulic model for the different scenarios.

Step 5 Flood hazard assessment

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

1. the regression line to derive the “expected” volume, given the value of the peak water level discharge; and
2. a sample from the normal distribution with mean 0 and standard deviation S_e (see step 2) to account for deviation from the expected volume.

Application of this procedure ensures that sampled volumes are correlated with the sampled peak discharges to reflect the relationship in the raw data. For each sampled pair of water volumes and peak discharges, the water levels at the areas under study are derived from 2-dimensional interpolations of the grids of the 6 x 5 simulated hydrographs described above. The result is an N-year synthetic series of water levels (h_1, …, h_N,) at each location. From this series the T-year return period flood water levels can be easily derived with an equation such as Gringorten’s formula:

$$p_i = \frac{r_i - 0.44}{N + 0.12} \qquad (2.5)$$

where: p_i = probability of exceedance of synthetic water levels of height hi for I, the particular area of interest under study;
N = total number of Monte Carlo samples; (1 = highest, N = lowest), and
r_i = rank number of the maximum synthetic water levels h_i

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 as those for mainstream flows, but the data interpolation 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 to flood hazard assessment. The method has been adapted for use in the upper part of the LMB for 16 drainage basins with areas ranging from 200 to 6,000 km^2 and for 1 basin of 19,700 km^2. The technique is applicable provided the regional curve for the upper part of the LMB is valid for the particular basin. Its use involves the following steps:

1. Creation of a regional sample of annual maximum flood peak water levels by pooling together the individual annual maximum values, scaled to their individual mean annual flood value. Discordance and homogeneity tests should be applied to assure regional homogeneity of data from the selected monitoring stations (see Hosking and Wallis, 1997).
2. Fitting of an extreme value distribution to the scaled ranked annual extremes. For the LMB basins considered by Adamson (2007), the Two Component Extreme Value (TCEV) distribution fits the observed frequency distribution of these 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 different phenomena creating the water discharge extremes (i.e. monsoon and typhoons). Typhoons create extremes far beyond the monsoon levels.
3. Applying the TCEV-values to un-gauged sites. A method is applied using regional data for the mean annual maximum floodwater discharge that describes the relationships between floodwater discharge and one or more climatic and/or basin characteristic(s). This relationship allows for floodwater discharge rates to be determined anywhere in the region if those other characteristics are measured. For the upper part of the LMB, the following relationship between floodwater levels and drainage area was identified:

$$Q_{ave} = A^{0.75} + err. \qquad (2.6)$$

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

The regression error (dispersion of the data around the fitted line) is considerable (S_e is about 50% of Q_{ave}), suggesting that additional descriptive variables characterising the area are needed to fully describe the floodwater discharge rate.

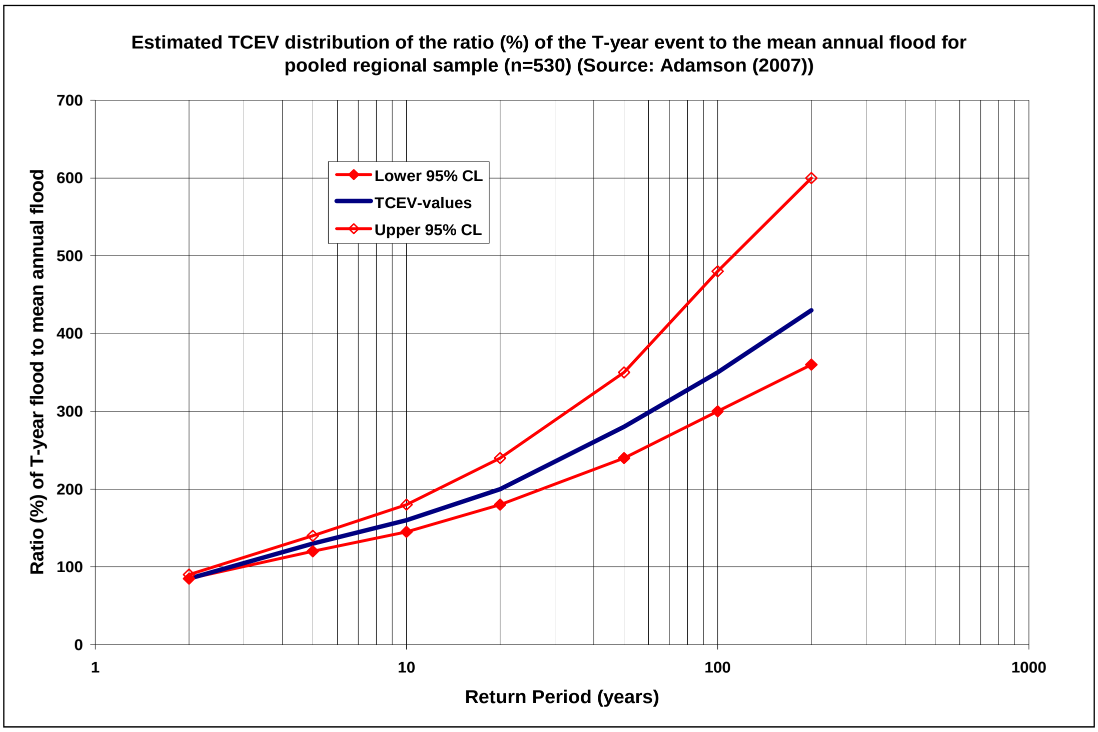


Figure 2-8 TCEV-distribution of the ratio of the T-year return period event to the mean annual flood for the pooled regional sample (Upper part of LMB, from Adamson, 2007).

In using the regional approach, the following remarks are made:

- In principle the method is very attractive and easy to use, provided that the base data can be properly validated and a clear relationship can be established between mean annual floodwater discharges and meteorological and river basin characteristics.
- The data set used in Adamson (2007) has been taken from the MRC database. Inspection of the data reveals inconsistencies in the data for flow extremes across different monitoring stations.
- Using Adamson's data set, Q_{ave} appears to correlate well with the mean annual floodwater flow. This, in turn should be directly related to annual rainfall which are generally available for un-gauged streams in view of the better distribution of rain gauges. Furthermore, other data can be used in other equations that predict maximum floodwater discharge rate or rainfall (such as stream length, basin slopes and land use data from available DEM), to improve the estimate of Q_{ave} values.
- An adjustment is required for instantaneous peak values relative to daily average maximum values in the above approach. In the case of flash floods a considerable adjustment is expected as the flood may last only for a number of hours.

2.4 Mainstream flood hazard assessment

2.4.1 General

The hydrological hazard along the Mekong River is determined by the discharge peaks on the river that generate the maximum water levels and by the flood volumes determining the duration of flooding. Conversion of hydrological hazard data into flood hazard data requires using a hydraulic model of the river and floodplain to convert water flow data into water level data. Data from selected hydrographs covering the full spectrum of possible combinations of flood peaks and of flood volumes can be used in the model. Special attention should be paid to variations of the river bed due to natural or human induced morphological changes, which affect the water level discharge ratings along the river. The Monte Carlo simulation sampling technique can be used to derive exceedance probabilities of water levels and floodwater damage. The simulation generates results for a large number of combinations of peak discharges, flood volumes and river bed conditions and this data can be used to estimate floodwater damage.

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

1. Data collection;
2. Database development and conduct of field visits;
3. Data validation and processing;
4. Hydrological hazard assessment in terms of flood peaks and flood volumes;
5. Flood hazard assessment using a hydraulic model that transforms selected flood hydrograph data to flood level data and applies Monte Carlo sampling to determine flood levels and durations for distinct return periods;
6. Preparation of flood maps through selection of flood levels, durations, and other features of the same return periods. (See Section 2.7).

The steps are elaborated in the following sub-sections.

2.4.2 Data collection

For assessment of the hazard of mainstream floods, the following data and information are required:

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

Below, is a list of the agencies in the MRC Member Countries that are responsible for collecting and providing this data.

Cambodia

Ministry of Water Resources and Meteorology (MOWRAM)

- Department of Hydrology and River Works (DHRW), for water level, discharge and rainfall time series;
- Department of Meteorology (DOM), for 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 Lakes for bathymetric data, hydrographic atlases;
- Department of Road and Transport

Ministry of Agriculture, Forestry and Fishery (MAFF)

- Department of Agronomy and Agricultural Land Improvement for soil maps and land Use maps)

Phnom Penh Municipality:

- Department of Public Works and Transport of Phnom Penh Municipality for urban flood protection, dykes/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 is a new government agency that combines what were previously the 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 is responsible for collecting and providing all related water data in Lao PDR as well as for the establishment and management of the country's hydrological and meteorological network.
The Hydrographic Atlas data of the Mekong River mainstream has also been transferred to the WREA.

Thailand

Ministry of Agriculture and Cooperatives (MOAC)

- Royal Department of Irrigation (RID), for hydro-meteorological data in most of the Mekong River tributaries, especially the Nam Mae Kok, Nam Mae Ing, Nam Chi and Nam Mum Rivers.

Ministry of Natural Resources and Environment (MNRE)

- Department of Water Resources for management of hydro-meteorological networks (previously under the Department of Energy Development and Promotion), including all the Thai Mekong River mainstream monitoring stations. Climatic and water quality data collection previously supported by the Mekong Committee were also collected and provided by this department including bathymetric survey data and hydrographic atlases.

Ministry of Information and Communication Technology (MICT)

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

Ministry of Interior (MOI)

- Department of Disaster Prevention and Mitigation, Department of, Local Administration, Department of Public Works, for urban and rural planning and flood mapping.

Viet Nam

Ministry of Natural Resources and Environment (MoNRE)

- Department of Water Resources Management
- Hydro-meteorological Services of Viet Nam, Southern Region Hydro-meteorological Center for hydrological, meteorological, water quality, and salinity data collection network management, data collection and dissemination, and flood, salinity and weather forecasting data.
- Sub National Institute for Agricultural Planning and Production (NIAPP) for flood maps in the Mekong Delta and soil suitability maps.
- Southern Institute of Water Resources Research (SIWRR), for hydraulic works (sluices, hydropower, reservoirs, sea, dykes, embankments), river training works, coastal zone management (river morphology, strategies and work for river bank protection), irrigation, drainage, soil reclamation, water supply and drain information. The SIWRR also operates and maintains meteorological and hydrological data, and cross-section data for the Mekong Delta and Dong Nai River basin.

2.4.3 Database development and conduct of field visits

The collected information is to be organised 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 that is being validated, and fully validated data.

During the field visit the data on flood protection and hydraulic infrastructure in the study area should be checked, including maintenance and operation in times of flood. All key hydrometric monitoring stations should be visited and monitoring and discharge measurement practices should be reviewed. Gauge stations and gauge histories should be inspected, including gauge reach, staff gauge connections, bench marks, gauge zero controls and shifts, gauge damages and repairs as well as records from comparisons of manual and automatic gauges. Flow measurement equipment calibration and functioning should be tested. Residents and officials should be interviewed on the extent of historic floods, flood protection developments and land use changes. Flood marks should be levelled and discussed with local residents. In connection with the field visit and where required, additional data can be collected or a (temporary) monitoring program can be established and implemented.

2.4.4 Data validation and processing

Thorough validation, correction and completion procedures (filling in missing data) should be applied to improve the reliability of the water discharge data (See also Section 2.3.2). The process should include three components:

- Screening of historical water levels involves inspection of the historical patterns of hydrographs, comparison of hydrographs at nearby monitoring 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 in the data.
- Stages of discharge measurement data should first be 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 as a result of natural or human induced morphological changes in the river bed can be assessed, by determining the variation of the water level for distinct high water discharges through the years. Particularly, this change is assessed for the natural bank full floodwater discharge.
- The next step is to apply the discharge rating to the water level data series in order to compute the water discharge data series. A comparison is made with the series in the database. Discharge hydrographs at neighbouring monitoring stations can be compared graphically and the consistency of the data at each hydrograph can be checked by means of water balances and double mass analysis. Comparisons with data at neighbouring monitoring stations can be used to validate peak water level measurements. Finally, peak values should be examined, graphically, statistically and using documents on drainage and storage conditions to spot possible trends indicating problems in the data and other anomalies. Data should be corrected to eliminate these trends and anomalies.

2.4.5 Hydrological hazard assessment in terms of flood peak water levels and flood volumes

Hydrological hazard is determined by peak flow and flood volume and their interaction. A matrix of flood hydrographs can be generated covering the full spectrum of possible hydrographs with peak water level values for return periods of more than or equal to two years ($T \geq 2$ years). The development of this matrix involves the following tasks:

1. Creation of homogeneous water discharge series data for the key measurement station at the upper boundary of the river reach under study;
2. Estimation of the marginal distributions of annual flood peak water levels and flood volumes (between June 1st and November 30th) at this upper boundary. The observed distributions of flood peak water levels and flood volumes are generally represented effectively by a GEV distribution;

3. Development of a regression equation that describes the relationship between flood volumes (V) and flood peak water levels (Q_p) V = f(Q_p) and estimate its standard error S_{eV}, in a process similar to step 3 in Section 2.3.4;
4. Specification of the matrix of flood hydrographs for distinct discharge peak water levels, similar to step 3 in Section 2.3.4.

Changes in the stage-discharge rating due to river bed variations can be taken into account by changing the hydraulic roughness used in the hydraulic model commensurate with the change in the water level. For this purpose, one should start by assessing the annual changes in the water level for natural bank full flow. The effect of roughness can be determined from comparisons of applied discharge ratings or plots of discharge data series versus water level data 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 monitoring stations in the modelled river reach. According to Manning's equation for a wide cross-section, if the water depth at bank full discharge changes from the original depth, h_1, to a second depth, h_2 ,with $h_2 = h_1 + \Delta h$, there is a simple equation for the hydraulic roughness, n, over the same cross sections. The new hydraulic roughness value is described by the relationship:

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

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

2.4.6 Flood hazard assessment

The hydrological hazard in terms of peak flow statistics can be converted into water level data by means of a hydraulic model of the concerned Mekong River reach. An accurate hydraulic model is needed for the river and floodplain being analysed. The model's boundaries should be chosen in accordance with the hydrometric network equipment and the limits of the area of analysis. It is strongly advised using a 1D-2D hydraulic model, where the Mekong River is represented as 1D and the floodplain as 2D, both readily derived from a DEM. This approach has clear advantages over a quasi-2D approach with storage cells, where qualitative judgments on the connection between river and floodplain introduce subjectivity. The chosen model should be calibrated for river and floodplain conditions representing the base case. Special attention should also be given to the position of the river bed (particularly in case of possible river bed shifts due to natural or human induced morphological changes).

Data from the 30 selected hydrographs can then be input using the model for the particular river and floodplain system. The water levels that are computed as functions of time and space can be placed in a database. The procedure can be repeated at least twice with adjusted hydraulic roughness and downstream stage-floodwater discharge relations to cover the full range of water level changes for bank full floodwater discharge. These results can be added to the database before using a Monte Carlo simulation procedure for flood hazard assessment. These simulations can be repeated to test the results of construction plans that are under consideration, after adjustment of the hydraulic model for the different scenarios.

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

2.4.7 Example: Mekong near Nakhon Phanom (Thailand)

Preparations for Monte Carlo analysis

Figure 2-9 shows the GEV-function fitted to the series of observed annual maximum water discharges of the Mekong River at Nakhon Phanom, Thailand. This function can be used to derive the floodwater discharges corresponding to return periods of 2, 5, 10, 25, 50 and 100 years (Table 2-5). Subsequently, the relation between peak flows and flood volumes (total flow volumes from June 1st until November 30th) can be derived from a regression analysis (with the fitted regression equation shown as the full line in Figure 2-10). The spread around this fitted regression line is also depicted in Figure 2-10 by the 4 dotted lines at distances of -1.96 S_e, -S_e, 0, +S_e, +1.96 S_e from the regression line (with S_e the standard deviation from the regression line). Then, for each selected peak discharge-flood volume in Table 2-5, the 5 accompanying flood volumes can be specified according to the spread in the flood volume-peak discharge relationship. Figure 2-11 shows the resulting 30 (6×5) grid points in combination with the five fitted lines from Figure 2-10. (This repeats some of the processes as shown in Section 2.3.3.)

For each of the 30 grid points a model simulation with ISIS can be run 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 water discharge as input series data. 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 can be selected and (slightly) adapted. The observed hydrographs that most closely resemble the features of the grid points should be 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 discharge was slightly altered, but the remainder of the hydrograph was slightly lowered to decrease the flow volume. The resulting hydrograph is a realistic model that closely resembles the observed hydrograph.

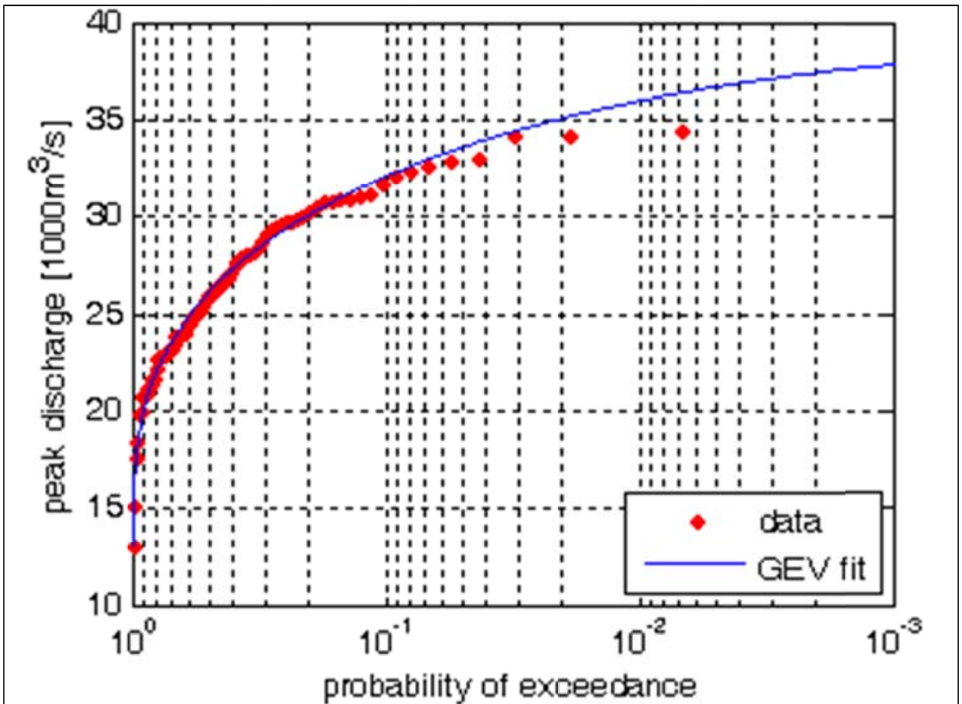


Figure 2-9 Fit of the GEV function to annual maximum daily discharge of the Mekong River at Nakhon Phanom.

Table 2-5 Parameters of the GEV distribution fitted to annual maximum daily discharge of the Mekong River 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

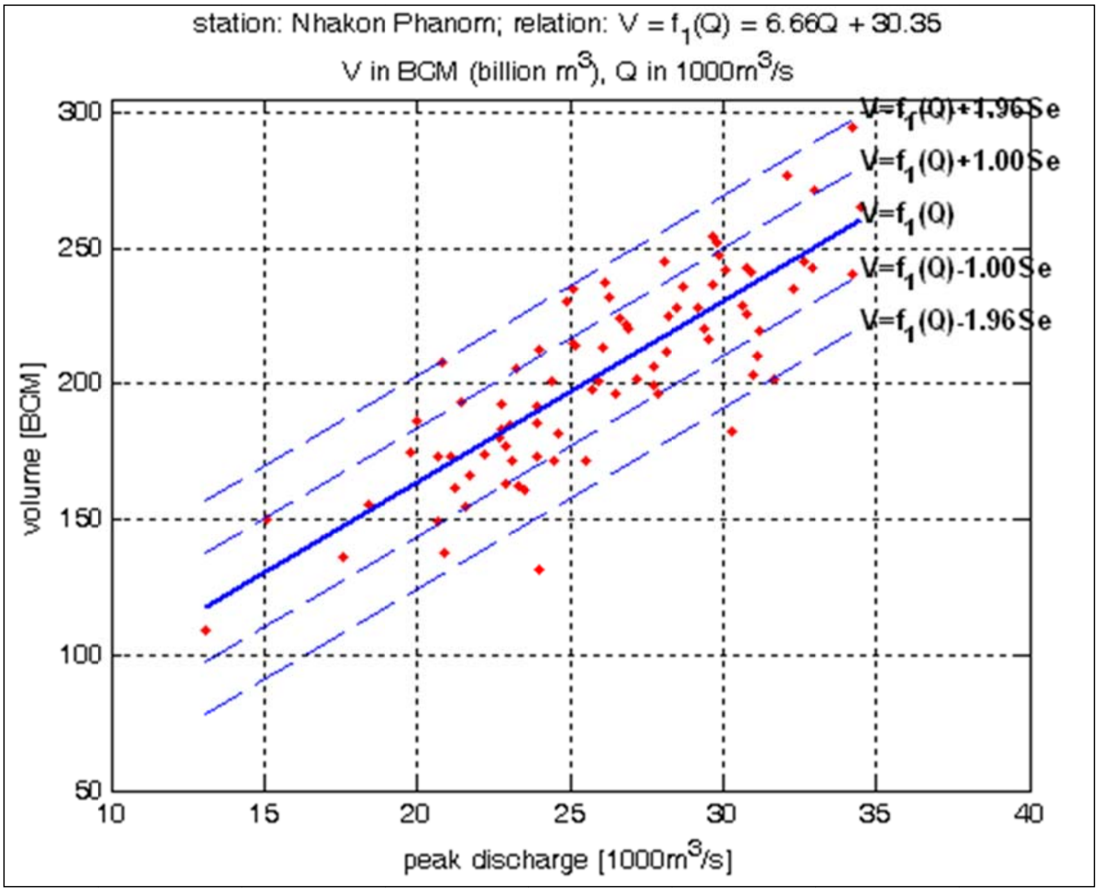


Figure 2-10 Peak water level discharge-Flood volume relation at Nakhon Phanom.

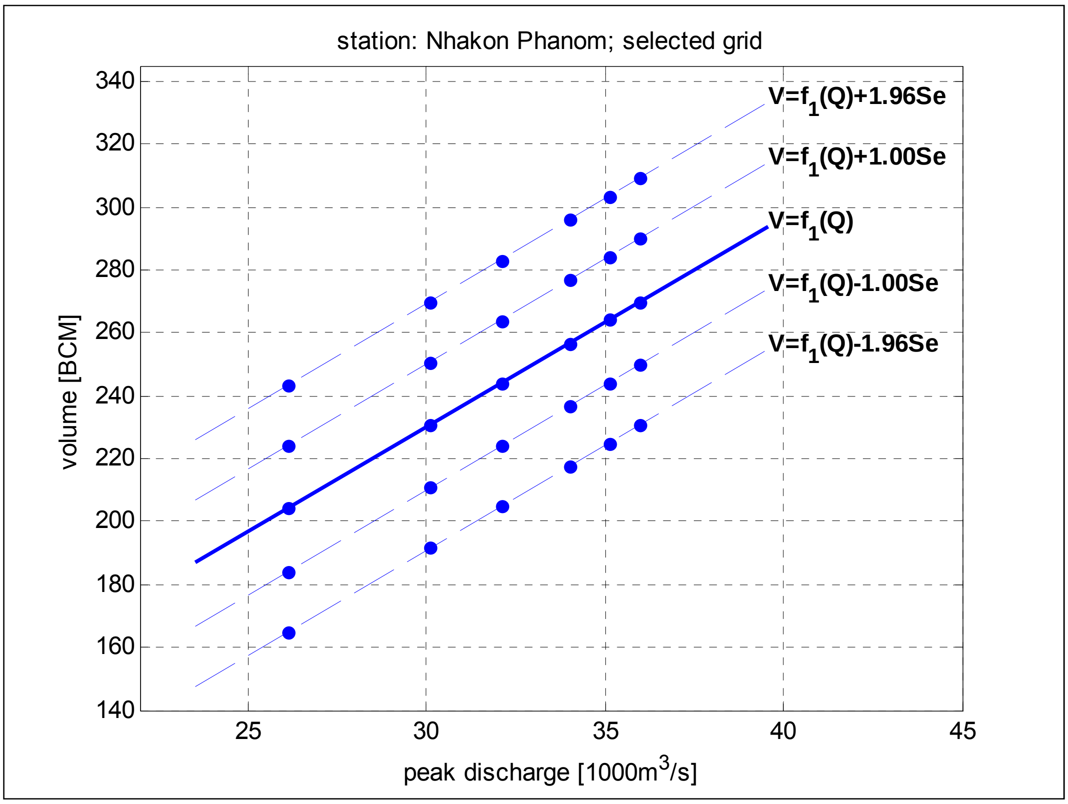


Figure 2-11 Defined 2D grid of discharges (with return periods 2, 5, 10, 25, 50 and 100 years) and volumes (based on the regression line and lines of deviation from the regression line).

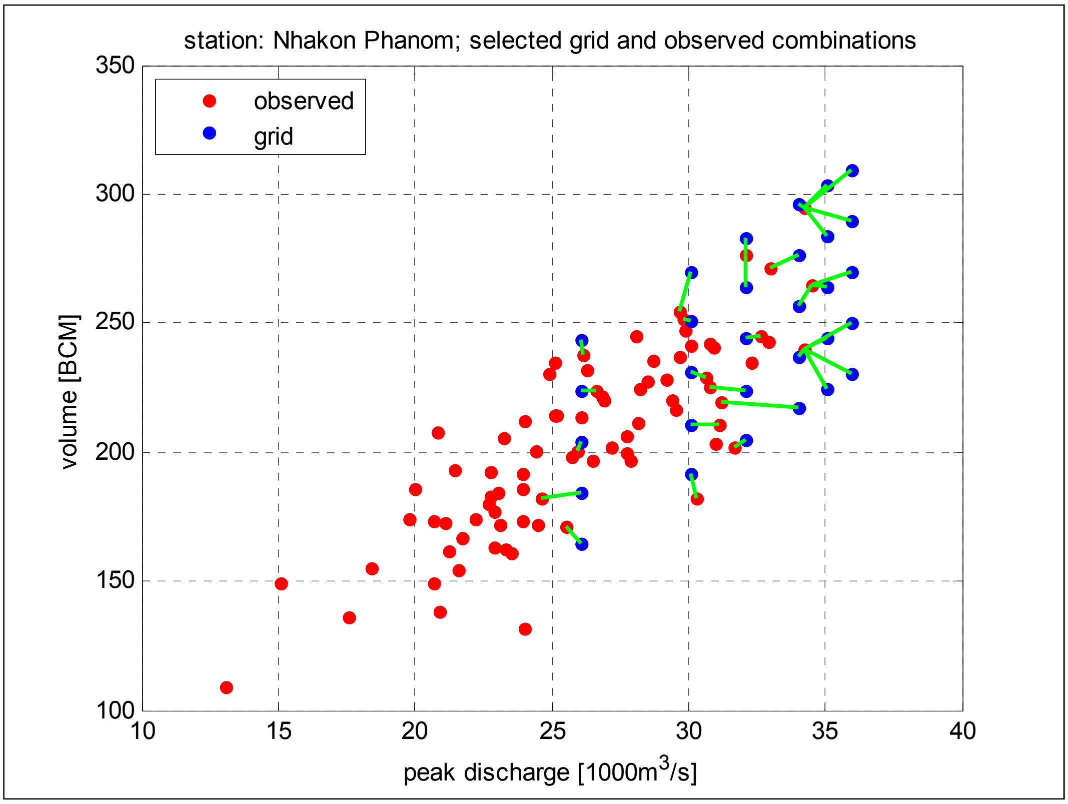


Figure 2-12 Observed combinations of peak discharge and flow volume (red dots) and selected 2D grid (blue dots). The green lines show the observed combinations that most closely reflect the grid combinations.

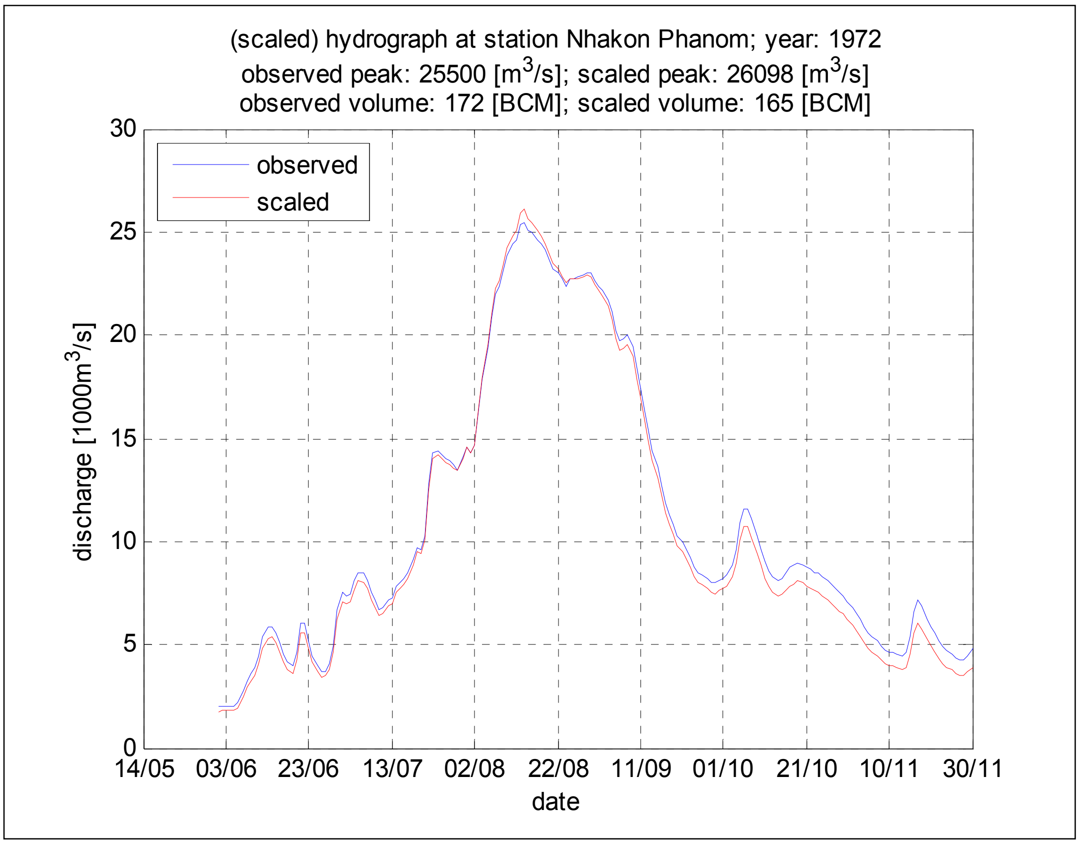


Figure 2-13 Example of scaling of an observed hydrograph to make it suitable for serving as one of the grid points in Figure 2-12.

Monte Carlo analysis and results

For this example, a Monte Carlo analysis was executed with N=100,000 samples. For the resulting *N* water levels the probability of exceedance was estimated through application of the formula (2.5) presented in Section 2.3.4. For a floodplain just downstream of Nakhon Phanom, the resulting frequency curve for the water level is presented in Figure 2-14. It starts with a basic level (measured in meters over Mean Sea Level (MSL) 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 probabilities of exceedance are lower. The once every 100-year floodwater level is approximately equal to 134.8 m+MSL (where the graph crosses the line of x = 10^{-2} per year). Similarly, the once every 100-year flood water level can be determined for other locations. Based on the results for all locations a spatial map can be produced using the GIS-procedures, described in Section 2.7.

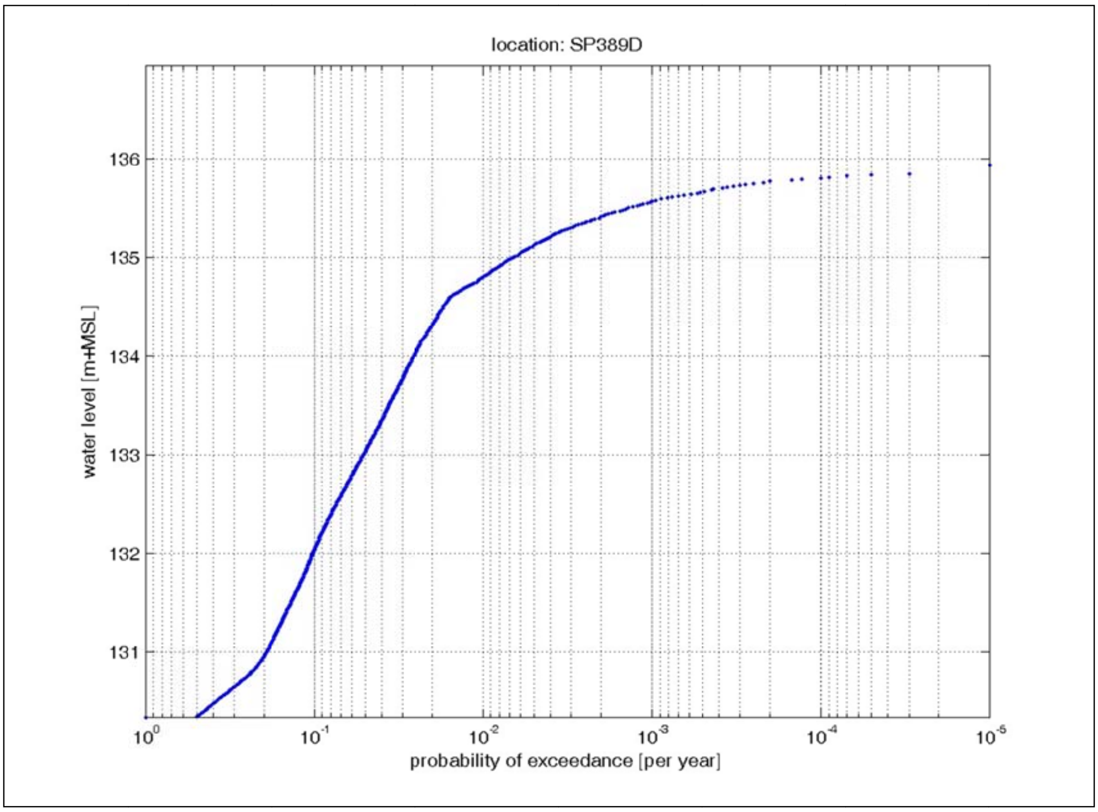


Figure 2-14 Derived frequency curve for maximum annual water levels at a location in the Mekong River floodplain just downstream of Nakhon Phanom.

2.5 Combined flood hazard assessment

2.5.1 General

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

The hydrological hazard of tributary runoff waters with high water levels at the confluence with the Mekong River can be simulated with a hydraulic model. The levels of river tributary runoff water can be converted into water levels in river and floodplain in the backwater affected zone near the river mouth using this model. The model uses data across the full spectrum of possible combinations of upstream floodwater inflow and downstream water levels. The hydraulic model should encompass the full area including the tributary and its floodplains starting from an area with no backwater flows and extending to the area where the rivers meet, as well as the area of the Mekong River around this confluence where there should be key hydrometric monitoring stations. The model applies discharge hydrograph data upstream and a stage-discharge relation downstream.

The simulation results derived from this model can be used in a Monte Carlo procedure to derive the exceedance probabilities of water levels and floodwater damages. The procedure usually includes the following three or four random variables, representing the main causes for high water levels in the downstream part of the tributary that is backed up with mainstream floodwaters:

1. maximum water discharge volumes in the Mekong River at the confluence of the Mekong and a tributary;
2. total volume of the floodwater in the Mekong at the confluence;
3. total volume of the tributary floodwaters; and
4. maximum water discharge volumes in the tributary.

Note that it may not always be necessary to explicitly take the tributary peak flow into account, particularly when floodplain inundations and associated damages are considered. In such cases the tributary flood volume, rather than the peak flow plays a more important role. Tributary peak flow is mainly a concern in the design of flood protection works along the tributary, in which case tributary flood volumes are not the relevant concern. In practice, generally only one of the two is considered and rarely both.

Special attention should be paid to variations of the river bed as a result of natural or human induced morphological changes. These can affect the conveyance of the rivers and hence the resulting stages. The river conveyance may be an additional variable that is needed in the Monte Carlo simulation procedure.

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

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

1. Data collection;
2. Database development and conduct of field visits;
3. Data validation and processing;
4. Hydrological hazard assessment in terms of flood peak water levels and flood volumes on the Mekong River and the specific tributary.
5. Flood hazard assessment using a hydraulic model that transforms flood hydrograph data to flood level data and interpolates from simulated water levels by means of a Monte Carlo procedure to arrive at flood levels and durations for distinct return periods.
6. 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, the following data and information are required:

1. Identification of key hydrological monitoring stations (Qh-stations) on the Mekong River tributary extending beyond the backwater reach of the mainstream and the along the Mekong River in the area of study;
2. Survey data of the tributary and Mekong River (full river bathymetry) and of floodplains in the study area and beyond, and data of relevant hydraulic parameters, including river bed material, vegetation, embankment elevation, etc.;
3. Updated Digital Elevation Model (DEM) of the floodplain in the area under study;
4. Soil maps of the floodplains;
5. Land use maps of the floodplain, including past, present and expected future land use;
6. Data on hydraulic infrastructure in and downstream of the study area, including its dimensions and operation in times of flood and planned future developments;
7. Historical flood maps (including flood levels, extent, depth and duration);
8. Layout, operation and maintenance information for the hydro-meteorological network around the study area including information on the nearest upstream (and for the Mekong

River, downstream) monitoring stations along the tributaries and Mekong River where relevant;

9. Time series data of water levels, stage-discharge measurements, discharge ratings and discharges series of the relevant monitoring stations as well as series data of rainfall and climatic variables in the region, particularly in cases when lateral water inflow downstream of the key monitoring station on the tributary is substantial;
10. Changes that have occurred in runoff characteristics of basins upstream of the study area that affect the homogeneity of the historical water discharge data series (including construction of reservoirs and land use changes).

2.5.3 Database development and conduct of field visits

The same database development strategy as outlined for mainstream floods (Section 2.3.3) applies here. The same holds for the field visits, with the following addition. When lateral floodwater inflow is substantial and can only be estimated from rainfall records, it is important to visit and inspect the rainfall/climatic monitoring stations in and around the contributing area. To judge the suitability of a monitoring station for use in rainfall-runoff modelling, the visit should include inspections and review of the monitoring station layout, equipment exposure, operating practices and maintenance.

2.5.4 Data validation and processing

Data validation and processing should follow the same steps as presented in Section 2.3.4. If lateral floodwater inflow measurements need to be derived using rainfall-runoff modelling (SWAT), rainfall and climatic data of the area of the lateral inflows needs to be validated and processed. This involves that the historical series are first screened graphically by comparison with nearby monitoring station records. Erroneous date entries can be identified by tabular comparisons. Monitoring practices during weekends and holidays should be inspected and data should be adjusted where necessary. Next, the data should be compared with data collected by the nearest neighbouring monitoring stations and also subject to double mass tests. Series data should be adjusted when necessary and completed where data is missing, using estimates based on data from reliable measurement stations. The resulting data series can then be converted to areal rainfall for sub-basins used in the SWAT rainfall-runoff model. The data series can then be compared with the series used earlier for the modelling. Where there are differences, it may be necessary to recalibrate the SWAT model for the areas where it is to be applied. Note that in several areas, rainfall-runoff modelling may not be needed to estimate the lateral floodwater inflow, such as in the Xe Bang Fai River example discussed in Section 2.4.7.

2.5.5 Hydrological hazard assessment

The hydrological hazard is determined by peak flow and floodwater volume on the Mekong River. These can be used to estimate the floodwater levels at the confluence, and the tributary flood volumes and peak flow on the tributary, as well as their interrelation. A matrix of flood hydrographs can be plotted to cover the full spectrum of possible hydrographs starting with the peak flow on the Mekong River for floods with return periods of $T \geq 2$ years. The development of this matrix requires the following tasks:

1. Creation of homogeneous floodwater discharge series for the key monitoring stations at the upstream boundaries of the hydraulic model on the tributary and the Mekong River.
2. Estimation of the marginal distributions of annual flood peak water levels and flood volumes (between June 1st and November 30th) at these upper boundaries (on the Mekong River and tributary). The observed distributions of flood peak water levels and flood volumes are generally well represented by a GEV distribution.

3. Generation of the following regression equations between peak water level flows and flood volumes with their standard errors:
   - Floodwater volume on the Mekong River (V_M) as a function flood peak discharge on the Mekong River (Q_{pM}):

     $V_M = f_1(Q_{pM})$;
   - Floodwater volume on the tributary (V_T) as a function of floodwater volume of the Mekong River (V_M):

     $V_T=f_2(V_M)$; and
   - Flood peak discharges on the tributary (Q_{pT}) as a function of floodwater volume on the tributary (V_T):

     $Q_{pT}=f_3(V_T)$;

     Note that these equations are not required when tributary peak flows do not play an important role. If, on the other hand, the tributary flood volume is not critical, it may be replaced by the tributary flood peak; see Section 2.4.1;
   - Plotting of the regression equations with year-numbers (return periods) to the grid points and additions of lines, parallel to the regression line at distances of +/- 1x S_e and +/-1.96 x S_e.
4. Specification of the matrix of flood hydrographs for distinct flood peak discharge values. This process requires:
   - Selection of flood peak discharge values and volumes (6×5=30) and associated hydrographs for the Mekong River in the same manner as in Section 2.4.7;
   - Determination of range of tributary flood volumes for each of 30 selected Mekong River flood volumes from the scatter plot about the regression line for the tributary flood volume – Mekong River flood volume relationship, generating, using the standard errors: for each selected Mekong River flood volume a low (R-1.96 S_{eVT}), medium (designated as Rf_2) and a high tributary flood volume (R+1.96 S_{eVT}). This results into 6×5 x 3 = 90 combinations of Mekong River flood peak, flood volumes and tributary flood volumes (producing a 3D-grid, as shown on the next page); and
   - Derivation of 90 synthetic hydrographs, by scaling observed hydrographs in the same manner as in Section 2.4.7.

The steps in the development of the matrix up to a level of 3 variables are depicted graphically in Figure 2-15.

As for mainstream floods, changes in the stage-discharge ratings (mainstream and/or tributary) due to river bed variations should be taken into account by repeating the model simulations with different values for 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.

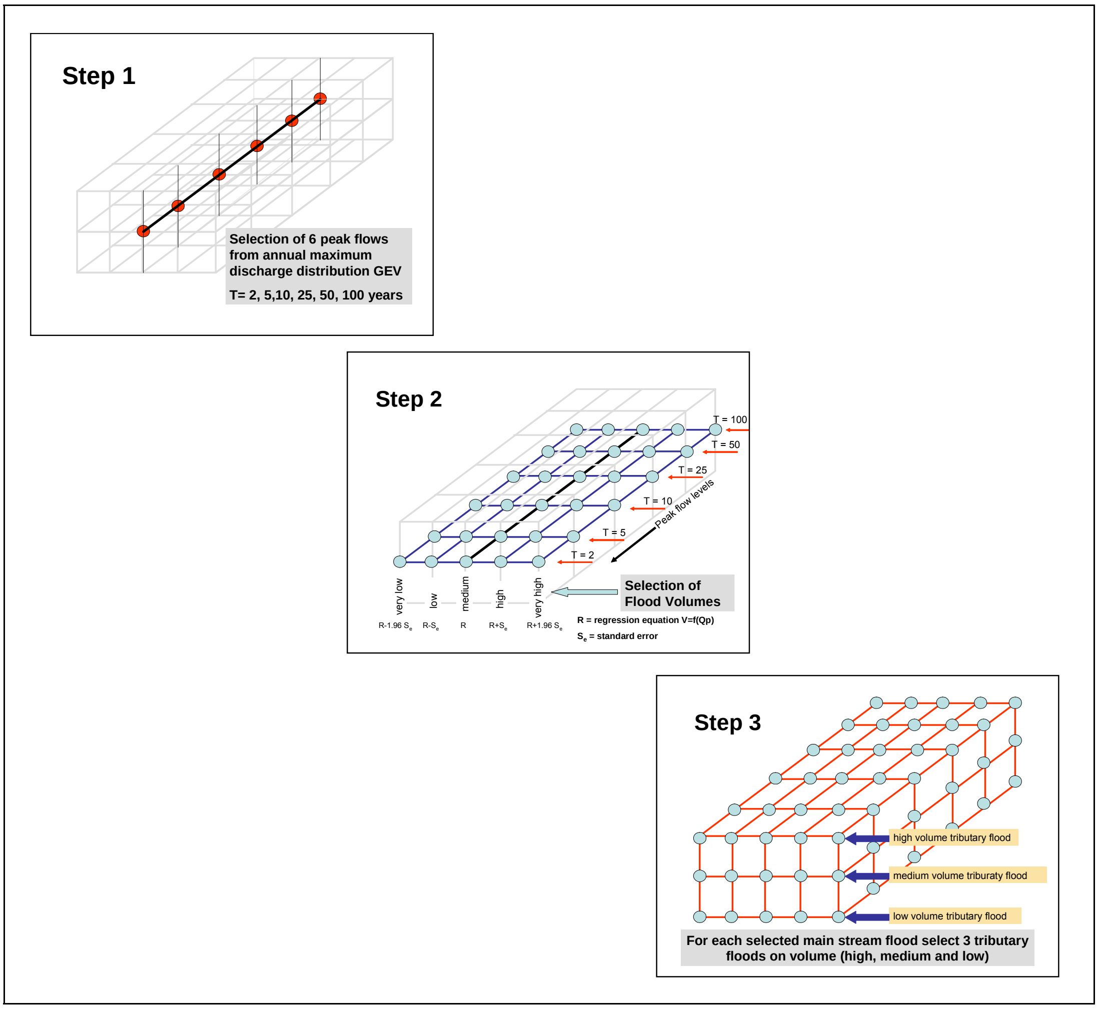


Figure 2-15 Development of the flood simulation matrix for combined floods.

2.5.6 Flood hazard assessment using a hydraulic model

The hydrological hazard in terms of statistics and relations between:

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

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

Data from the 30 selected Mekong River hydrographs and 90 tributary floods can then be input using the model for the particular river and floodplains system. The water levels that are computed as functions of time and space can be placed in the database. If relevant, in view of river bed changes, the simulations can be repeated at least twice with different specifications for hydraulic roughness and downstream stage-discharge relations to accommodate the conveyance changes. These should be added to the simulation database before using a Monte Carlo simulation procedure. Simulations are also necessary to analyse any planned construction.

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

2.5.7 Example: combined floods in the lower Xe Bang Fai River Focal Area (Lao PDR)

Combined flooding takes place in the floodplains along the lower Xe Bang Fai River, where the water levels are affected by backwater from the Mekong River. The Xe Bang Fai River drains an area of 10,240 km^2 and discharges its waters into the Mekong River at That Phanom, Thailand which is located between the key Mekong River monitoring stations: Nakhon Phanom upstream and Mukhdahan, Thailand downstream. The flow in the Xe Bang Fai River is measured, among others at Mahaxai and Ban Xe Bang Fai at Highway Bridge 13. (See Figure 2-16.) The Mahaxai monitoring station surveys an area of 4,520 km^2, whereas the drainage area at Ban Xe Bang Fai amounts to 8,560 km^2. These account, respectively, for 44% and 84 % of the entire basin. Between Mahaxai and Ban Xe Bang Fai, the Xe Bang Fai River is joined by the Nam Oula and Se Noy Rivers. The monthly average flows in the Xe Bang Fai River at Mahaxai and the Mekong River at Nakhon Phanom are presented in Table 2-6.

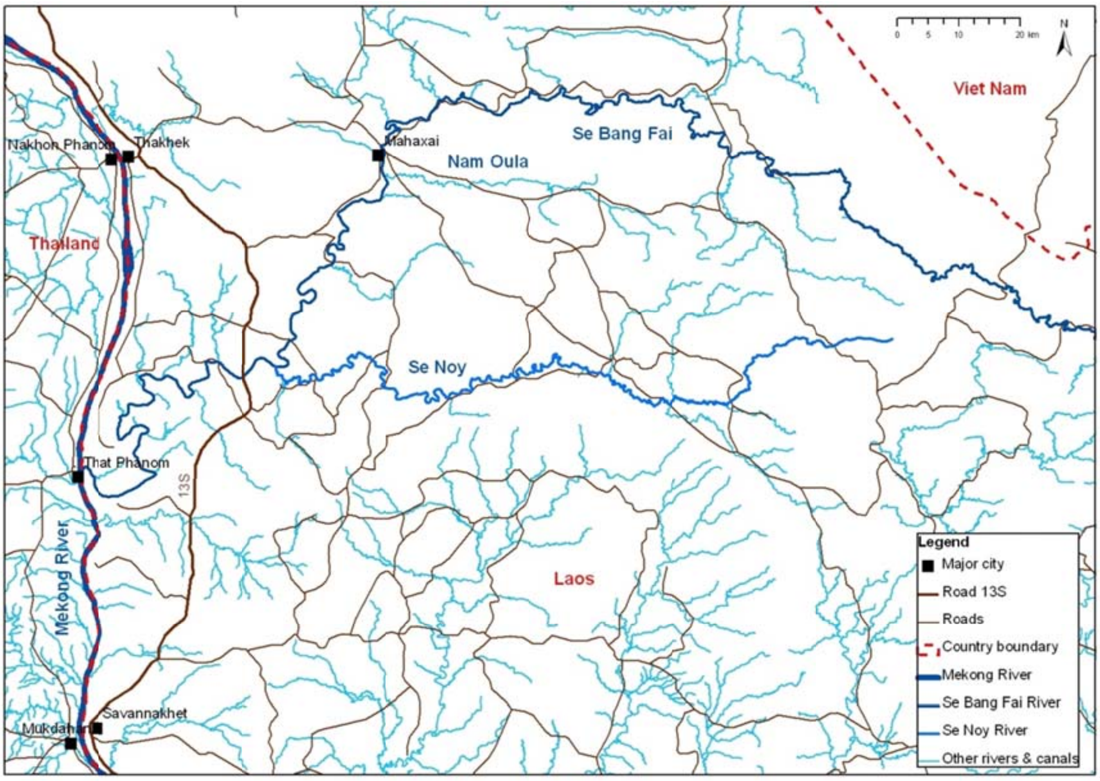


Figure 2-16 Hydrological map of Lower Xe Bang Fai River basin.

Table 2-6 Average monthly and annual flow (MCM) of the Xe Bang Fai River at Mahaxai and Mekong River at Nakhon Phanom.

	Jan	Feb	Mar	Apr	May	Jun	Jul
Mahaxai	60.0	41.5	37.2	34.7	90.8	565.6	1601.4
Nakhon Phanom	6,277	4,469	4,130	4,000	6,492	17,722	35,993

	Aug	Sep	Oct	Nov	Dec	Year
Mahaxai	2,370.7	1,687.9	635.9	240.5	105.8	7,504.4
Nakhon Phanom	54,457	51,055	29,808	14,860	9,111	238,376

Floods in the Xe Bang Fai River may occur from June to early October, coinciding with high water levels on the Mekong River. The water levels in the Xe Bang Fai River at Highway Bridge

13 at Ban Xe Bang Fai are seriously affected by backwater from the Mekong River, while Mahaxai is backwater free.

Hydrological hazard assessment

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

- The Xe Bang Fai River floodwater discharge records for Mahaxai for the period 1988-2006.
- River flow measurements at Ban Xe Bang Fai. The Ban Xe Bang Fai data establishes the relationship between tributary water inflow along the river and at a specific point, given the backwater effects on the stage-discharge relation at Ban Xe Bang Fai. Tributary water inflow between Mahaxai and Ban Xe Bang Fai can then be estimated as a function of the flow at Mahaxai, without having to rely on questionable inflow estimates from a very limited number of rainfall monitoring stations.
- The Mekong River floodwater discharge at Nakhon Phanom and the flow from the Xe Bang Fai River. The water levels at That Phanom can be determined by adding these two data sources and considering the conveyance capacity downstream of the confluence, represented by the stage-discharge relation of Mukhdahan. The Nakhon Phanom floodwater discharge series data cover the period 1924-2005.

The discharge series data have been thoroughly validated using similar approaches to those explained in Section 2.3.4. Where necessary, the data has been adjusted. (See the Xe Bang Fai River Flood Hazard Assessment (FHA) Report for details.) Using this data, the hydrological hazard in terms of marginal distributions of peak water flows and flood volumes and their interrelations have been quantified. Statistics for Nakhon Phanom are presented in Section 2.4.7. Statistics for Mahaxai are presented in Table 2-7, Figure 2-19 and Figure 2-20.

The matrix of flood hydrographs for distinct discharge peak water levels can then be specified, starting with the flood peak water levels at Nakhon Phanom. This is described above in Section 2.4.7. The result consists of 30 (6×5) combinations of peak water level discharge and flow volumes and 30 associated water discharge hydrographs. For each of these 30 Mekong River flood volumes, 3 Xe Bang Fai River flood volumes can be selected at distances -1.96 S_{eVXBF}, 0,+1.96 S_{eVXBF} from the Xe Bang Fai River flood volume-Mekong River flood volume regression equation using the standard error measure, S_{eVXBF}. (See Figure 2-20.) The result is a 3-dimensional grid for peak discharge and volume in the Mekong River (at Nakhon Phanom) and flood volume in the Xe Bang Fai River (at Mahaxai) as depicted in Figure 2-17. The grid contains 90 points (6×5×3), meaning 90 discharge hydrographs for Mahaxai are required for the Monte Carlo analysis. This can be achieved through rescaling of observed hydrographs, as described in Section 2.4.7. Figure 2-18 shows an example of a scaled hydrograph.

Table 2-7 GEV-parameters, flood peak discharges and flood volumes (June-November) for distinct return periods in the Xe Bang Fai River at Mahaxai.

Parameter	Flood 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

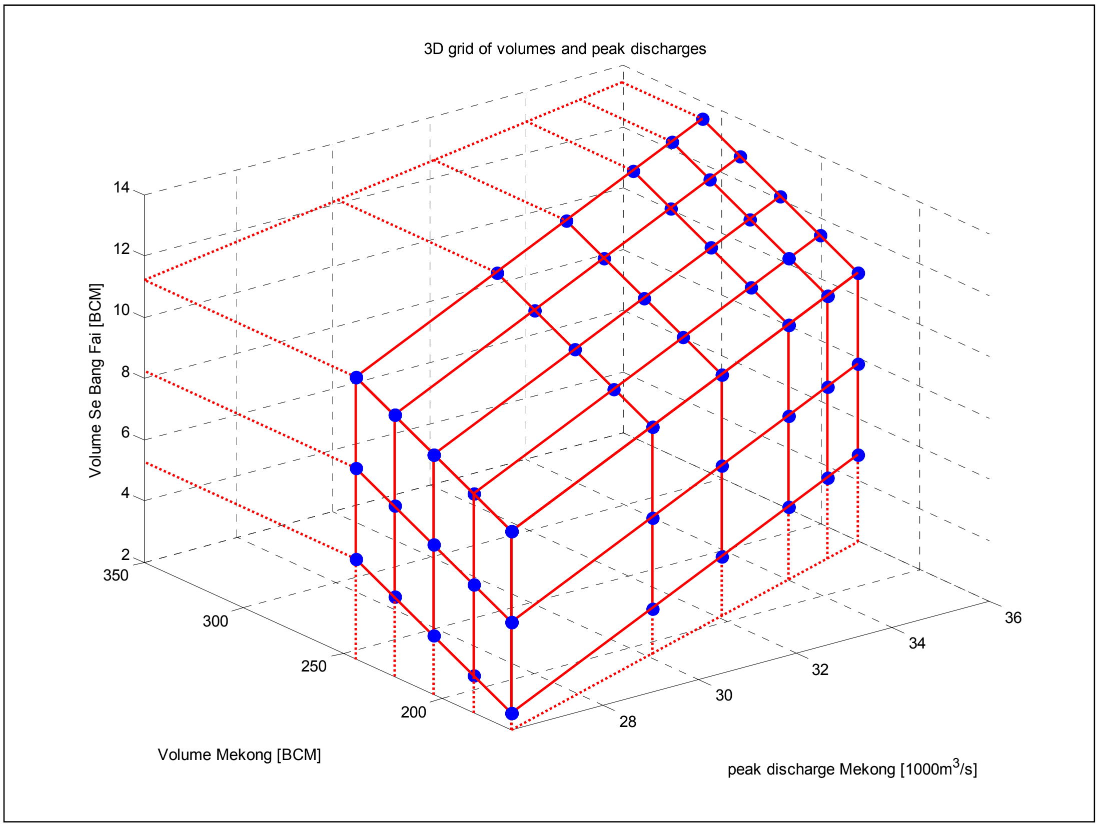


Figure 2-17 Impression of the 3-D grid for peak discharge and flood volume in the Mekong River (at Nakhon Phanom) and flood volume in the Xe Bang Fai River (at Mahaxai). The blue dots only show the 'outer side' of the grid; the full grid contains 90 such dots.

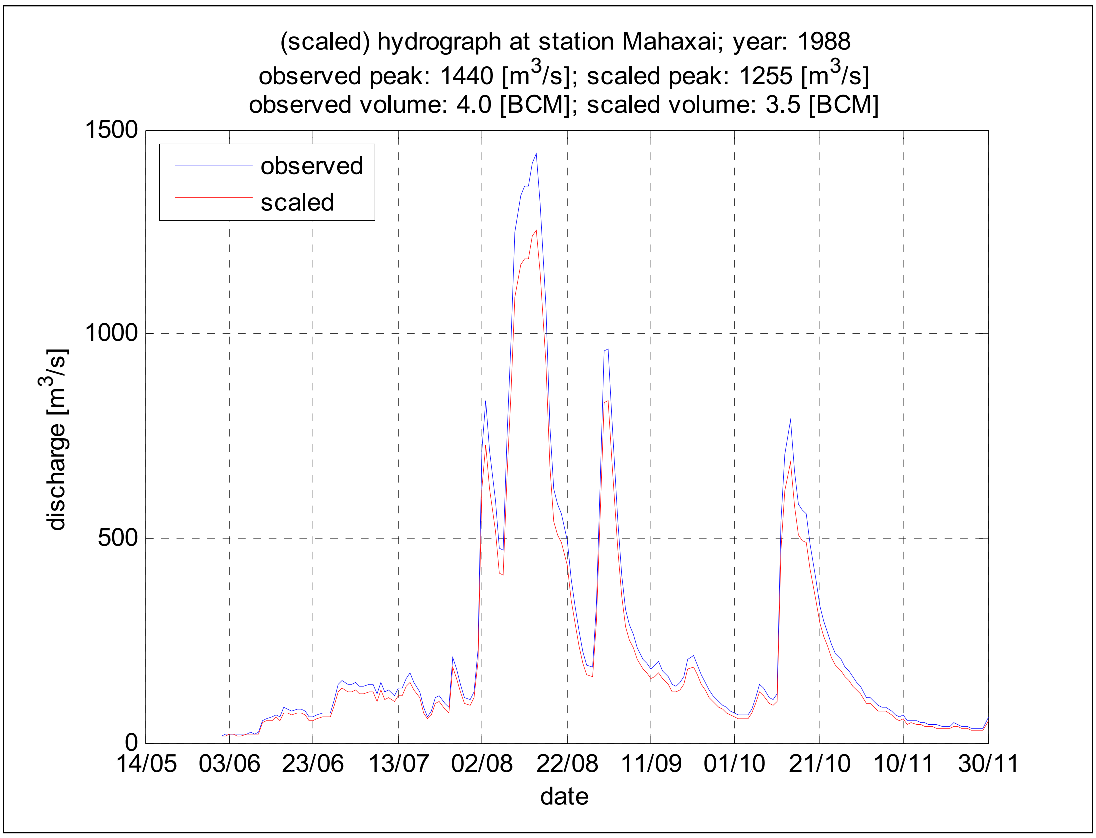
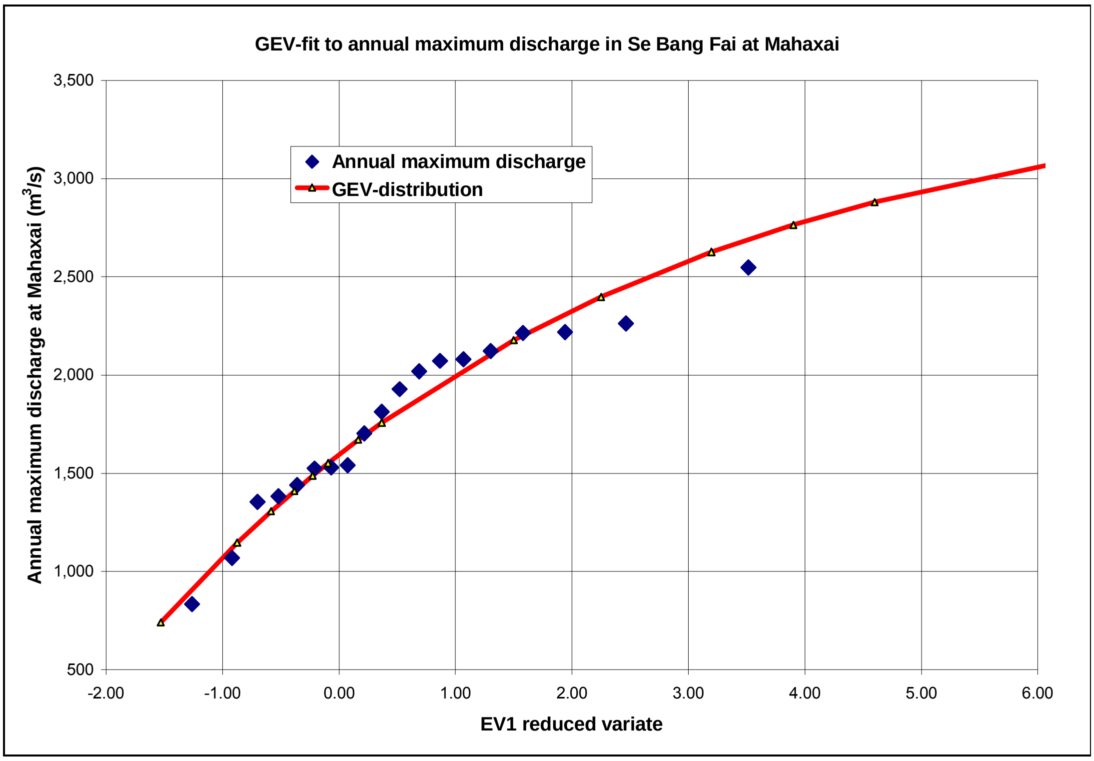


Figure 2-18 Scaling of an observed hydrograph for the Xe Bang Fai River at Mahaxai.



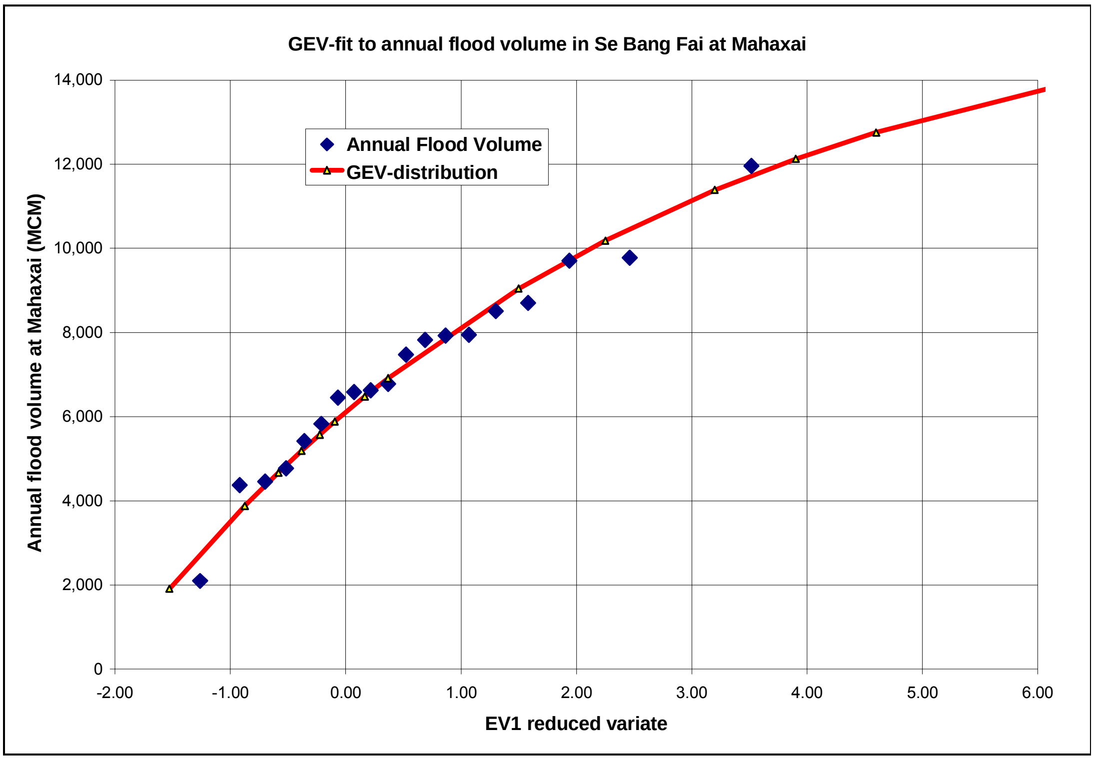
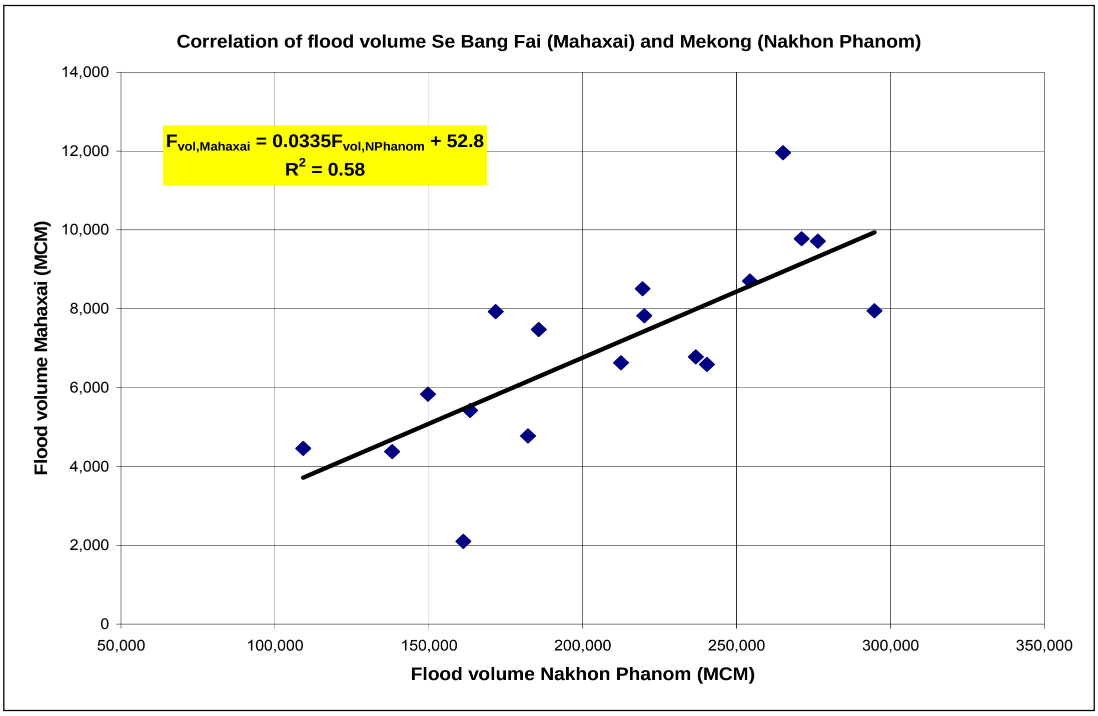


Figure 2-19 GEV-fit to marginal distributions of annual maximum discharge and flood volume at Mahaxai (Xe Bang Fai River).



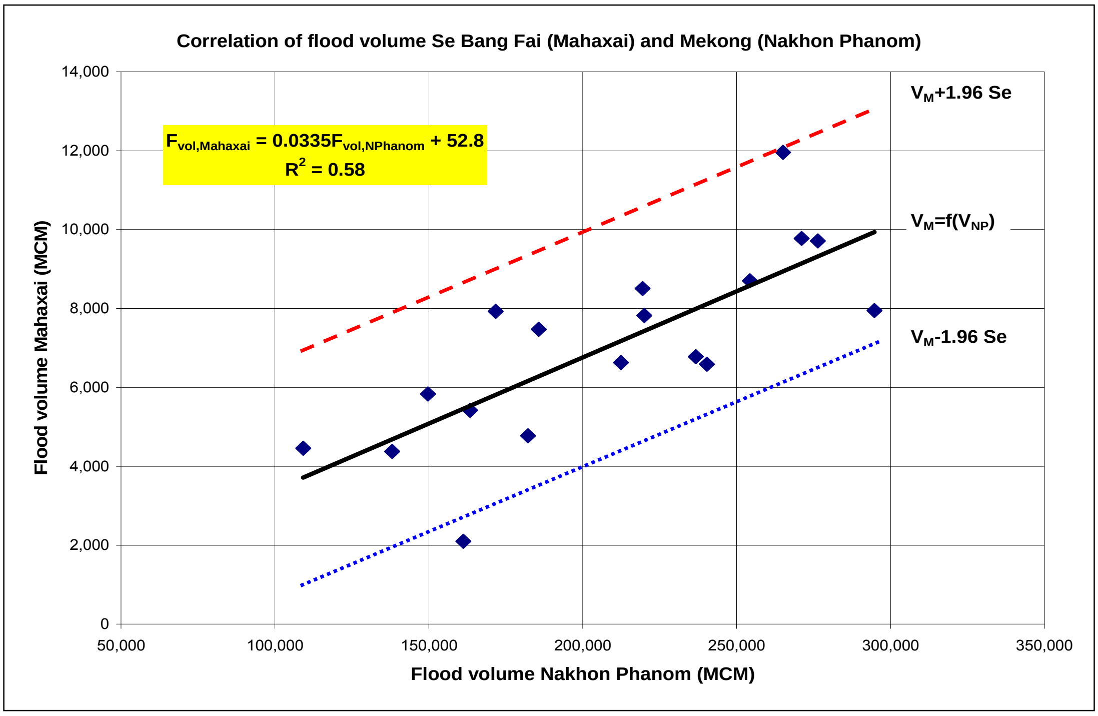


Figure 2-20 Flood volume – peak discharge relation for Nakhon Phanom and flood volumes relation between Mahaxai and Nakhon Phanom, without and with S_e-related lines.

Flood hazard assessment

The 90 flood hydrographs of the Mekong River and Xe Bang Fai River selected above can be input to the hydraulic model of the Xe Bang Fai River delta model for conversion of water flow data into water level data. The model layout and boundary conditions are schematically displayed in Figure 2-21.

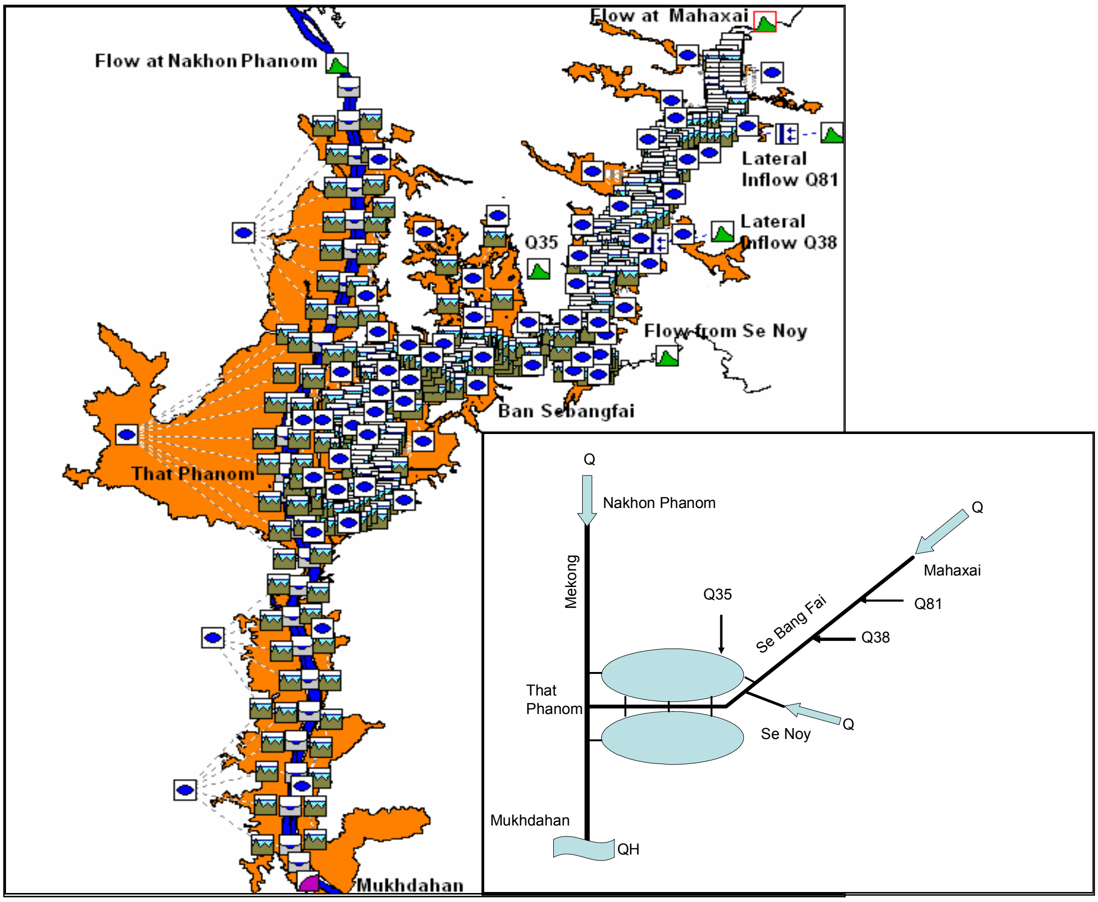


Figure 2-21 Xe Bang Fai River hydraulic model with boundary conditions.

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. The equation that can be used is Manning's equation, as described in Section 2.4.5 and is slightly rewritten here as:

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

where: h = water depth at $Q_{bankfull}$ [measured in meters, m]

Δh = change [m]

In addition, the Mukhdahan rating should be adjusted to eliminate unwanted backwater effects on the floodwater level data for That Phanom. The hydraulic model can be run with the same hydraulic boundaries while adding the adjusted Manning-roughness values.

Monte Carlo sampling of the model boundaries interpolation can be run for computed water levels for each grid cell in the hydraulic model to obtain a frequency distribution for the water levels at each cell. Figure 2-22 shows an example of the frequency distribution at a location in the floodplain of the Xe Bang Fai River, derived using the Monte Carlo random sampling method.

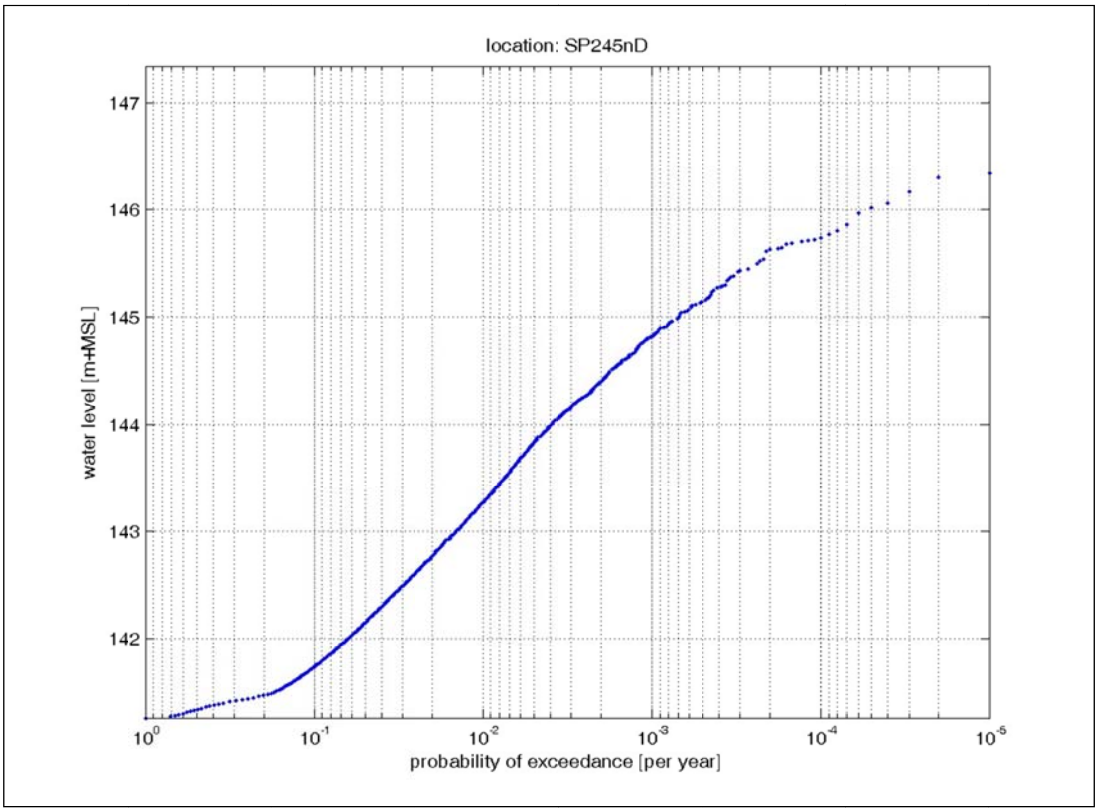


Figure 2-22 Derived frequency curve for maximum annual water levels at a location in the floodplain of the Xe Bang Fai River.

Flood hazard mapping

The procedure for flood hazard mapping is described in Section 2.7. As an example the flood depth and extent map of the Lower Xe Bang Fai River is shown in Figure 2-23 , for a return period of T = 100 years.

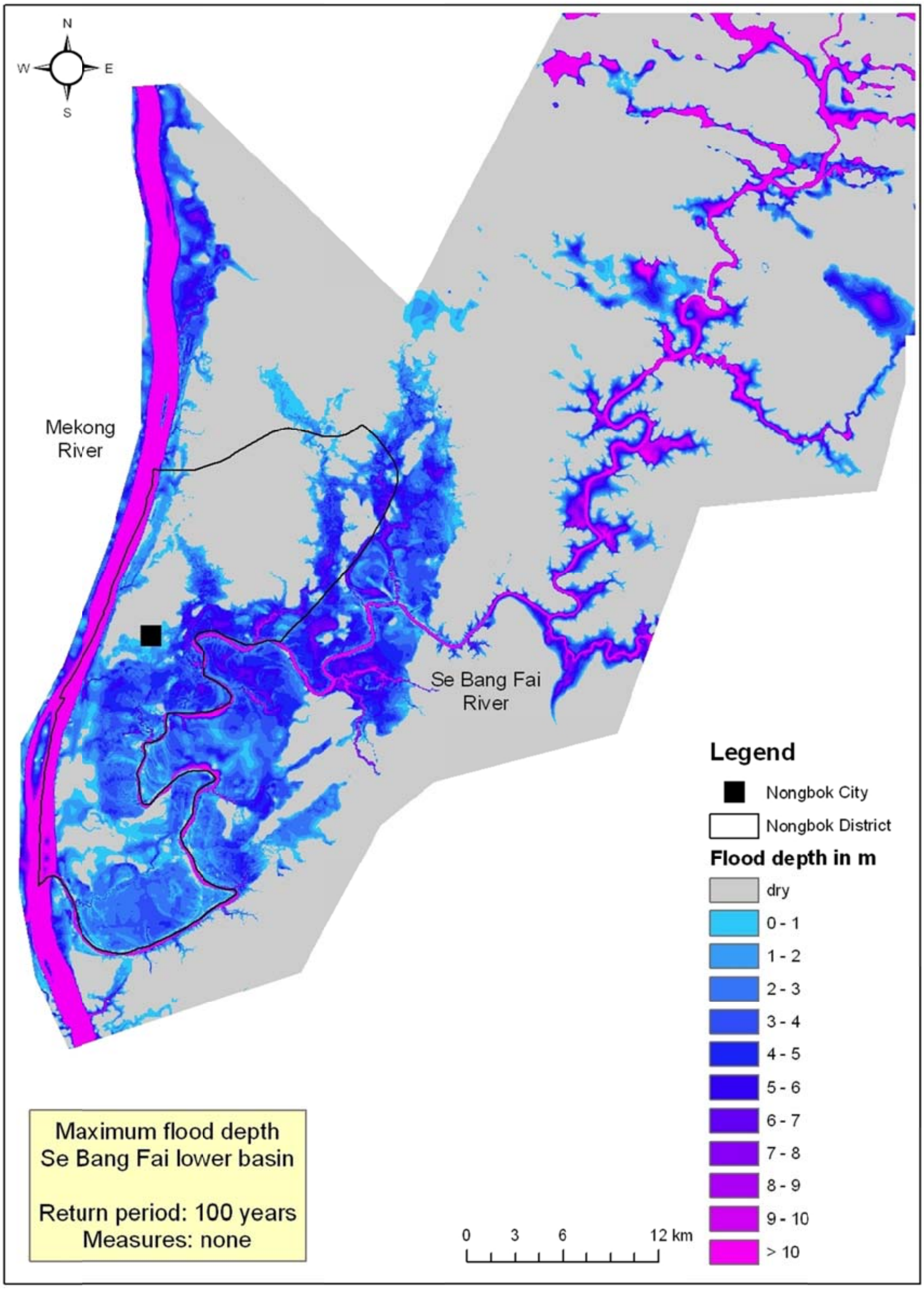


Figure 2-23 Flood depth and extent map of the Lower Xe Bang Fai River, for a return period of T = 100 years.

2.6 Flood Hazard Assessment in the Mekong Delta

2.6.1 General

The floods in the Cambodian floodplains and Mekong Delta (see Figure 2-24) are classified as a special type in the LMB due to their specific external and internal boundary conditions and the delta's unique hydraulic infrastructure. Whereas the flood levels near Kratie are mainly dependent on the Mekong River floodwaters and a small amount of backwater from the Tonle Sap Lake, additional factors play a role further downstream. In the Mekong Delta's downstream areas, flood levels are dependent on upstream and lateral inflows, local rainfall and downstream water levels where the river empties into the sea. Floodwaters in the Mekong Delta are conveyed via the Mekong and Bassac Rivers and their floodplains, including the *colmatage* canal system, which diverts and regulates the flow of floodwaters from and into the River. In the Mekong Delta the river regime is modified by seasonal water storage in the Tonle Sap Lake and in the Mekong River floodplains, creating slowly rising and falling water levels.

Essentially, the hydrological hazard in the delta is the result of upstream and lateral inflows, 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 to the Gulf of Thailand and East Sea. It has been developed to compute water levels, flow velocities and river discharges in the delta as a function of the hydrological hazard components.

Assessment of the flood hazard in the Mekong Delta downstream of Kratie benefits from the existence of a relatively long historical water discharge data series for Stung Treng, just upstream of Kratie. Furthermore, for the tributary inflow further downstream and to the Tonle Sap multi-year data series have been created preserving the serial and cross-correlation with the Mekong River flow. The Stung Treng time series data, which cover the period 1910-2006, have been used as boundary conditions for a hydrodynamic model (based on the ISIS-modelling package) to derive a 97-year series of water levels in flood-prone areas. The ISIS model also adds local rainfall, evaporation, water use and tidal conditions at the Gulf of Thailand and the East Sea for the year 2000. 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 by the model.

The steps required for the flood hazard assessment are similar to those in other hazard assessments and include data collection and conduct of field visits, database development, hydrodynamic model development, and then flood hazard assessment followed by the preparation of flood maps.

2.6.2 Data collection and conduct of field visits

The hydraulic model is based on conditions in the Mekong Delta in 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 reflected in the model schematization with different potential constructions and for those that have occurred since 2000. Hence, detailed information is required on layout, dimensions, capacities and operation of the hydraulic infrastructure and flood protection works relative to the model conditions. Field visits can be used to compare the currently existing infrastructure with its schematisation in the model. The model needs to be updated to reflect key changes.

As for the hydrological boundary conditions, the 97-year time series data of upstream, lateral and downstream boundary conditions are a realistic representation of the variability of the hydrologic conditions in and around the Mekong Delta.

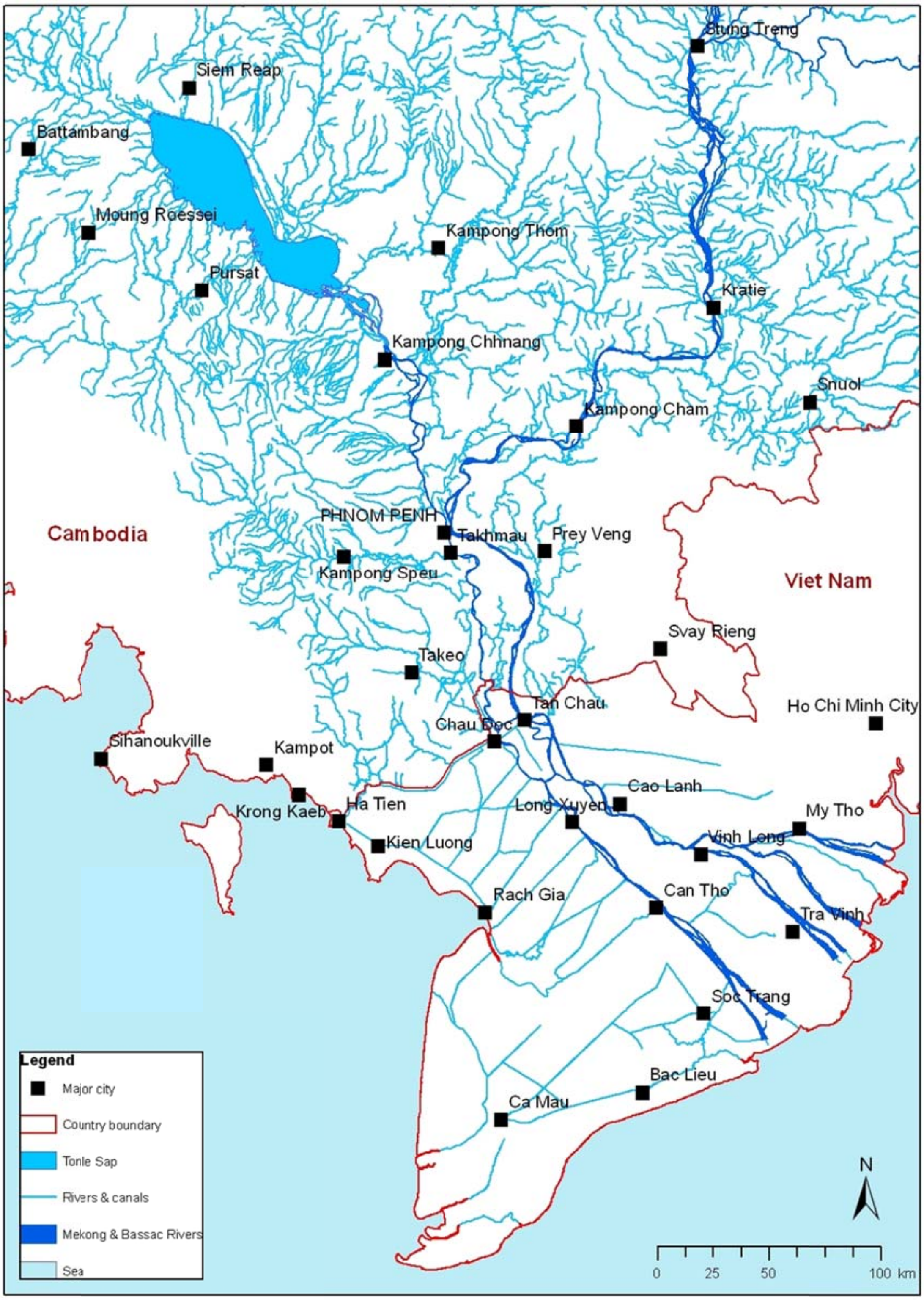


Figure 2-24 Hydraulic infrastructure of the Mekong Delta.

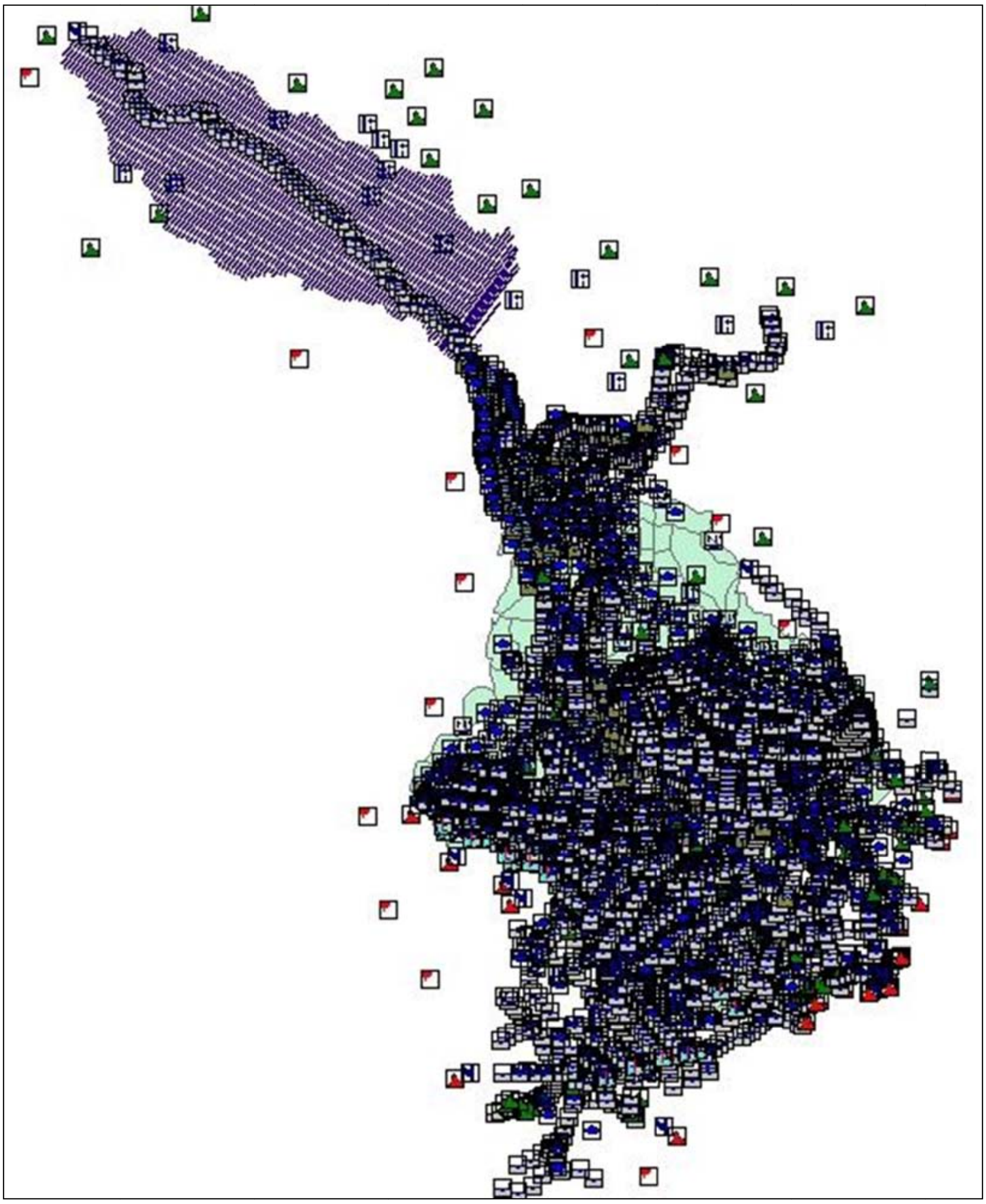


Figure 2-25 The schematisation of the Mekong Delta using the hydrodynamic delta model (ISIS) involves a large number of hydraulic nodes downstream of Kratie, next to floodplain 'reservoirs and river cross-sections.

2.6.3 Database development

A database has been developed for flood hazard assessment in the Mekong Delta that includes the following types of included databases and data:

1. A model database, including schematisation of the hydraulic infrastructure, its structure layout and operations, and hydrological boundary conditions.
2. A result database, including the simulated water levels and flow velocities of the base case and potential infrastructure construction scenarios as inputs for flood hazard assessments.
3. A digital elevation model (DEM) of the Mekong Delta.
4. Data for water levels, flood depth and flood duration for distinct flooding return periods.
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 water flows in river channel networks. It provides an implicit numerical solver for the de Saint Venant equations for 1D flow. The model computes water levels and floodwater discharges at select intervals on a non-staggered grid. Floodplains are included as storage cells connected to the stream channels via two-way weirs. The system was introduced to the MRC under the Water Utilisation Programme (WUP-A) and now serves as part of the Decision Support Framework (DSF). The model covers the MRB from Kratie, Cambodia to the East Sea, including the Tonle Sap Lake and its floodplain, the Cambodian floodplains, and the Vietnamese sections of the Mekong Delta. The model used in FMMP-C2 is based on Delta Model Version-2009, with adaptations and recalibrations of the original model.
The schematisations of the Cambodian and Vietnamese sections of the Mekong Delta that are used in the model are presented in Figure 2-25.

The boundary conditions of the model are based derived from the following data, with each category then described in turn, below:

- upstream discharge at Kratie;
- tributary inflows to the Tonle Sap and Tonle Sap Lake;
- tributary inflows to the Mekong River d/s of Kratie and the Tonle Sap;
- rainfall;
- evaporation;
- water use; and
- downstream boundary characteristics at the Gulf of Thailand and East 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, however, is the difference between stage-discharge ratings according to conventional discharge measurements and those based on Acoustic Doppler Current Profiler (ADCP) records in use at Kratie since 2002. The ADCP records, due to erroneous referencing of the measurements, lead to lower discharges for the same water levels than the ratings based on conventional discharge measurements, the differences increase for the higher stages. Therefore, unless concurrent current meter and ADCP-measurements are taken at Kratie and Stung Treng, and discharge rating curves are updated, it is advised using only the Stung Treng records, based on conventional measurements. The Stung Treng records are consistent with measurements of the water flow at Pakse on the Mekong River. Since the hydrodynamic model has been calibrated on recent discharge series at Kratie with flood volumes that are about 8% less than those at Stung Treng, the historical Stung Treng data used in the model can be corrected to reflect these differences, using a reduction of 8%. (Note that this 8% reduction is not applied to the data and statistics presented below for Stung Treng, itself.)

The annual maximum discharge series and flood volume of the Mekong River at Stung Treng are shown in Figure 2-26 and Figure 2-27.

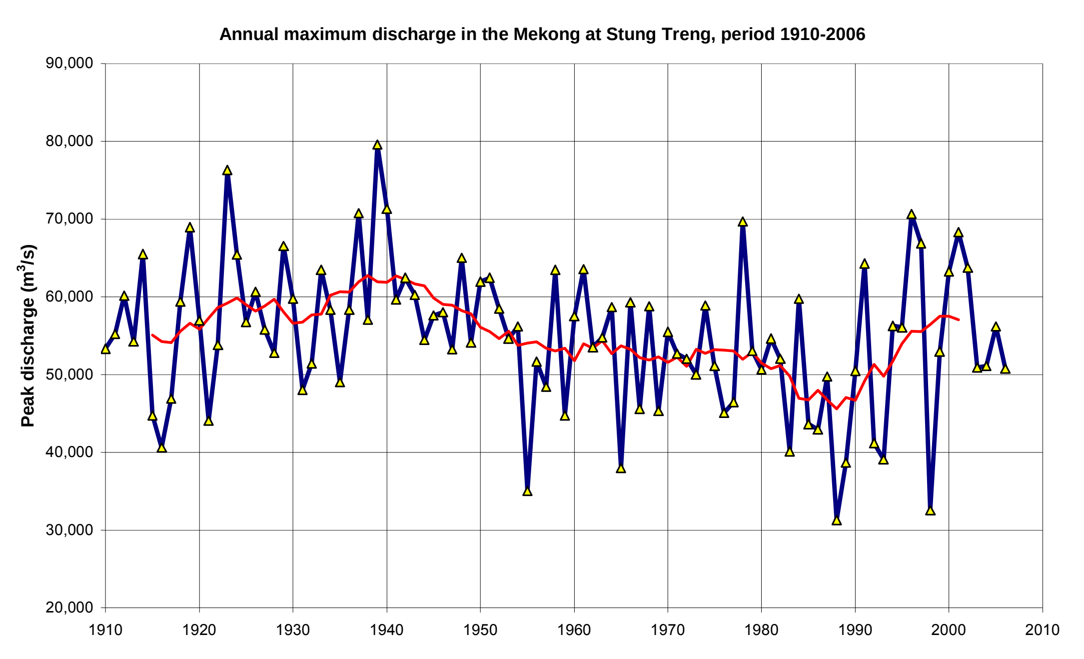


Figure 2-26 Annual maximum water discharges at Stung Treng, 1910-2006.

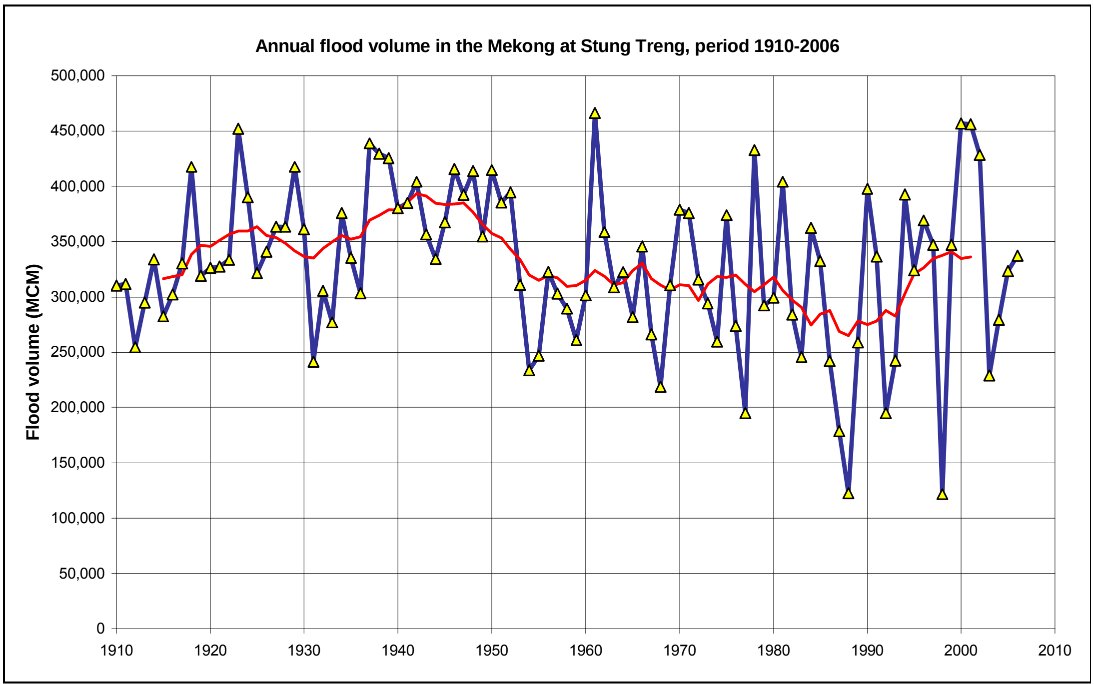


Figure 2-27 Annual flood volumes at Stung Treng, period 1910-2006.

Tributary inflow to the Tonle Sap Lake

The area draining into the Tonle Sap Lake, bounded by Cambodia's National Highways 5 and 6 that surround the lake, encompasses 68,830 km^2 and includes the drainage areas of 13 Stungs (rivers). Water inflow data series of daily discharges are available for the years 1997-2004. A model has been developed to extend the time series data to 1910-2006, using contemporary data to determine the relationship between flows at Stung Treng and then applying data from Stung Treng to generate the missing data at other sites. The estimates rely on a multiple regression equation for monthly tributary flows. The flows have been regressed on the tributary inflows of the previous of month to reflect the serial correlation of the sites, and on the Mekong River flow at Stung Treng in the same month to preserve the cross-correlation. Following standard statistical practices, a normally distributed random number was added to preserve the random variance that would normally exist between the two data sets. The monthly flows were then disaggregated to daily flow values based on their degree of agreement with data from the years in which there were existing measurements. These daily flow measurements from years with actual data were then scaled per month to the required generated value. The resulting seasonal inflow to the Tonle Sap Lake is shown in Figure 2-28. The average monthly inflows as a percentage of the annual totals in comparison to the Mekong River discharges at Stung Treng are presented graphically in Figure 2-29.

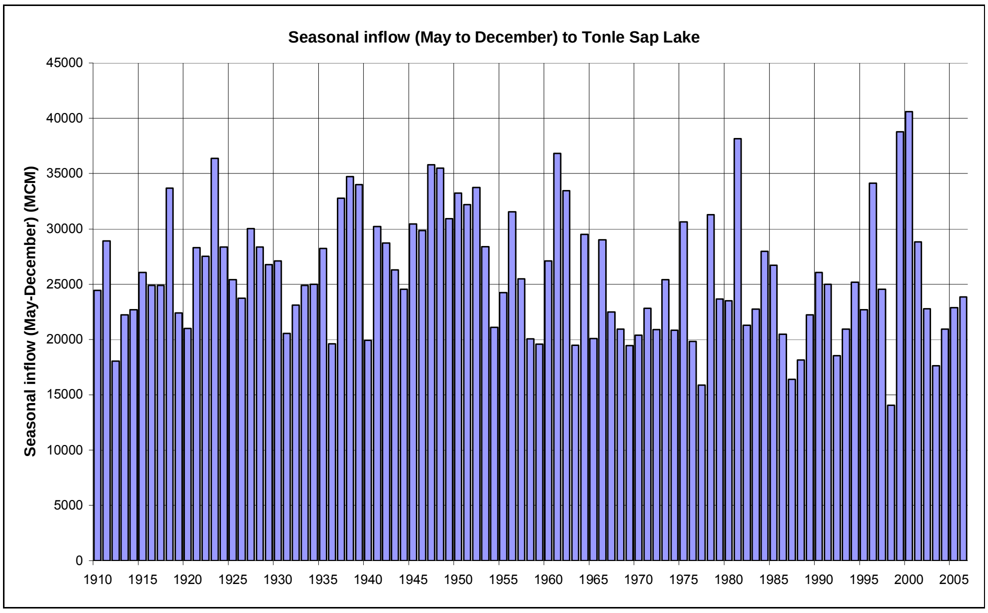


Figure 2-28 Seasonal hydraulic inflow to the Tonle Sap Lake, estimated from 1910-2006, with recorded data for 1997-2004.

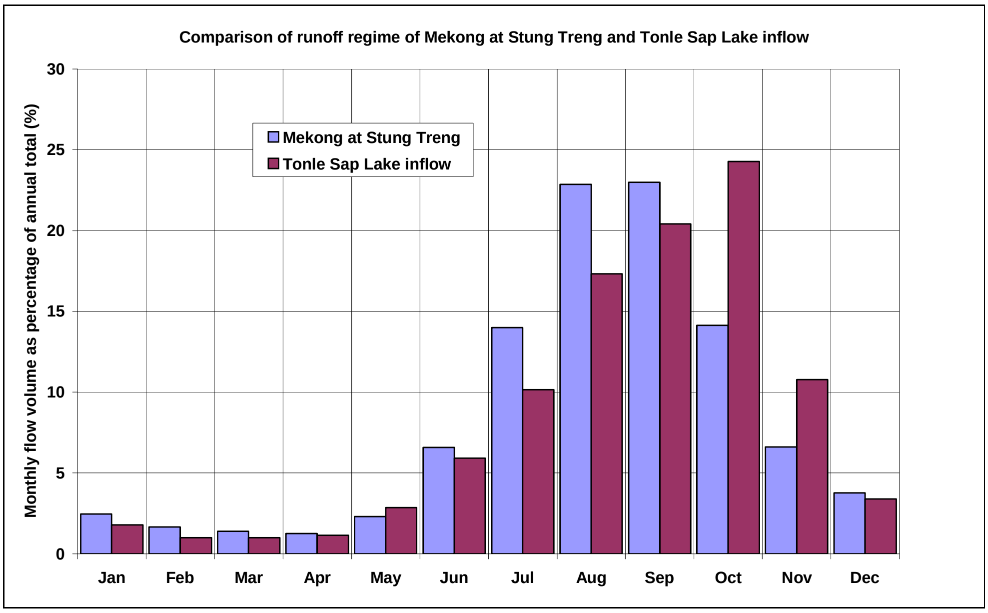


Figure 2-29 Average monthly flow regime of the Mekong River at Stung Treng and of the Tonle Sap Lake as percentage of the annual totals.

Tributary inflows to the Mekong River

Apart from the inflows to the Tonle Sap Lake, the Delta Model also requires inflow series data for the Prek Te, Prek Chhlong, Prek Thnot, East Vaico River, and West Vaico River tributaries. The daily water flow series for the period 1985-2006 is available from the DSF files created by the SWAT model. Since the SWAT-series data show no correlation with the flows in the Mekong River, a pragmatic approach was used to extend the data series; applying a repetition of the time series 1985-2006 also for the years 1910-1984 to create a 97-year series.

Rainfall

Daily rainfall series of 9 locations in Cambodia and of 5 locations in Viet Nam are required as inputs to the hydraulic model for the Mekong Delta. Data is available for these locations for 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, such as in Can Tho in 1985. Analysis of this data shows weak or no correlation between that seasonal rainfall at the selected locations with water inflows to the Tonle Sap Lake, and no correlation at all with the flows in the Mekong River. As with tributary inflows, a repetition of the series 1985-2006 was applied to create a data set covering the years 1910-1984.

Evaporation

The model requires evaporation data from the same locations as the rainfall data. For the locations in Viet Nam, a daily data series is available from 1985with the exception of 2002. The data 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 where daily evaporation data was unavailable.

Water use

There are 128 different sites included in the Mekong Delta model where water is used for agriculture, domestic and industrial purposes. The variation in water use 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 water usage amounts to 16.5 Billion Cubic Meters (BCM). During the flood season, the demand for water is about 4.4 BCM in total, i.e., less than 300 m^3/s.

Sea boundary characteristics

There are 19 different water level boundaries defined in the Delta Model. These boundaries are taken from hourly observations made at the 6 monitoring stations listed in Table 2-8. The hourly observations used in the Delta Model are records taken from the year 2000. A comparison with historical records demonstrates that the use of this series does not introduce a bias in peak water levels.

Table 2-8 Overview of water level monitoring stations at coastal boundaries in Viet Nam.

Monitoring station	River	Province	Remark
Rach Gia	Cai Lon	Kien Giang	Waters drain into the Gulf of Thailand
Song Doc	Song Ong Doc	Ca Mau	As above
Ganh Hao	Ganh Hao	Ca Mau/Bac Lieu	Waters drain into the East Sea
My Thanh	Bassac	Soc Trang/Tra Vinh	Waters drain into the East Sea
Ben Trai	Cua Cung Hau	Tra Vinh/Ben Tre	Southern Mekong River outlet, with waters draining into the East Sea
Vam Kinh	Cua Dai	Ben Tre/Tien Giang	Northern Mekong River outlet, with waters draining into the East Sea

2.6.5 Flood hazard assessment

The ISIS model is used to simulate data series throughout the Mekong Delta based on regression equations and the use of the 97 year water discharge data series at Stung Treng. The main outputs of the model are estimated water levels at all river sections and floodplains in the model area. For each location, the series of 97 annual maximum water levels can be derived using the model outputs. The estimates of the probabilities of exceedance of the water levels can then be generated using the Gringortens formula (see equation (2.5) in Section 2.3.4). Since the data series of annual flood maxima covers close to 100 years, the estimated 100-year cycle of water levels is, by definition, approximately the same as the maximum observed water level over the 97 year period of actual data.

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 parts of the Mekong River Basin (see previous sections). The water levels are calculated for (among others) ISIS river cross-section nodes and reservoir nodes. A cross-section is an imaginary 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), which is an area of the river (mostly embanked) with an even water level. A GIS can be used to identify areas of the river where water levels are even, through a process of interpolation of the node water levels. (See Figure 2-30.) After subtracting the ground levels (+MSL, stored in a Digital Terrain Model (DTM) or Digital Elevation Model (DEM) the water depths, i.e. the flooding levels, can be determined. (See Figure 2-31 and Figure 2-32.) Flood maps can also be produced for various flooding frequencies (return periods or probabilities), for annual-maximum levels and for seasonal maximum levels up to the first of August. Flood damage and flood risk maps for agriculture, housing and infrastructure are based on these water depth maps and on economic/ damage data.

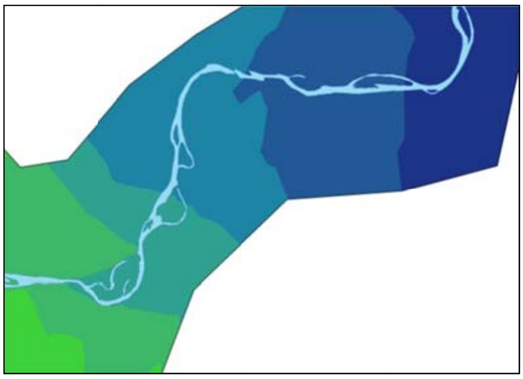


Figure 2-30 Water level map, based on interpolation of ISIS nodes.

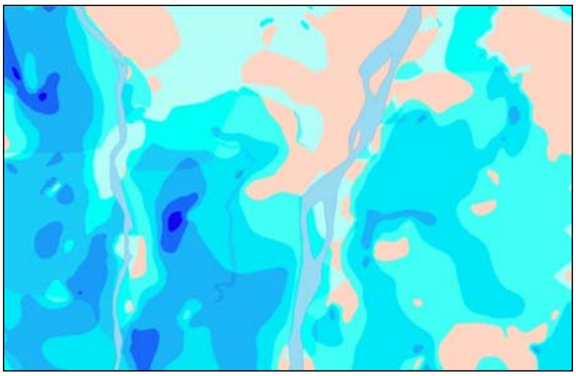


Figure 2-31 Water depth map, generated from a water level map subtracting the DTM (ground) levels.

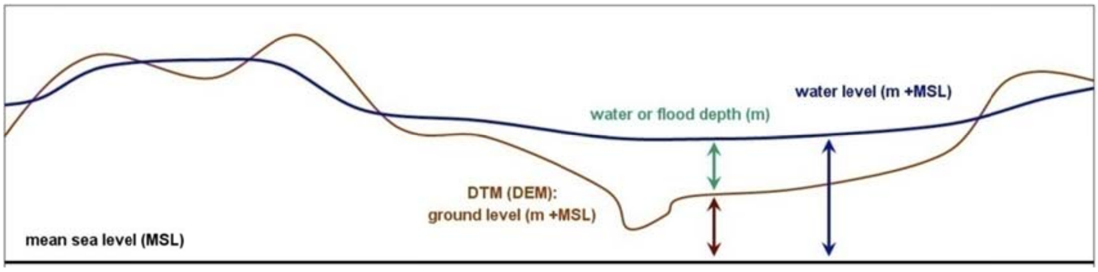


Figure 2-32 Depiction of how water or flood depth is obtained by subtracting the ground level (DTM) from the water level (hydraulic simulation + GIS interpolation).

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 MRB is Indian 1954, while the standard MRC projection is UTM (northern zones). As the data sets from the hydraulic model use another datum, they need to be 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 'geo-referenceable' table;
B: Creation of spatial data; and
C: Creation of flooding maps.

The three main steps (see Sections 2.7.2, 2.7.3 and 2.7.4) and corresponding data sets and tasks are schematised and numbered in the flow chart in Appendix 5. The description below follows the numbering in the flow chart.

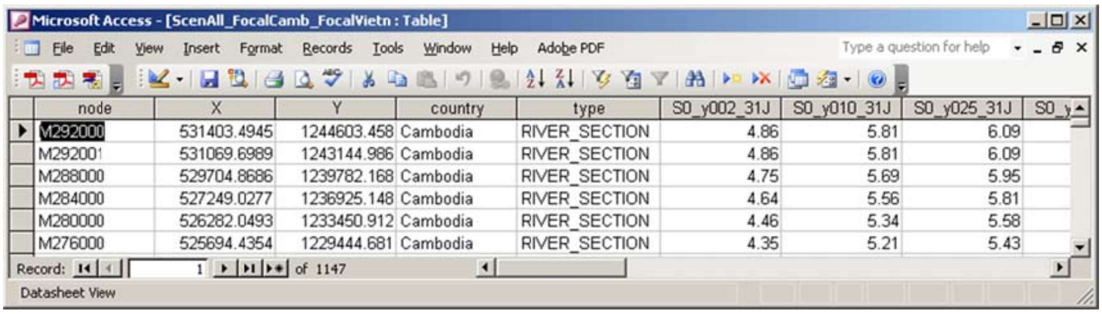
2.7.2 Transfer of modelling results (A)

The transfer of modelling results (water levels) into a 'geo-referenceable' table involves the following steps:

A-1, A-2:
The hydraulic model, ISIS, can export the (unique) node identifier 'ID's' (names), their x/y-coordinates, and the calculated water level per node, into a comma-separated file (CSV).

A-3, A-4, A-5:
Some of the ISIS output can be processed with MatLab software, which provides suitable tools to determine e.g. the maximum water levels associated with certain return periods. Otherwise, the data can be presented on a spreadsheet and transferred to a database, like Microsoft Corporation's Access.

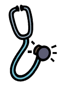
A-6, A-7:
In Access, separate data sets can easily be combined into one table by using Queries (based on node ID's). Placing all of the data in one table reduces the work to be done in the GIS, explained in the following steps.



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 information 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 information in a data-file (DAT-file, ASCII format). The cross-section nodes have x/y-coordinates specified. The reservoir nodes also have 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.

Due to the lack of coordination with the DAT-file, the GIS-files from ISIS need to be used for the reservoir outlines. For the cross-sections, either the DAT-file or the (not always updated) ISIS GIS-files can be used. Extracting the relevant cross-section information from a DAT-file for use in a GIS is time-consuming (the DAT-file for the LMB contains more than 170,000 lines).

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

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

B-2, B-3, B-4:
ISIS calculates with (among other data) reservoir nodes and (river) cross-section nodes. (See Figure 2-34.) For the creation of maps, these two types of nodes need different processing. To accommodate for this, the Access data-table can be split in two with one table containing the reservoir nodes, and another containing the cross-section nodes. These two tables may be split again for examining different areas inside the basin (e.g., focal area in Cambodia and focal area in Viet Nam).

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

Figure 2-34 ISIS schematization. ISIS calculates with (among other data) reservoir nodes (+) and cross-section nodes (dots). A spatial component of ISIS contains cross-sections (blue lines) and reservoirs (purple polygons).

Creating a river cross-section point data set for interpolation

To create a data set of water levels or water depths that covers every location within the area under study, the node information from ISIS needs to be prepared for interpolation and conversion to a 'raster' using both 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 for which ISIS water levels have been calculated. In such case the following steps need to be conducted for the cross-sections:

B-9: In ArcGIS, a buffer of 150 m should be 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 should be copied to the buffer. If more than one node falls inside the buffer, the buffer should be deleted.

B-12, B-13:
The polylines inside the (remaining) buffers should get the same data as the buffer (= data of the cross-section node) attached.

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

- Creating a reservoir point data set for interpolation

Like the cross-sections, reservoirs represent horizontal water levels. Two of the same steps apply here as for the cross-sections.

B-11, B-14:

The reservoir polygons with only one ISIS reservoir node inside use the data of that node. If more than one node falls inside, the reservoir polygon should be deleted (in this case, the GIS-files have apparently not been 'synchronised' with the DAT-file). The resulting layer contains reservoir polygons with the information of one reservoir nodes attached.

There are two options to obtain the required water levels: 1) the reservoir information is merged with the cross-section information for joint interpolation to obtain the associated 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 flood mitigation scenario considered, 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 if option 2 is selected.

B-16: Each polygon should be converted into a series of points on the polygon outline (e.g., 15 points are sufficient). These nodes have the same data as the polygon and also 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) should be put into one layer (C-1). This layer (which may be split into, for example, a Cambodian and a Vietnamese layer) should be the basis for water level point interpolation (See Section 2.7.4).

2.7.4 Creation of flooding maps (C)

Water level (flooding) maps can be created in two steps: 1) the point data, with water levels (B-15 or B-17, depending on the chosen option), can be interpolated to create a raster that will cover the area(s) under study, and 2) the reservoir polygons can be converted into a raster and used to replace the raster resulting from step 1.

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, including: Inverse Distance Weighting (IDW), Spline, Kriging, and Natural Neighbours (NN). Although no in-depth analysis has been done, the Natural Neighbours (NN) method and the Inverse Distance Weighting (IDW) method appear to be suitable for the LMB. Both the NN and IDW methods allow for the option of including 'barriers' or 'linear discontinuities, such as embankments or canals in the interpolation. Details on the interpolation methods can be found on the Internet.

Flooding maps can then be created by following the steps presented in Appendix 5.

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 (the raster size is 50 m as in the DTM), resulting in a rectangular raster covering the area with the points used as inputs.

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

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

C-7: The polygon-based raster (reservoirs; C-6) can replace[2] the point-based raster (cross-section nodes, reservoir nodes; C-3) to assure that the reservoir areas do, indeed, have a horizontal water level.

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

The raster can then be 'cut out' more precisely using a "mask" (polygon) with the exact delineation of the area of interest (or using several masks to delete various areas that are under study). The result is a raster of the area(s) under study with each raster cell (50 m 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.

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

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

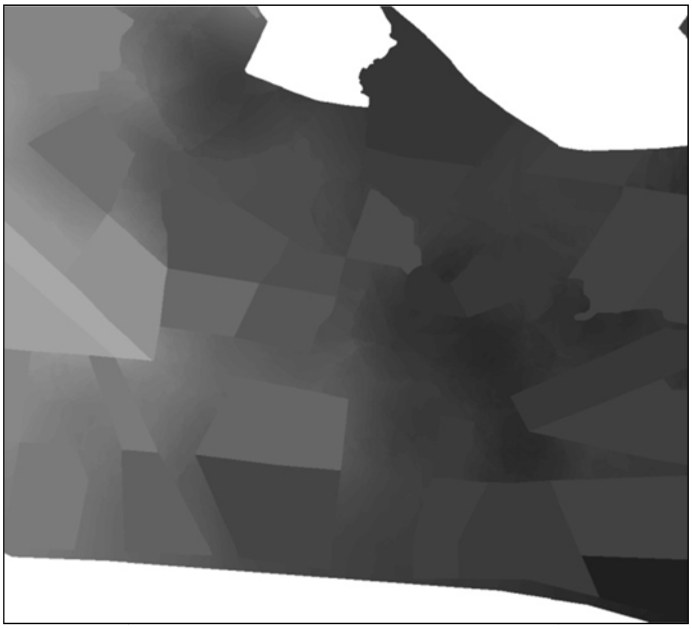


Figure 2-35 Example of a raster, with the reservoir raster (angular areas) superimposed on the point based raster.

The previous steps result in a flood (water) depth map; an example is depicted in Figure 2-36.

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

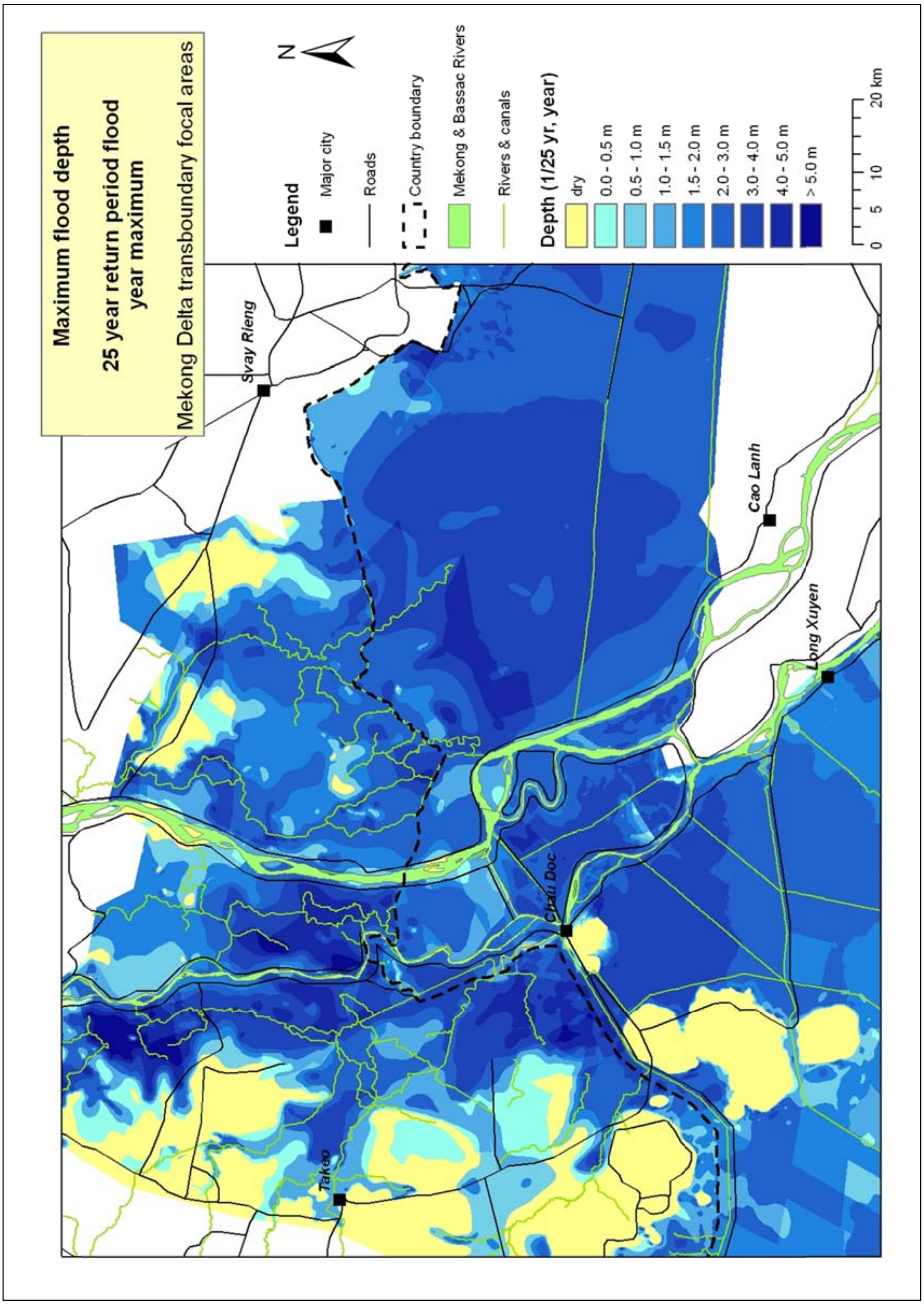


Figure 2-36 Example of a flood depth map, here in the Mekong Delta for a flood with a return period of 25 years.

2.7.5 Data sources

Data generated by the ISIS model (with x/y-coordinates) includes:

a) Those polygons that represent reservoirs (i.e., areas with horizontal water level);

b) Those polylines that represent river cross-sections (i.e., lines with horizontal water level);

c) Model calculation nodes for the reservoirs and cross-sections. 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 Section 2.7.3); and
d) 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 (flood risk reduction measures).

Data from the MRC/FMMP GIS includes only one category:
e) DTM or DEM data. In 2009 two DTM's were being used at the MRC; *b-dtm50upd* and *dem0603*. Both are based on interpolation of 10 m contours (on some map sheets, 20 m contours), spot heights and rivers/streams (using topographical maps with ratios of 1:50,000 and 1:100,000, 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*, the areas with errors are two large areas near Kampong Chhnang and Kampong Cham. In *dem0603* many smaller areas across the LMB have errors. As *dem0603* is used in ISIS and its erroneous areas are smaller, the MRC prefers use of this DEM.

CHAPTER 3

FLOOD DAMAGE ASSESSMENT

3 FLOOD DAMAGE ASSESSMENT

3.1 Introduction

This chapter focuses on flood damage assessment. It outlines the classifications of flood damages and of 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 are presented (Section 3.5). Methods for the assessment of other types of damages are summarised in Section 3.6. Section 3.7 describes how the results of damage estimates can be presented. In order to develop damage models, data collection is also critical. This topic is treated in Section 3.8. Finally, examples of damage assessments for the LMB are presented in Section 3.9.

The next Chapter (4) explains 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, including 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 impacts on humans, their health and their belongings, on public infrastructure, cultural systems, cultural heritage, social systems, ecological systems, industrial production and the competitive strength of the affected economy. However, flooding may also have benefits and this topic is presented separately in the next Section (3.2.2).

An overview of different types of damages/consequences is presented in Table 3-1. Damage is divided into tangible and intangible damage, depending on whether or not the losses can be easily assessed physically. 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 are not traded in a market and require different methods of assessment if monetary terms are to be used as a standard for comparison. They are indicated on the table as ‘intangibles’.

Table 3-1 Classification of flood damages.

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

Another distinction can made between the direct damage, caused by physical contact with floodwaters, and damage indirectly following from a 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 social and cultural systems and 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 category 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 that have been used in the past by neo-classical economists are:

1. Direct and tangible damages

- **Damages to properties and infrastructure**
  In the targeted areas, property and infrastructure damage can include damage to houses, schools, offices, commercial and industrial buildings and installations, hydraulic works, energy, transportation and other public infrastructure, and supplies/assets of individuals and businesses. The extent of these damages is usually proportional to the magnitude and duration of the flood. Damages to property are usually calculated as 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 larger the submerged cultivated area that sustains losses. However, if floods occur after harvesting, there may be no crop damage at all. Damage to livestock and agricultural equipment also depends on the magnitude and duration of the flood. These damages are measured by the costs of replacing livestock or the loss of income due to a distress sale. The damages to agricultural equipment/tools are the costs of replacement or restoration of these assets.

2. Indirect and tangible damages

- **Costs of temporary relocation and rescue**
  The costs of relocation and rescue are incurred by local government agencies and non-governmental organisations (NGOs) before, during and after floods to support affected people living during the flood and recovering after the flood.

- **Costs of cleaning and sanitation**
  Cleaning and sanitation expenses incurred after a flood are mainly labour costs borne by individuals, households, enterprises and institutions to clean their houses and buildings.

- **Income losses and higher costs of living**
  Losses of income due to disruption of economic activities and/or services by floods effect: (i) individuals, landless labourers, families and enterprises; and (ii) large commercial and industry enterprises that have been partly or fully closed for some period of time during high flood water levels. Higher costs of living due to temporary relocation, the purchase of food and other items that otherwise would be available from a family farm of household,

[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.

lack of basic supplies as safe water and electricity, and additional costs for transportation and daily activities all fall into this category.

- **Costs of illness**
  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. Health costs due to flooding affect humans and livestock are related to worsened environmental conditions and increases in water-borne diseases. These costs include additional healthcare costs for families and individuals, and additional expenditures by local government for disease prevention and treatment, as well as for sanitation control during a flood. Methods for the estimation of loss of life are briefly discussed in Section 3.6 as an example of measurement of one of these categories of other costs.

- **Other costs:** Other categories are elaborated by specialists in other fields. Some of these are becoming increasingly important in assuring that the measures meet concerns in international laws and treaties and particularly for sustainable development and rights protections during disasters like flooding. Other important indirect damages include environmental losses, e.g., due to pollution, and societal disruption in general. The latter include loss in social stability, problems in income distribution and loss of confidence in government, negative impacts of flooding on tourism revenue, loss of income or revenue for people or enterprises outside the target areas, and other forward and backward economic linkages. These are omitted from the study.

3.2.2 Flood benefits

Flooding in the MRB causes not only damage, but also benefits. Since these benefits can offset the damages, it is important to take these into account in damage assessment. Flooding has an important and beneficial role in maintaining natural fisheries, wetlands, and soil fertility. Flood control measures need to take these into account. Benefits can be measured in the following areas:

- **Fishery sector**
  Flood water provides habitat for fish breeding, nursing and growth. Natural fish stocks are an important resource for residents of the LMB; particularly in Cambodia and Viet Nam. Low flood levels reduce natural fish stocks. Though benefits depend on the magnitude, timing and duration of flooding, there is generally a direct relationship between flooding and natural fish stocks.

- **Agricultural production**
  Flood waters have a number of agricultural benefits. They: (i) brings sediment to the floodplain especially boosting the fertility of acid sulphate soils; (ii) flush toxic substances from cultivated soil; (iii) kill the rats and other pests; (iv) speed up the process of plant waste decomposition; (v) improve soil structure; and (vi) promote soil fertility. This impact can be measured by comparing harvests in years of different flood levels.

- **Coastal land expansion**
  Flood water brings sediments to river mouths in Viet Nam, slowly expanding the Delta's land area into the sea. This can easily be measured and valued.

- **Biodiversity conservation**
  Flooding plays an important role in maintaining biodiversity in the MRB, especially in the wetlands in the LMD. There are a number of studies on these beneficial impacts, the monetary values calculated in these studies can be applied.

In general these benefits are associated with relatively small floods and processes that occur relatively frequently (e.g., annual or seasonal floods). Extreme events that are infrequent (higher return periods) generally bring fewer benefits.

3.3 General approach to 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 geographic area of the study, b) the objectives, c) the availability of resources for conducting the study, and d) the availability of data. These factors are outlined below.

a) The geographic area

The size of the area under investigation can vary from areas of national or even international scale to local areas, hence ranging 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 method and the accuracy of the results of a specific study must match the objective of the study. If the goal of the study is 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 prioritisation of investment), more precise measures are needed. Before investing in a more precise study, one should consider whether such detail information really effects the results or decisions to be made.

c) The availability of resources

Budget or time restrictions usually limit the precision that can be achieved in a study. If only a small budget and/or little time are available, quick and easy methods and approximate measures are needed.

d) The availability of data

The effort or costs of damage evaluation can be significantly reduced if necessary data already exists. The availability of pre-existing data should determine 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, the type of data is pre-existing and available in a country or region can also have a significant impact on the choice of a method.

Selection of damage categories

A key question in damage evaluation is which categories of damages should be included. While it would be desirable to take all of the types of damages listed in table 3.1 into account in a damage assessment, this could lead to extensive and costly studies. It is often more practical to come to an agreement accepted by all stakeholders on which damage categories are the most important, seek consensus on measures of estimation if precise measures are unavailable or costly, and to focus on them to keep the analysis manageable. It is important that these selected categories constitute the largest part of the total damage. For example, in the standardised damage accounting method that is used in the Netherlands the following main damage categories are prioritised: land use, infrastructure, households, companies and 'other'. Within each of the main categories are sub-categories (e.g., agricultural use, urban use, or recreational use within the main land-use category).

Less important categories can also be included by using estimation measures, such as applying a typical damage multiplier to account for them. For "intangible" damage categories that are inappropriate to standardise in terms of market values, other measures can be chosen such as the number of lives lost. (See, for example Section 3.6 for a discussion of methods for estimating loss of life).

3.3.2 Direct damage assessment

Methods for the estimation of direct economic damage to physical objects, such as structures and houses are well established, and the use of 'damage functions' to estimate these damages is widespread. (See below for further explanation and also Penning-Rowsell and Chatterton, 1977; Dutta *et al*., 2003; Kok *et al.*, 2005; and Jonkman *et al.*, 2008 for additional background.)

Flood damage estimates require information on the:
a) intensity of flooding;
b) number and type of land uses affected by floods, and their value; and
c) susceptibility of land uses to flooding (represented by floodwater damage function/ equations).

These factors are presented schematically in Figure 3-1 and detailed below.

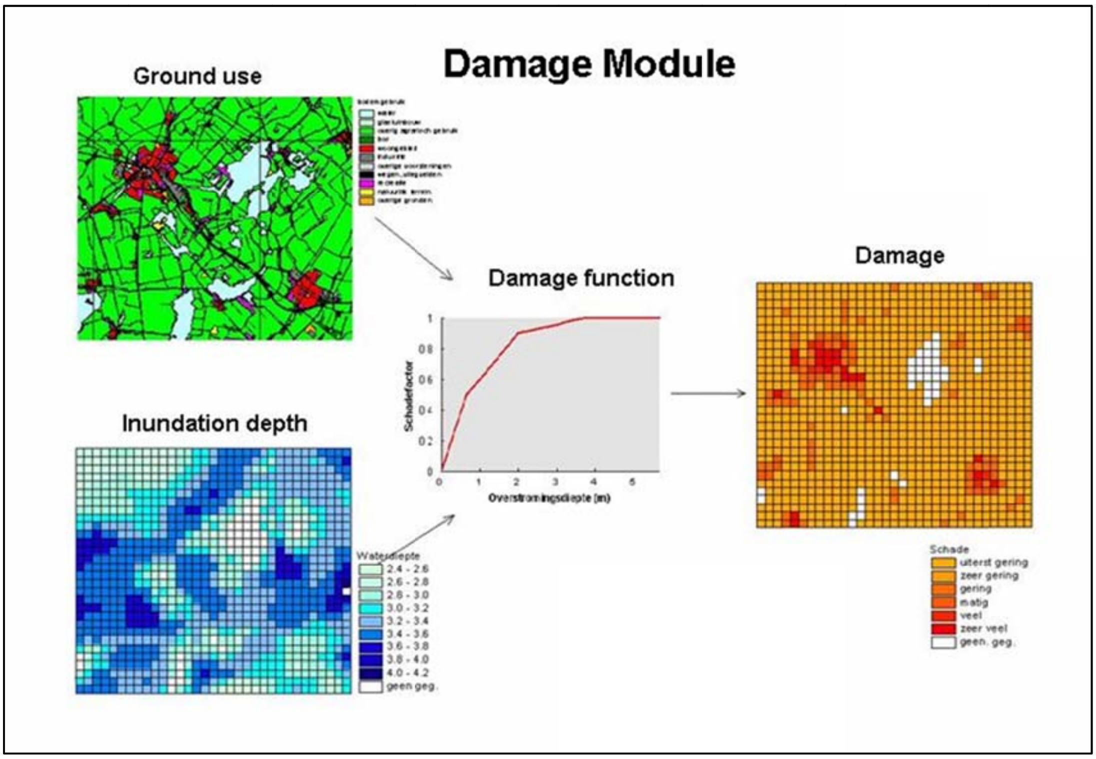


Figure 3-1 General approach to damage estimation, with the relationship between land use and flood depths used to calculate damages.

a **Intensity of flooding**

Data on the intensity of a flood, (i.e., the affected area, the flood water levels, and inundation characteristics) are essential to damage estimates. The area and depth of inundation are the most important factors in measuring intensity, but non-intensity factors such as the duration, time of occurrence, and water velocity can also have a significant influence on damage depending on the types of flood. Information on the intensity of flooding and its measurement is presented in the flood hazard assessment (Section 2).

b **Number and type of land uses affected land uses, and their value**

Different types of land uses that correspond with damage categories are a key part of damage valuation. For example, for property damage, information on the location, number and type as well as the elevation of properties potentially affected by a certain flood is a part of damage estimation. Such information is normally available in the form of primary data from field surveys or secondary data, such as public maps. General information on data collection and land use surveys is presented in Section 3.8.

c **Susceptibility of land uses to flooding**

Susceptibility relates economic damage to flood conditions. Often, (*stage*) *damage functions* using flood depth measures are the standard tools, but other flood characteristics, such as flow velocity or flood duration could also be relevant and can be added as variables in the modelling equations. Further details on damage functions are presented in Section 3.3.

It is possible to describe how these elements in the damage model can be combined to estimate the total damage in a flooded area in an equation. It is simple to describe in words for those not accustomed to mathematical symbols. The total damages are a summation of the damages at all of the specific points in the flood area and the damage in all of the categories related to the intensity and characteristics of the flood:

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

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/flood characteristics (e.g., intensity) 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 can be derived and then applied in the damage assessment (e.g., correlating historical damage data with floodwater depth).

3.3.3 Damage functions

Damage functions relate the level of damage to flooding conditions. An example of a damage function is given in Figure 3-2 for damage to homes and their contents in the Netherlands based on the 1953 flood (See Kok *et al*. (2005).) The figure shows that flood damage is total (100% or a factor of 1.0 in the chart) when water depth exceeds 4.5 meters. There is a large variability in damage functions, often different by country. For example, in the United States the Federal Emergency Management Agency (FEMA) has developed the HAZUS risk assessment software model that includes damage functions for different damage categories[4].

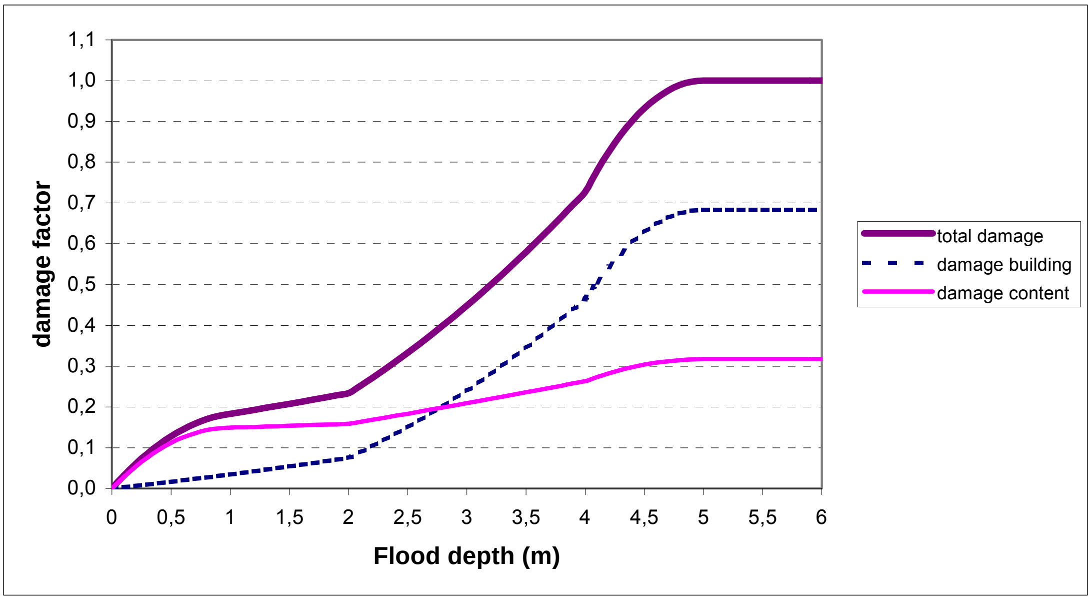


Figure 3-2 Example of a stage damage function for houses in the Netherlands (Kok et al., 2005). Note that the curves for building damage and contents show these as percentages of the total damage.

Influence of flood characteristics on the damage function

Most stage damage functions include water depth as the main determinant of direct damage. However, other flood characteristics, such as flow velocity or flood duration can also influence damages. Thieken *et al*. (2005) investigated the influence of these and other factors, including flood duration, contamination and flood damage preparations, based on data for the 2002 floods in Germany. Other factors, including psychological ones like risk perception of residents in flood prone areas and their preparedness can also influence susceptibility to risk and, hence, damage. Such factors have yet to be included in damage functions − at least explicitly.

In the application of damage functions to estimate the damage for agricultural land use (e.g., for crops or rice paddies), other factors besides flood depth are important in assessing damage. Duration of flooding, for example, can extend damage and/or prevent harvesting. There is also a seasonal effect, since damage depends on the stage at which floods occur in the growth and harvest cycle. Damage functions need to account for these damage processes (moment during the year, duration) and characteristics of the land use (such as crop characteristics).

Relationship between structural damage and economic damage

An important source of economic damage is the structural damage to buildings, especially homes. Figure 3-3 shows how economic damage is connected to structural damage. The level of structural damage caused by a flood is determined by the physical forces (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 (i.e., hydrostatic and hydrodynamic forces), and on the building's resistance to flooding. To convert the structural damage to economic estimates requires insight in the building's pre-disaster market value and the replacement cost. Apart from damage to the structure, the damage estimate in monetary terms should also include damage to the inventory of the structure (for instance items in the building).

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

In the description of damage functions, above, the economic damage estimate is described as directly related to flood characteristics. However, it is sometimes important to have insight into the degree of structural damage and the number of damaged or destroyed buildings. The degree of structural damage can be measured in the number of damaged or destroyed buildings. In Appendix 2 existing methods for the analysis of structural damage are summarised. 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.

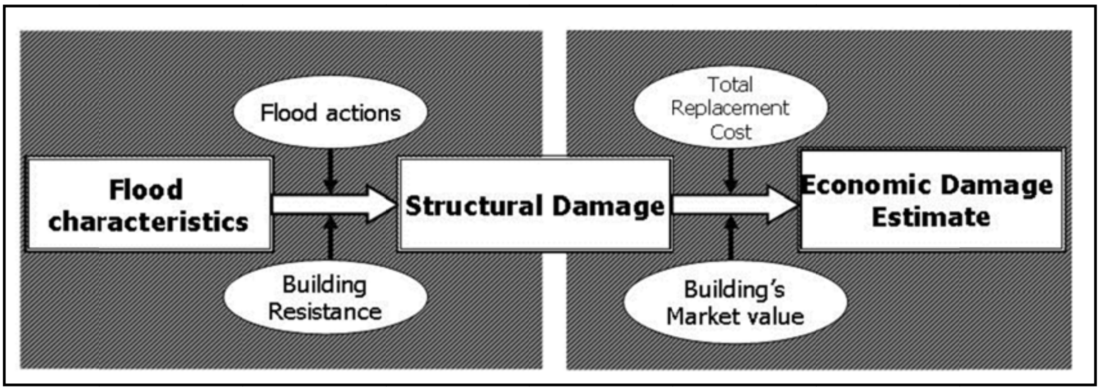


Figure 3-3 Schema of structural flood damage analysis.

3.3.4 Relative and absolute damage assessments

There are two basic approaches to damage assessment using damage functions; one using 'absolute damage' functions (a specific financial measure) and one using 'relative damage' functions (percentage loss of the total potential loss). The approaches 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 the absolute damage approach, the damage functions describe the relationship between flood depth or flood water levels and the direct monetary damage value. Surveys on damage during historical floods combined with data on inundation depth and land use information, can be used to generate equations for damages in specific asset categories (agriculture, housing, infrastructure, etc.).

2. **The use of relative damage functions for damage assessment**
   In the relative damage approach, the damage function describes the relationship between flood depth and flood damage for each specific land use category as a fraction (or percentage) of the maximum potential damage (100% losses). The total value of assets at risk is calculated by combining land use information and asset values. Then, this sum is compared to the maximum potential damage to express the damages as a percentage rather than in monetary terms.

Figure 3-4 depicts 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.

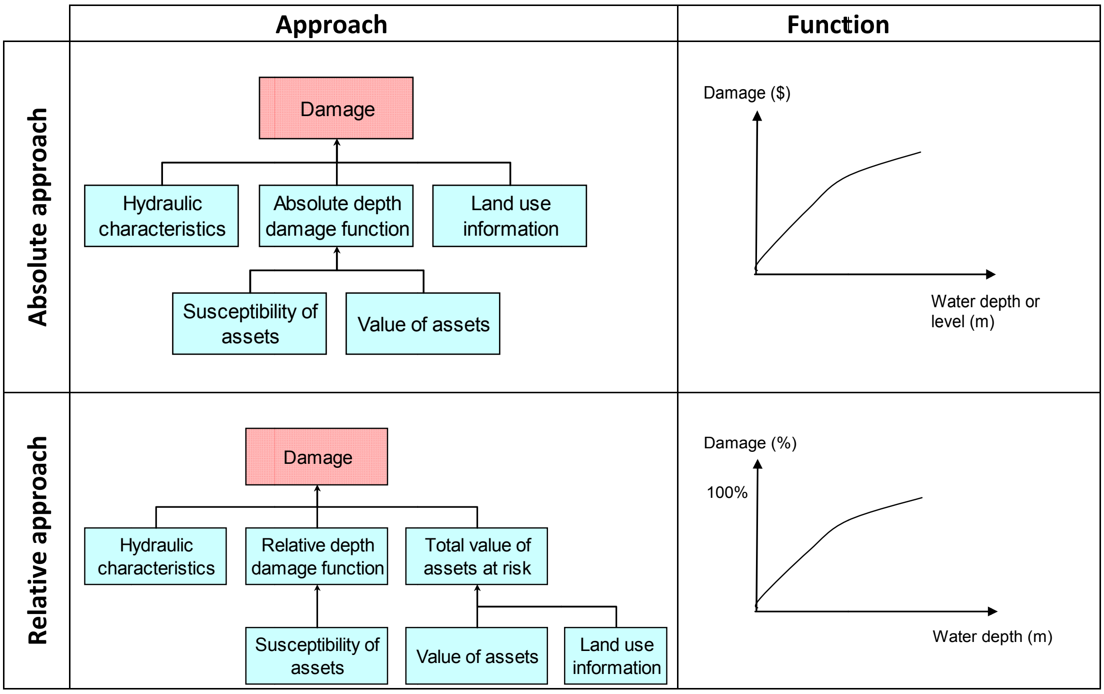


Figure 3-4 Absolute and relative damage approaches.

The two approaches have advantages and disadvantages in applicability to other areas and in adaptability to local data.

Absolute damage functions are specific to the areas where they have been derived. For each new region, data is required to derive the specific absolute damage functions for that area. Relative damage functions are more generally applicable since they look at damage impacts on land-use categories. 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, relative damage functions can only be extended to other areas where damage processes and susceptibilities are similar (e.g., floods to similar agricultural lands and structures). The absolute damage approach is thus more suitable when large regional differences exist in the above factors.

Absolute damage functions are also advantageous where a comprehensive set of absolute damage functions already exists. If on the other hand, detailed data on asset values is easily available, the relative damage approach may be more convenient.

Note that for both approaches, the varying levels of detail at different geographic levels can distort the analysis and hide errors. If data at the commune level is combined with data at the district level and the results are presented at the commune level, this kind of 'false' accuracy is likely.

3.3.5 <u>Assessment of indirect damages</u>

Indirect damages include such categories as 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. The loss of production of companies affected by flooding, induced production losses of their suppliers and customers, the costs of traffic disruption or the costs of emergency services are also included in indirect costs.

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. If an important airport or road network is affected by flooding and has to be closed for a long period or if a cluster of important companies is affected, these losses can be substantial. This effect can estimated using a model that includes the existing network of linkages within an economy. The method relies on "input-output" models. (See, for example, Van der Veen *et al*. (2003)). Yet, these approaches are being researched and published in academic literature but have not yet developed for practical use.

Today, in practice, 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.

Surveys can also be useful to determine the indirect damage categories and the damage costs for indirect damages. Eventually, this offers data that can demonstrate a ratio between direct and indirect damages. With such a 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 LMB are found in Volume 2C.

3.4 Damage models

For consistent decision-making it is desirable to have a standardised approach for damage assessment on a wide level, such as for a river basin or at the country level. With this in mind, governments in several countries have developed standardised methods and software tools that can be used across countries 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), and the standardised damage model developed in the Netherlands (Kok *et al*., 2005). In these approaches, the land use data and damage functions are included in a computer model, such that the damage can be easily estimated if information for a certain flood scenario is available. Based on the approach developed in the Netherlands, a more generic model/tool has been developed under the name of DACA (Damage and Casualties Assessment) and has also been tested in Thailand – 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 need to be processed;
- The underlying data on land use and values of assets is available in GIS format;
- There may be a large number of calculations and/or different scenarios being compared (e.g., situations with various alternative protection schemes and measures).
- Different areas considered in the model use the same equation for damage estimates (i.e., the land uses and housing types are comparable).

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

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 uses and their economic value, as well as the different characteristics of flooding scenarios. The tool calculates direct damage, production losses and indirect damages, in ways that tie damages to their origins and that are designed to aid decision makers in land use planning, flood management and mitigation planning DACA also pushes governmental agencies and departments towards more collaboration due to its reliance on a standard approach and transparency in methods and data.

The Thai Department of Water Resources has tested DACA in a pilot area in Thailand; the province of Chiang Rai, which includes several rivers.

Source: "Development and Use/Demonstration of DACA in de LMB" (Anonymous, 2009; Leenders *et al*., 2009).

3.5 Economic and financial issues in damage assessment

Within the context of damage assessment the economic valuation of damages and land use values are important. Some of the main (and, yet, fully unresolved) issues are summarised 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

There are different perspectives on damage appraisal, starting with the distinction between financial and economic valuation. Financial evaluations consider damage from a perspective of a single person or firm, neglecting public affairs and focusing on the actual financial burden on an individual or firm. Economic evaluations are broader. They seek 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 used for public policy.

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 what economic value to assign to them.

The basis for valuation favoured by neo-classical economists 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, it is widely recognised that several effects "distort" market prices and need to be taken into account in damage estimation[5].

[5] Since these ideal conditions are never fulfilled in a real-world market, neoclassical economists try to calculate what they call the ideal 'shadow price' of the good under examination. They translate market prices into shadow prices by trying to account for some of the distortions that are easy to measure such as taxes and subsidies ('transfer payments' to particular individuals or groups), or by trying to account for monopolistic market prices or influences of major buyers and sellers with other agendas into 'competitive' market prices that assume an 'equality' of all potential buyers and sellers.

The concept of depreciation should be applied in order to reflect the value of a good at the time when it is damaged by a flood. Replacement costs, alone, can sometimes overestimate damage, because replacement usually involves improvements while depreciation accounts for the diminution in value of something over its project usable life. Old goods which are damaged during a flood are usually substituted by new, more productive and better performing goods (Messner *et al.*, 2007).

Similarly, for a small group of irreplaceable assets, replacement cost accounting and depreciation are inapplicable and market values may not apply; such as artistic treasures, religious or heritage structures with emotional value or spiritual significance tied to the belief of a people (such as ancient trees and spirit shrines in the MRB), and forms of cultural or biological diversity that may be key to survival of a larger system. Other standards of valuation need to be applied.

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 USD 50,000 this year could have a higher or lower price next year depending on expectations people have about the future and their willingness to consume now or later, and on other factors.

Damage values that are used in a certain damage model are usually based on 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 changes in the values and amounts of damages. Usually, economic growth increase values, but values can also decrease and damage factors can increase or decrease with changing conditions (like changing population densities), while relative values can also change.

3.6 Loss of life and health effects

3.6.1 Introduction

Apart from the estimation of economic damages, or conversion of damages into economic terms,, there are several approaches to the estimation of other damage types and/or for the calculation of damages in different measures. Loss of life and general health impacts are an easy example. In this Section some existing approaches and literature are briefly summarised.

Note that while these approaches and methods are not yet part of standardised methods used by those currently empowered to conduct damage assessments[6], this should not reflect on their importance.

Note that when damages like the loss of life are expressed in terms of economic damage (e.g., a monetary value or damage sum per fatality), there is no uniform approach given that different societies, different decision-makers and different disciplines apply different values to human life. Valuing the loss of life directly raises ethical and political questions that are not easily visible when economic 'market' valuations are used for other damage categories. To avoid these discussions, those currently conducting damage assessments prefer to assess the loss of life separately and independently from the economic damages.

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

3.6.2 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 loss of life in a given area:

1) Information regarding flood characteristics;
2) An analysis of the exposed population and evacuation procedures;
3) An estimate of the mortality (percentage of deaths) among the exposed population.

The application of these steps and the level of detail of the analysis depend on the type of flooding studied. For any application, the output of hydrodynamic flood simulations can be used to estimate flood characteristics (see Section 3.3). For large-scale flooding associated with dyke breaches (such as in the Netherlands or New Orleans), steps 2 and 3 can be applied without a high level of detail. General estimates of the possibilities for evacuation of the population can also be used. In this analysis the effects of warning systems also need to be taken into account. An example of 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 reach a safe place.

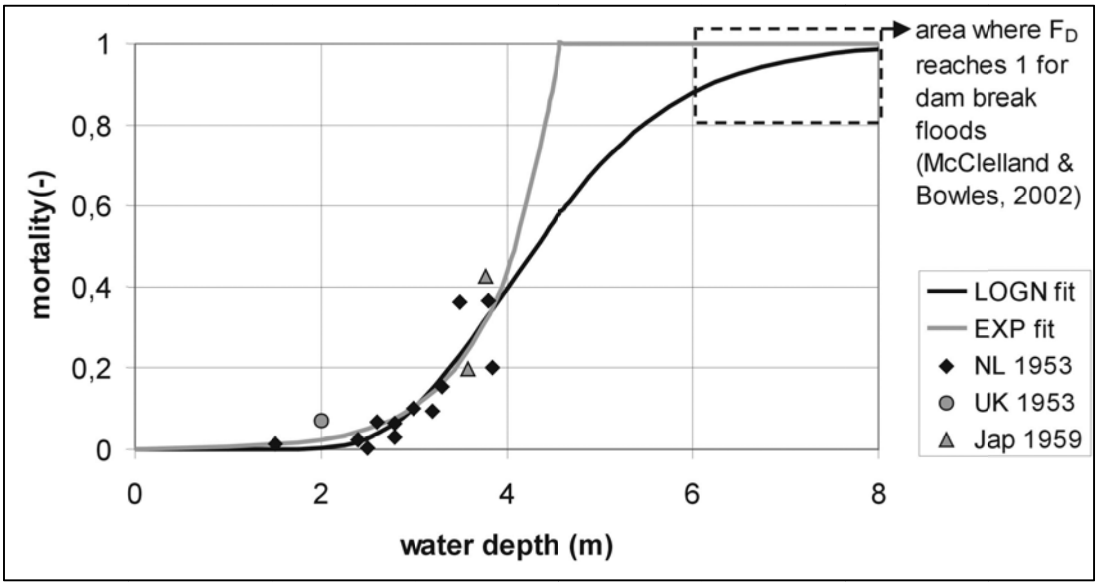


Figure 3-5 Example of a mortality function derived for large-scale flooding in the Netherlands (Jonkman, 2007).

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, depth-velocity multiples 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 of relatively low depth-velocity multiples. The critical depth-velocity multiples for maintaining vertical stability range from 0.6 m^2/s to about 2 m^2/s. This means that a flow with a 1m depth and a velocity of 1 m/s would most likely lead most individuals to be swept into the floodwaters. 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 and their importance is highly dependent on (among other factors), general health and medical infrastructure in the area (before and immediately after the flood), climatic factors, type of floodwater (fresh water or salt water) and duration of flooding, There is no standardised approach to “predicting” these health effects. Hajat *et al*. (2004) and Ahern *et al*. (2005) offer a comprehensive overview of the available information regarding health impacts of floods.

In addition, there are often longer term psychological health effects as a result of flooding. There is also evidence of a link between psychological health effects and post flood mortality (see, e.g., Bennet, 1970).

Flooding can also have adverse effects on the environment and the social system. These damages are generally analysed by means of qualitative/descriptive methods and require the hiring of appropriate specialists.

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 amount for the flood scenario (in USD or another currency);
- The absolute damage value by category and the distribution of the total damage over the categories;
- “’Underlying’ data (raw data that has already been presented in monetary damages as part of the overall damage) such as numbers of flooded houses, or flooded hectares of farmland;
- Damage per hectare as an indicator of “damage density” in the area.

As the effects of a flood are spatially distributed it can be relevant to present maps that offer information on the damages. Geographical information systems (GIS) facilitate this. (See Section 2.7). The resolution of these maps and the level of spatial detail depend on the (geographic) scope of the analysis and the data available.

Damage per hectare can be determined precisely if the underlying data (e.g., land use and values) are available in a high level of detail per unit area. It is also possible to average damage per hectare over a larger area when damage functions are available for a larger area, e.g. a district.

Example of a damage assessment

A damage assessment for a flood scenario in the Netherlands is offered below as an example. This flood scenario depicts the flooding of the densely populated South-Holland province due to an extreme coastal flood. This scenario describes the flooding of an area with one million inhabitants where flood consequences can be serious. The total damage for this scenario is estimated with the Dutch standardised damage model at roughly 23.7 billion Euros.

Table 3-1 offers 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 Province in the Netherlands (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%

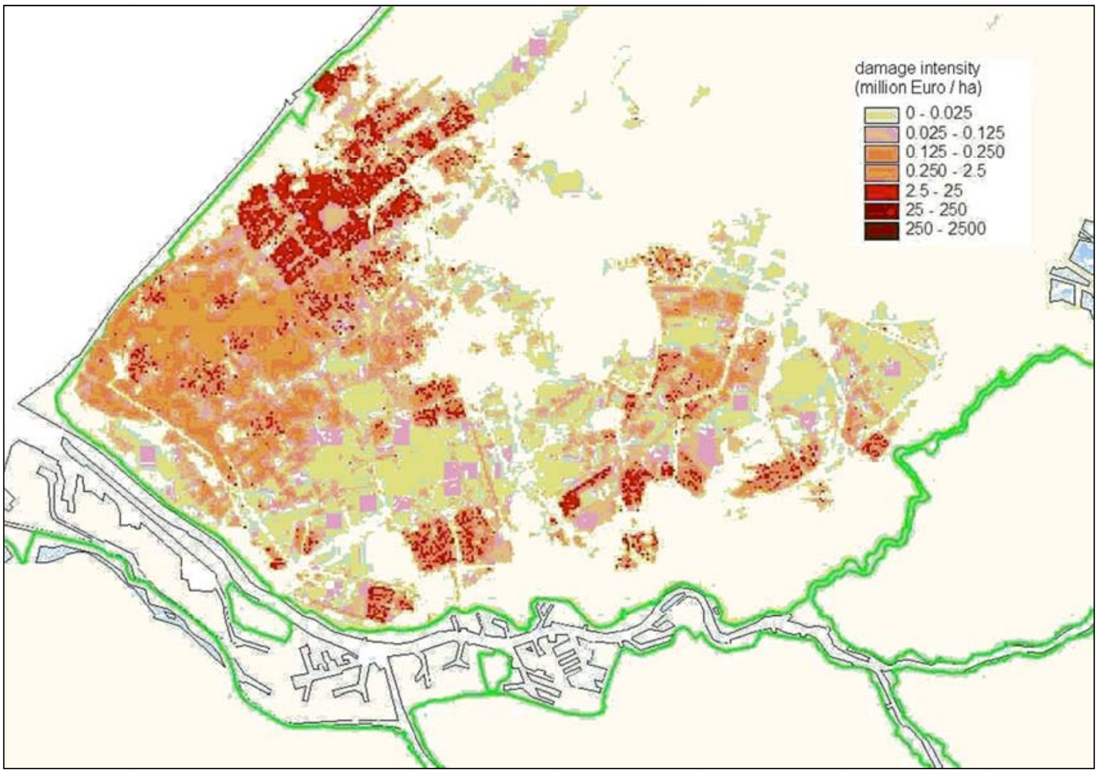


Figure 3-6 Damage intensity per hectare of the flooding of South Holland Province in the Netherlands.

3.8 Data collection

If no damage functions are available, they need to be developed using data from historical flood events. The table below offers a general overview of the damage categories, their definition, the type of data and sources that could be utilised to collect data, and a summary of measurable items that can be used as data. The table is based on the presented general classification of flood damages (see Section 3.2.1). As part of this data collection, data on benefits of flooding should also be included.

The table below can be seen as the model list of information for several items. In practice, however, data on many of these items are still often impossible to collect given the limited availability of secondary data, time and budget constraints. Section 3.9 shows 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 missing persons due to the flood	Secondary data	District/Provincial level direct flood damage reports	- No. of deaths - No. of injuries - No. of missing persons
Damage to properties and infrastructure.	Estimated replacement or restoration cost of an affected structure and inventories in the targeted areas such as houses, schools, offices, commercial and 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 - Other items. based on the actual indicators that are available in the Provincial and District damage reports
Crop damages	Agriculture land inundated or 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 sales			- No. of dead poultry, large and small livestock
Damages to fishery	Damaged aquaculture and fishing equipment			- 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 conditions of no flooding. Such costs include additional cost of health care that families and individuals spend 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 a flood	Primary data	District, NGOs	- Transport, temporary shelter costs, costs 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 during high flood water levels		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 losses (e.g., home-based businesses, hired labour) - Loss of work 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 that otherwise would be available on the farm must be purchased			- Costs/purchases of food, water, fuel, etc.
Cost of prevention measure	Preventive measures			- Cost of sand bags, etc.
Cost of cleaning up after the flood	Cleaning of houses, shops and other buildings			- Labour costs and materials
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 savings. to fields.

3.9 Flood damage assessment in the Mekong River 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. These areas and their counties were:

Country	**Focal Areas**
Thailand:	Lower Nam Mae Kok
Lao PDR:	Bokeo province and the Lower Xe Bang Fai River basin
Cambodia:	Kratie province, Right Bank Bassac River and Left Bank Mekong River
Viet Nam:	Upper Se San River basin, Plain of Reeds (PoR) and Long Xuyen Quadrangle (LXQ)

The four delta focal areas in Cambodia and Viet Nam 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 Section 3.9.4 on 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 of Koh Andet, Koh Thom and Kampong Trabek. More information on the damage assessments for these districts can be found in the Volume 2C "Flood Damages, Benefits and Flood Risk in Focal Areas".

3.9.2 Approach and methodology

As described in Section 3.3.4, there are basically two approaches to flood damage/risk assessment: absolute damage and relative damage. In the absolute damage approach, historical damage data for an (administrative) area are used to assess the flood damage/risk in that area. In the relative damage approach inundation-damage relationships are developed on a per unit (land area such as hectares or homes) 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 (in absolute damage curves) and it should be available at government agencies (see Section 3.3.4).

For the bottom-up approach, various data sets and many processing steps are required to generate relative damage curves (see Section 3.3.4).

In this study both approaches are applied for damages to housing and agriculture. For infrastructure damage and relief costs, only the top-down approach can be applied due to a lack of adequate spatial information.

Hydrological hazard data (peak water discharges and volumes for different return periods) are of sufficient accuracy to be used in risk assessment. The methodology can usually be applied basin-wide. However, use of the data is not easy. Hydrological hazards must be converted into flood hazards (with measures of flooding depth and duration for different return periods). Limited topographical information and the lack of available high quality models hamper accurate flood damage/risk assessments. Flood damage/risk maps for LMB focal areas should, therefore, be considered with caution.

Flood vulnerability assessments have been made for a number of sample districts in the focal areas. These assessments allow for the estimate of indirect damages due to flooding in addition to reported direct damages. Damage curves could be estimated providing the relation between flood damages and inundation depth and time of flooding in certain areas.

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

3.9.3 Damage categories

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

- **Infrastructure and Relief**
  The damages combined in this category included those to facilities, equipment and materials for education, health, irrigation, bank erosion, fisheries, transport, communication, industry, construction, drinking water and sanitation, along with the costs of rescue operations, support and relief.

- **Housing**
  Housing damages measured the value of homes swept away or demolished by floodwaters, partly damaged or submerged, and those with damaged roofs, along with other private property damage such as damage to cultural and historical structures, offices, small industrial units, markets and commercial centres and warehouses.

- **Agriculture**
  Agricultural losses were measured in rice growing areas, flower and vegetable growing areas, and areas for other annual crops and perennial crops, and also included losses to large and small livestock and poultry, agro-chemicals and erosion of farm land and housing land.

The importance of these categories varies among the focal areas given their different topographical characteristics and pre-existing levels of flood protection. The rank share of each category in terms of total flood damages for the areas in the four MRB countries are presented in Table 3-4.

Table 3-4 Observed rank share of damages in the focal areas

Categories	Laos	Thailand	Cambodia	Viet Nam
Public infrastructure	3	2	1	1
Housing	2	3	3	2
Agriculture	1	1	2	3

Source: Direct flood damage inventory

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

3.9.4 Data collection and surveys

In Stage 1 of the FMMP a data collection and processing methodology was developed, which was expected to yield the required data for the focal areas, within the constraints of availability of secondary data, time and budgetary limitations. This data collection and processing methodology is summarised here.

Flood damage data is collected and flood level data is measured from various administrations at provincial, district and commune levels. At the provincial and district levels, flood damage records were collected for as many years they existed.

Households and businesses were surveyed in order to inventory of flood vulnerability characteristics and direct and indirect flood damages.

Focus group discussions in the project areas also provided insight into a range of issues such as the benefits of flooding, traditional coping mechanisms and community resilience.

One of the purposes of surveys was 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. For this purpose the 2006 flood was selected as this flood was considered the 'reference flood' given its characteristic as 'average flood'. The year was appropriate since the survey was conducted while the memory of the flood was relatively fresh.

Household and business interview respondents were asked to also estimate damages they would suffer if water levels were to reach higher levels than in 2006.

The sources of data on direct and indirect damages included interviews with officials, households, and businesses:

- **Provincial and District officials**
  Review and validation of existing data on casualties and direct damages caused by historic flood/erosion events. The data consisted of extensive listings of in-kind and monetary damages. Damage categories included educational facilities, healthcare facilities and assets, road and transport facilities, irrigation facilities, water supply and sanitation infrastructure, power facilities, and communication infrastructure.

- **Households**
  Collection of data from individual households for the 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 for higher floodwater levels, agricultural assets and incomes, measures of crop losses, livestock losses, fish/shrimp losses, other non-agricultural household income sources (e.g., home-based businesses, outside employment) and health impacts.

- **Local businesses (non-home-based)**
  Collection of data from individual businesses for the 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 collection of baseline vulnerability data and focus group discussions on preparedness:

- **Collection of baseline flood vulnerability data**
  In consultation with local district and/or commune officials and existing databases, data were assembled to document key aspects of flood and erosion vulnerability. The data included: demographic information on population composition and growth, number of

households, household assets, economic activities, poverty statistics, land ownership information, land use and cropping patterns, fisheries production, animal husbandry, and inventories of the types of structures and infrastructure in the area. In addition, the baseline incorporated data on business activities, educational facilities and assets, healthcare facilities and assets, road and transport facilities, irrigation facilities, water supply and sanitation infrastructure, power facilities, and communication infrastructure. This data feeds readily into the flood data database in addition to being useful for the formulation of flood risk management strategies.

- **Focus group discussions on community preparedness**
  The survey team facilitated focus groups with local leaders, community/mass organisations and men and women living in the study area who perform different economic activities and are of different socio-economic status. The discussions elicited qualitative information on the beneficial and detrimental effects of floods and erosion. Prior to commencing the discussions, a guidebook was prepared to standardise the approach and to promote comparisons. The focus group discussions covered the history of flooding in each area, participants' perceptions 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 these approaches a survey tool was developed. The tools consisted of questionnaires (for the first three approaches) and a guideline (for the focus group discussions). For focal areas where bank erosion is the main cause of damages, a revised methodology in order to collect data at district level for each relevant river bank section, without the need for household or business interviews or focus group discussions. The full set of tools consists of:

- Questionnaires for a Provincial and District Level 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; and
- National Report outline.

These tools were translated into local languages and spreadsheets for questionnaire analysis were prepared and provided to the survey teams, along with guidelines on how to prepare a national report.

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

Overview of data sources for damage assessment using a GIS

For the absolute approach to 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.

Table 3-5 offers an overview of the data sources used to determine flood damages in the Cambodian focal areas. Maps were produced at both district and commune levels, although the commune level data for housing damages 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: Hydrology and Topography		
ISIS maximum water levels for different return periods of flooding	Max. water levels for different seasonal periods (e.g., early flood season, rainy season) and various return periods (e.g., once every 2, 5, 10, 25 or 100 years)	ISIS hydraulic model (MRC)
Digital Elevation Model (DTM, DEM)	Topographic data for the whole MRB	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 (Japan International Cooperation Agency (JICA) land use map)	Coverage (areas) of early floods and of seasonal rice and rainy season rice cultivation	MRC GIS data, JICA
Average house values per district	-	FMMP-C2 surveys
Damage functions		
'Damage - floodwater depth' curves for damages to housing and rice harvests at the district level	Relation (mathematical function) between the local flood level (flooded areas) and the damage on housing or rice cultures	FMMP-C2 surveys

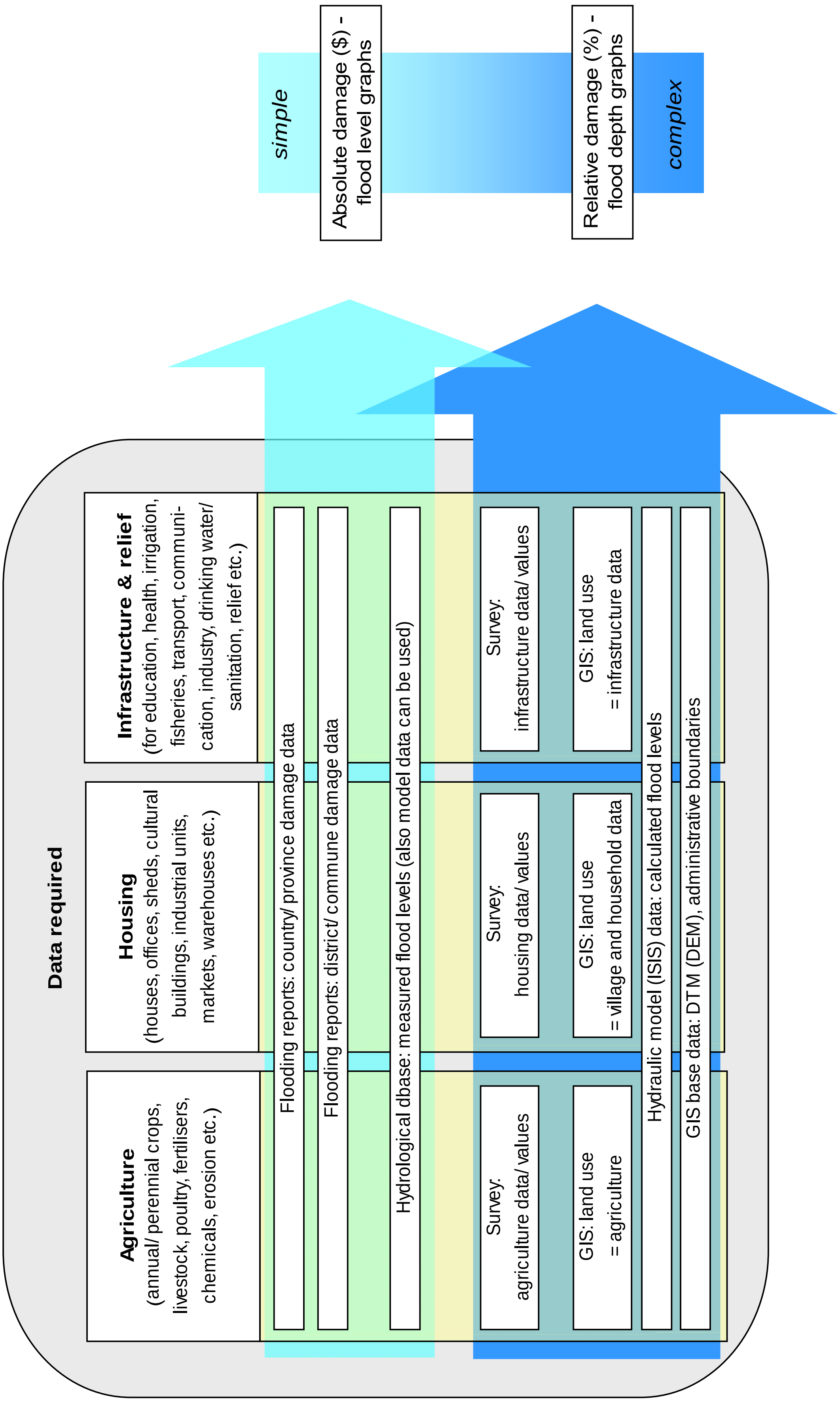


Figure 3-7 The absolute and relative flood damage assessment approaches require different data sets.

3.9.5 Derivation of damage functions

For the estimation of damages for specific floods, the following data sources and equations need to be combined (also see Section 3.3.2 for similar information):

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

During the first stage of the study (in 2008) household survey were carried out to investigate flooding extents and flood damages in several districts. This survey showed that for some items (e.g., houses, roads) the maximum annual flood depth largely determines the amount of damages. In agriculture there is a difference in damages between the ‘early flood’ crop and the ‘rainy season’ crop. Damage to the ‘early flood’ crop is mainly caused by June – July floods, while damage to the ‘rainy season’ paddies is the result of October flooding.

Government data from the commune level and MRC survey flood damage data taken from three Cambodian districts can be used to derive the relationships between floodwater levels and flood damages for the three categories of infrastructure and relief, housing, and agriculture. Figure 3-8 shows the results for Koh Andet District.

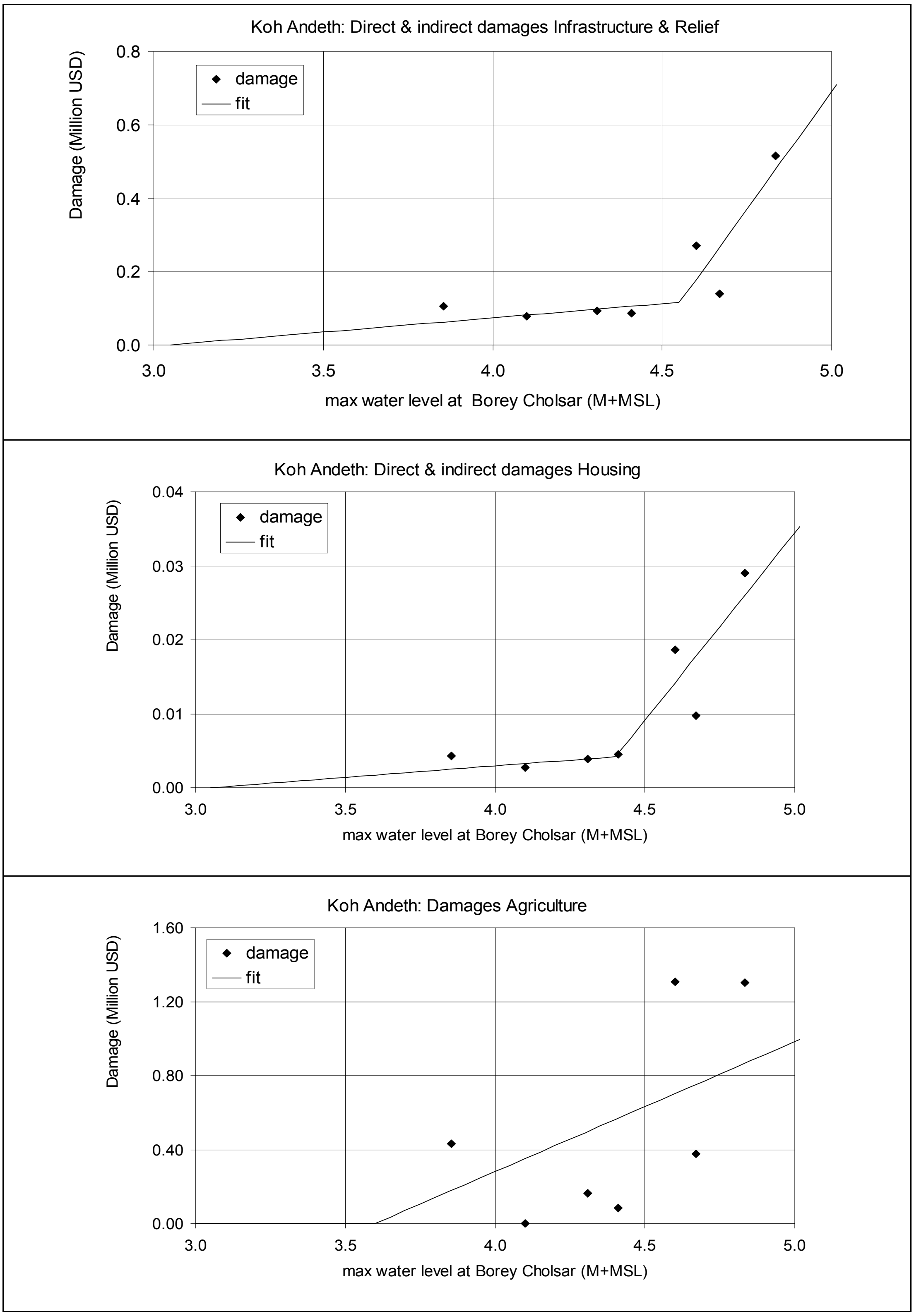


Figure 3-8 District flood damage curves for three categories of damages in Koh Andet District in Cambodia.

Damage functions for housing from the household and business survey

In addition to the damage curves derived from the districts data, damage functions were derived using data from the household and business survey that relates damage to floodwater depth in and around houses. This approach followed the "relative damage approach" (see

Section 3.3.4). Thus, functions include water depth and damage fraction. Figure 3-9 shows the relative damage function derived for housing damages for Koh Andet District.

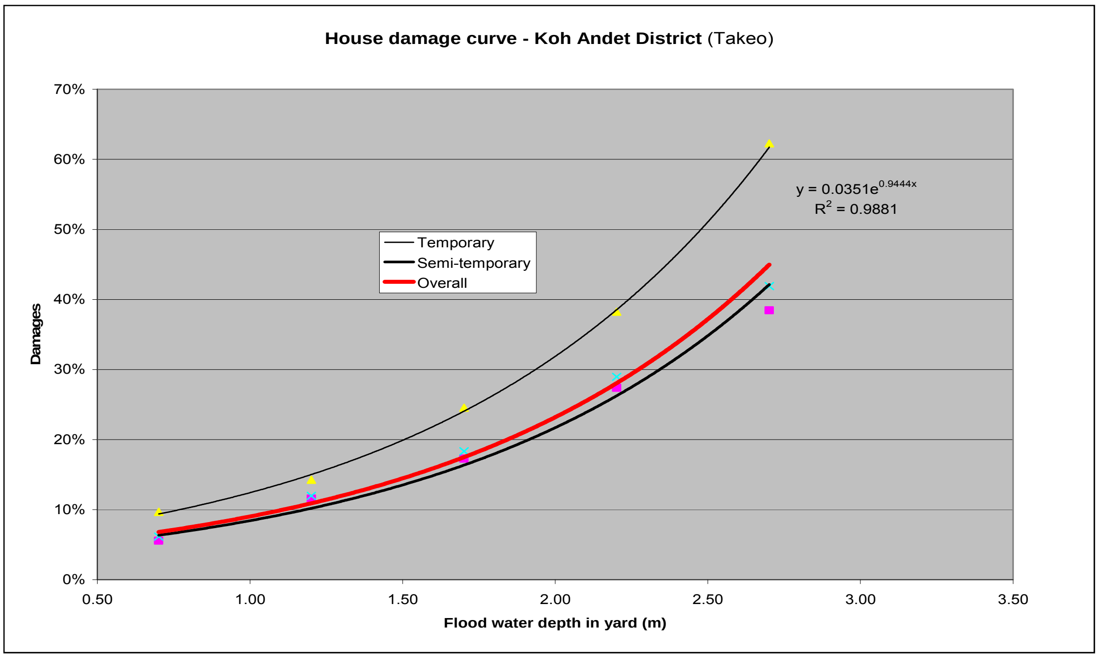


Figure 3-9 Example of a damage function for housing, relating housing damage (as % of the total value) to floodwater depths.

Damage functions for rice paddy cultivation

Based on information collected during the Focal Group Discussions, damage curves for rice crops in relation to flooding depths in the districts of Koh Thom, Koh Andet and Kampong Trabek have been estimated both for early flood season rice 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. In this case, damages were most directly dependent on the time of year in which the flooding occurred. For other regions, damage to rice paddy cultivation can also be dependent on the duration of the flooding.

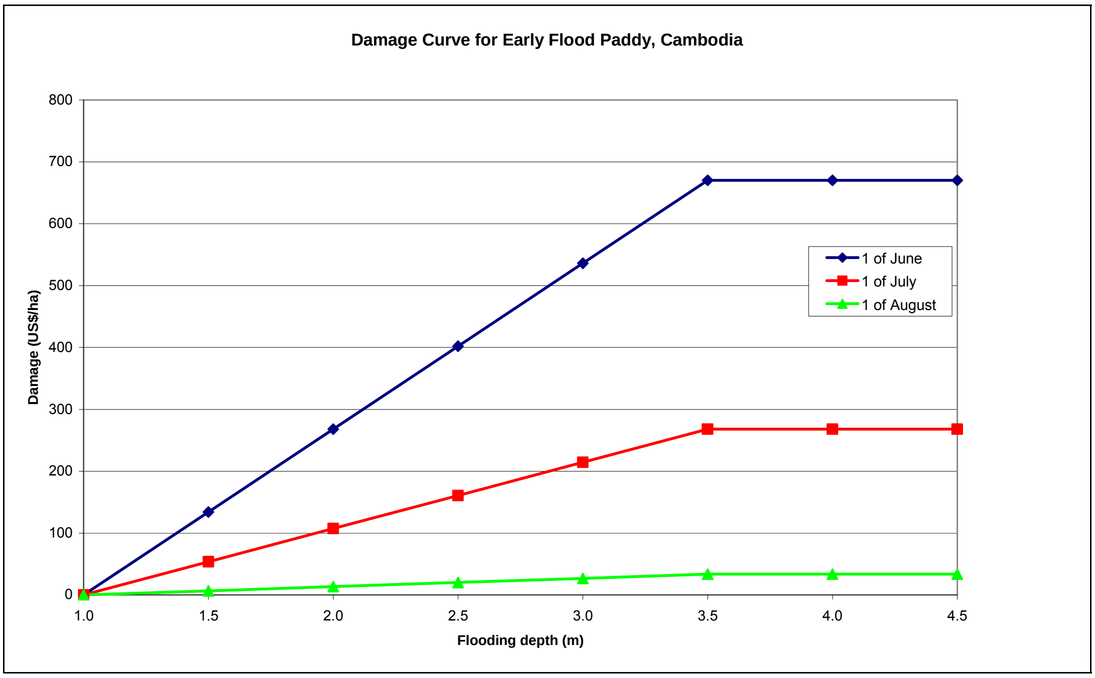


Figure 3-10 Relative flood damage curves for rice paddies, Cambodia.

3.9.6 Creation of damage maps

There are essentially two types of damage maps:

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

Examples of both and explanations of the differences are presented in Section 3.3.4.

Figure 3-11 depicts the steps for creating the (absolute or relative damage curve based) maps. The data for creating the damage maps can be combined in several ways, but no matter which analysis is used, the (absolute or relative damage curve based) maps should be similar.

1. Damage maps based on absolute damage curves

Absolute damage curves are created with historic flood damage data, relating floodwater depths for a specific area to damage (see Figure 3-8). The flood level data at the time/date of flooding can be taken from measurements at a gauge station in a district or determined using a hydraulic model covering that same district. Absolute damage curves are linked to the long-term flood levels from the same station, generating in a damage probability curve. Damage figures for certain flood return periods can be interpolated from this curve. In the example in Figure 3-11, the map shows district boundaries plus the damages for specific flood return periods in the district with the data represented on a ‘pie’ chart on one map and a bar chart on the other.

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. (For example, see Figure 3-9 (housing) and Figure 3-10 (rice paddies).) The damage data may come from a field survey or may be based on professional estimates. A land use map depicts the spatial distribution of different land use areas (such as rice growing areas). A flood map (see Chapter 2) shows the water depths in an area for a certain flood return period (based on hydraulic modelling results). By combining the land use map (e.g., rice paddies, villages or roads) with the flood map (water depths at specific flood return periods), the areas with rice paddies and certain water depths for different flood return periods are specified. This information can be combined with the relative damage curves, yielding a measure of the damages from the flooding of areas like paddies. Maps like those in Figure 3-11 shows the damages for specific flood return periods in the area with the data represented on a 'pie' chart on one map and a bar chart on the other. Maps can also be generated by shading such as those in Figure 3-12 and Figure 3-13.

3.9.7 Results of damage assessments

The damage assessments results for district level focal areas in Cambodia have been generated using the absolute damage approach. Table 3-6 shows the results for Koh Andet District for four floods of four different probabilities. The results can also be shown on maps. Figure 3-12 and Figure 3-13, for example, display the total damage and the damage per hectare for rice paddies.

Table 3-6 Damage data for different return periods for Koh Andet District. Damage is shown in million USD.

	Probability (1/year)			
Damage Category	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 probability estimates, the overall risk can be assessed, as will be shown in Section 4.5.

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 needs to be taken if data from different detail levels is combined.

To create maps based on relative damage curves, there is a need to perform a series of calculations both in a spreadsheet and in a GIS. For details on the steps and calculations in the spreadsheet, see the spreadsheet with the necessary guidelines that is included on the CD/DVD available at the MRCS FMMP Office in Phnom Penh.

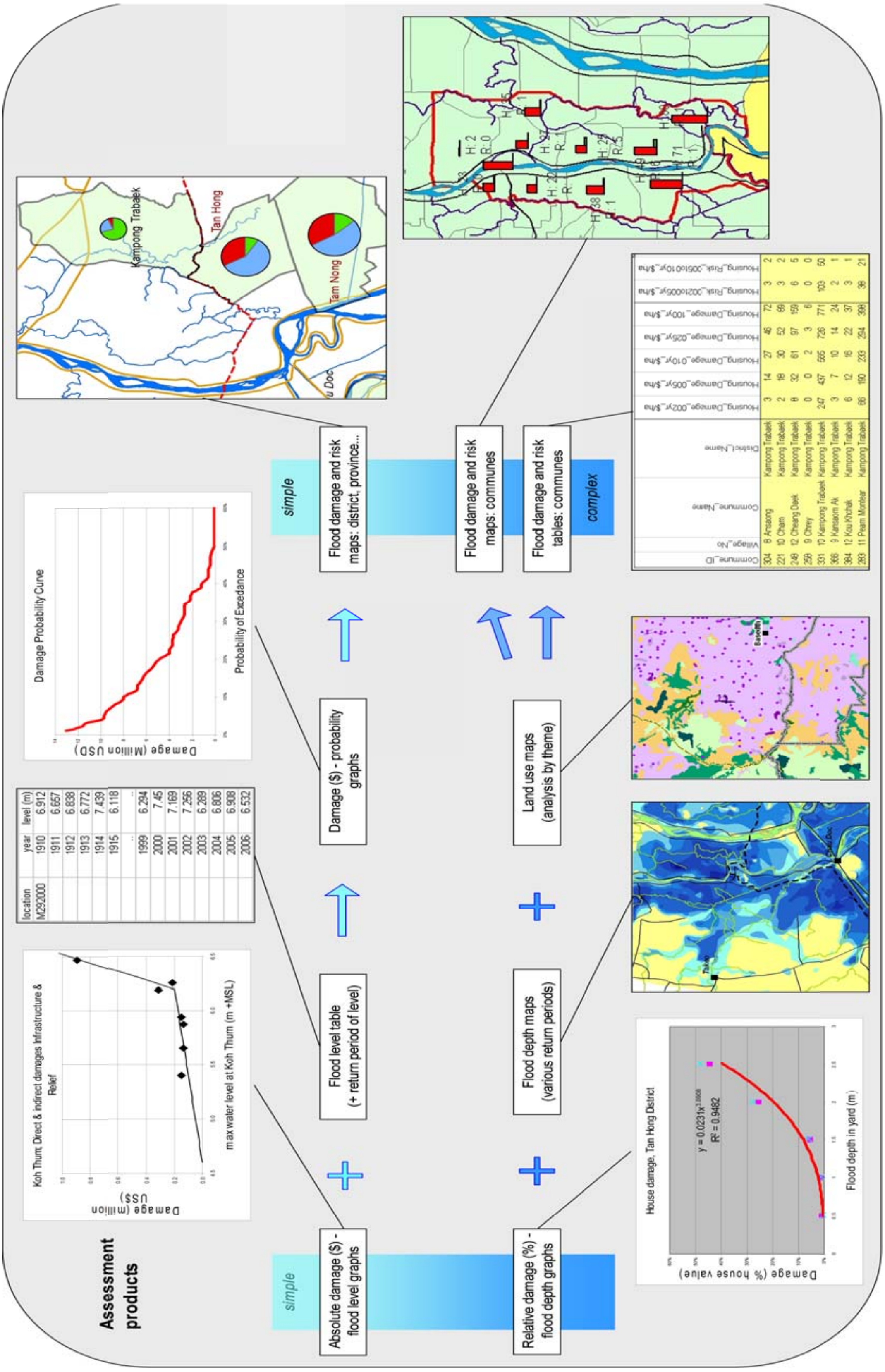


Figure 3-11: Steps (simplified) to create maps based on absolute and relative damage – flood depth curves.

Textbox 2: Creating Specialised Damage Maps Based on Relative Damage Curves

Cambodia, creating a housing damage map based on relative damage curves

The ISIS-based floodwater or basin water depth maps can be combined with village location maps, to generate water depth information (by return period) for each village. By taking floodwater damage curves for damage to homes (Figure 3-9), combining this with district-average home values and data for the number of households per village, it is possible to calculate the flood damage to housing per village and per commune. By transferring the data from the spreadsheet to a GIS, these results can be displayed on a map.

Cambodia, creating a rice paddy damage map based on relative damage curves

To calculate damages to rice harvests for different flooding return periods, the Japan International Cooperation Agency (JICA) land use map showing the rice cultivation areas can be used as a basis. The paddies that are flooded once every two years are considered to be ‘early flood’ paddies, while the other paddies (on higher grounds) are considered to be ‘rainy season’ paddies. By combining the floodwater depth maps (by flood return period) with these rice paddy maps in a GIS, transferring the GIS data to a spreadsheet and by combining the data with the rice damage curves (of e.g. July for ‘early flood’ rice; see Figure 3-9) in the spreadsheet, it is possible to calculate the damage to the rice crop. These results can be transferred to a GIS to display damages to the rice crop on a map by districts or communes (see Figure 3-13).

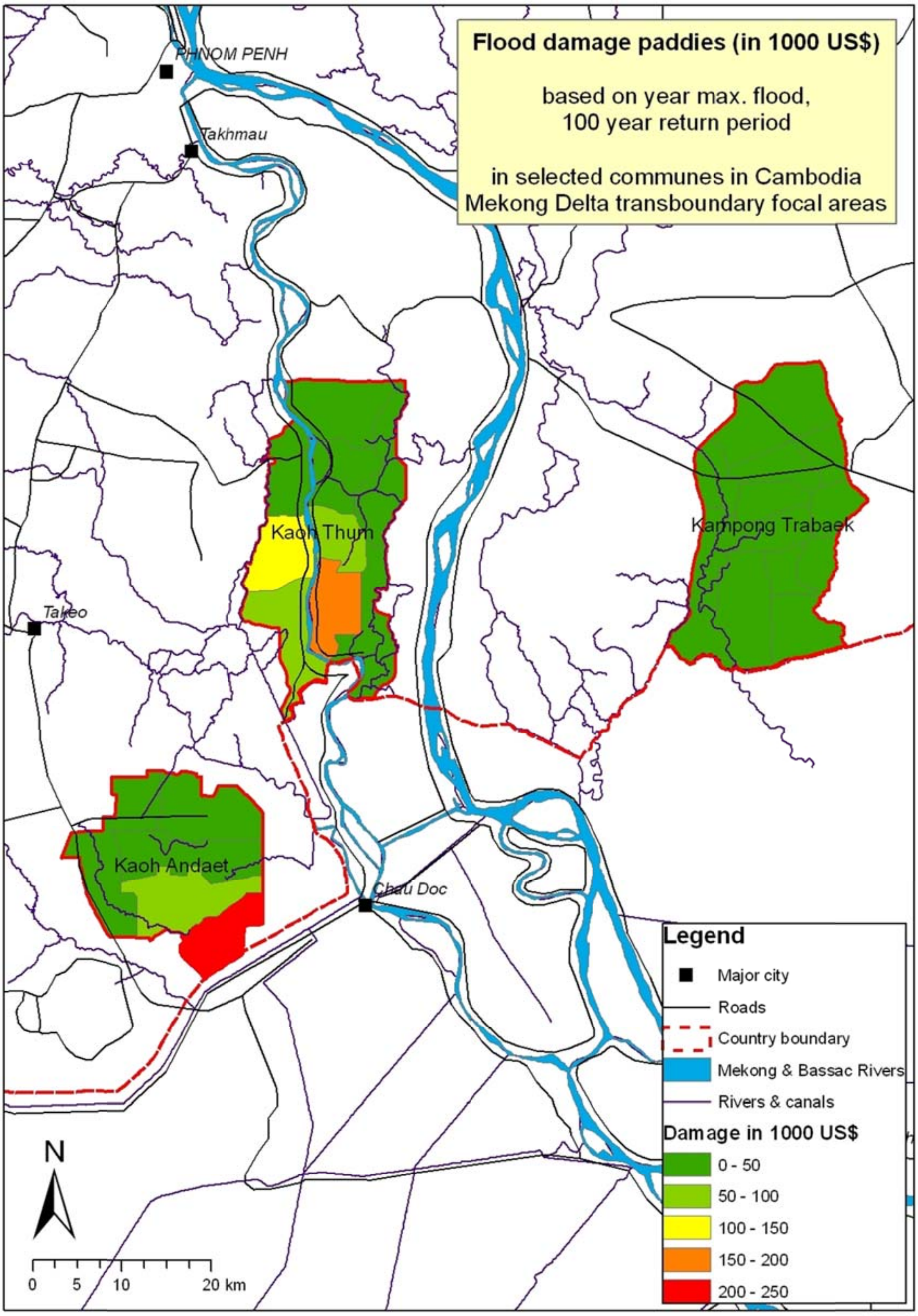


Figure 3-12 Example of a damage map based on relative damage curves, showing total damage to rice paddy fields in 3 districts and their communes in Cambodia.

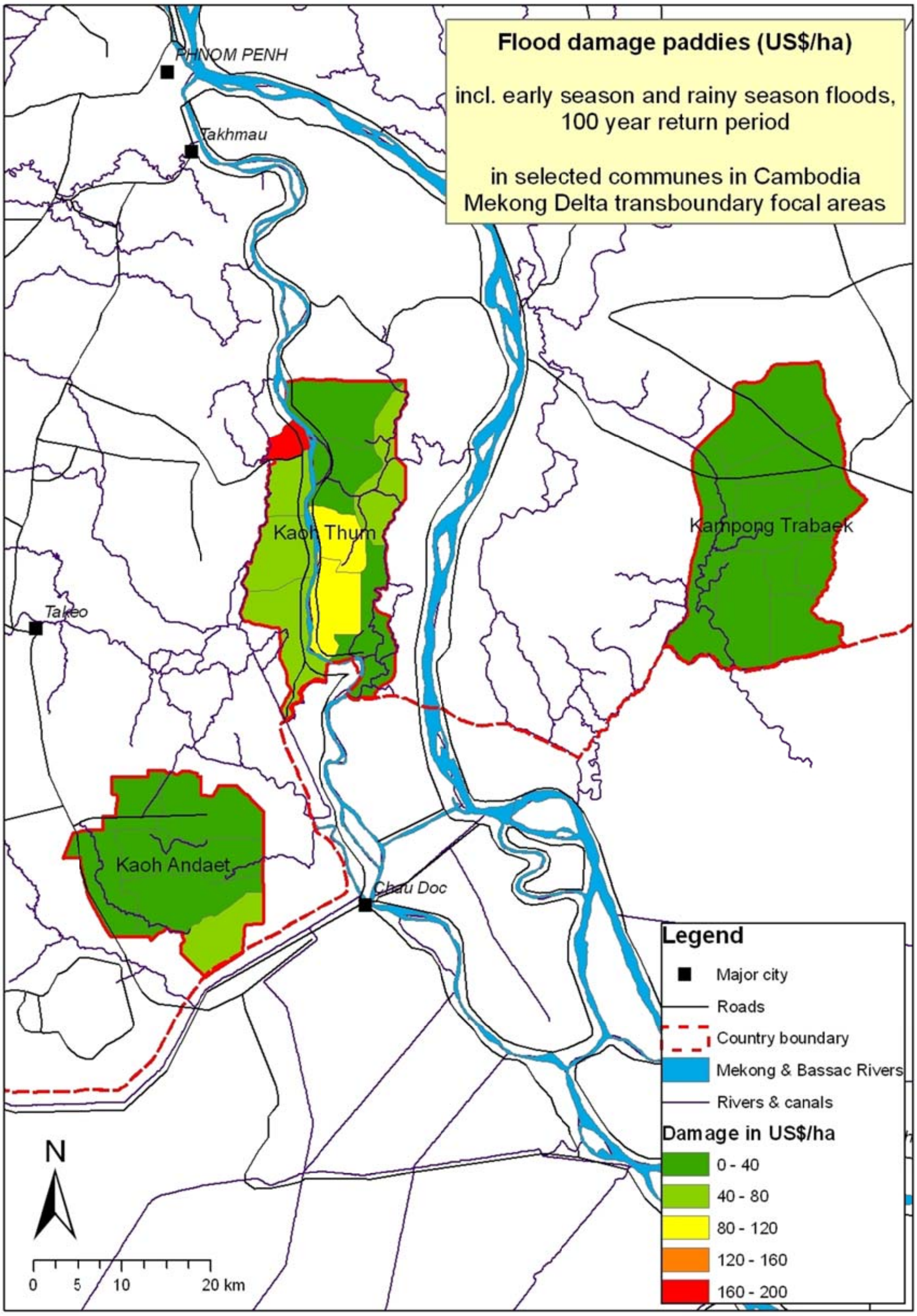


Figure 3-13 Example of a damage map based on relative damage curves, showing damages to rice paddy fields per hectare in 3 districts in Cambodia and their communes.

CHAPTER 4

FLOOD RISK ASSESSMENT

4 FLOOD RISK ASSESSMENT

4.1 Introduction

In risk assessment, the results of both hazard and damage assessments are combined. This chapter describes the approach to risk assessment (Section 4.2) and the 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 risk is determined for a case study area for the LMB.

4.2 General approach

Flood risk is generally defined by the simple equation,

Risk = Probability x Damage (4.1)

For example, if an area has a probability of flooding of 1% per year (or 1/100 per year) and the expected damage from such flooding is USD20 million, the risk would equal USD 200,000 per year. Since 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 floodwater discharges. This information can be obtained from historical data or probabilistic analysis of hydrological processes.
2. Next, the relationship between the floodwater discharge and the water (flood) depth should be derived. This can be done using 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; i.e., the '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.

Figure 4-1 shows cleverly, using several graphs (starting in the lower right hand corner) how each of the steps yields a set of data that fits into the next step in an integrated process. In the picture, each graph shares a common data axis with a graph used in the previous step.

In Section 4.4 this approach is elaborated for areas in the LMB.

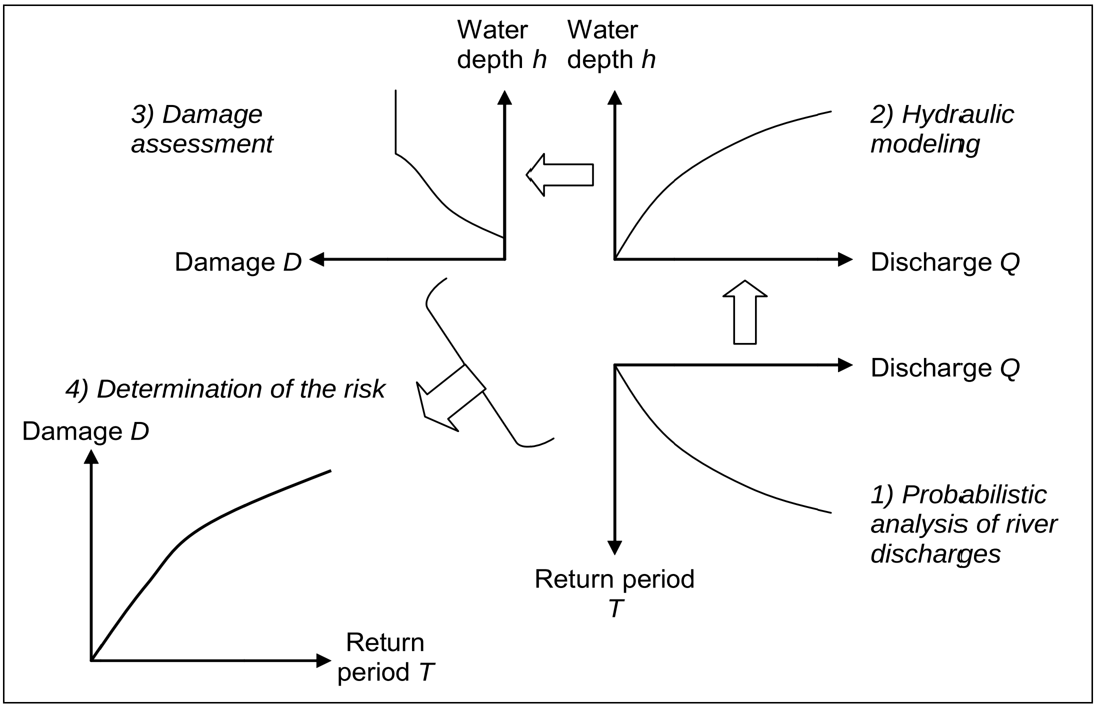


Figure 4-1 Conceptual approach for determination of flood risk.

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. One useful way to do this is with a Monte Carlo simulation. The simulation takes existing data and then uses the equation that a regression analysis suggests for existing data to randomly generate data for missing data points using a random selection. In this way, flood hazards and damage values can be estimated for all events and can be combined to estimate the risk.

However, rather than looking at every possible type of flood, the standard approach is to select a limited number of potential 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 are used as the standard return period or frequency measures I flood estimates. For each of these flood return periods, models can be used to generate a hydraulic simulation and damage assessment.

Table 4-1 Illustrative summary of damage and probability calculations for a range of flood scenarios.

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

Different flooding scenarios can be defined by their return period or frequency; i.e., the average recurrence interval between two floods with a certain floodwater level and the corresponding damage. Another measure often used is the probability of ‘exceedance’ of an event with a specified damage; i.e., the probability (per year) that a certain damage value will be exceeded. These two metrics can be stated in terms of each other 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 (flooding of greater magnitude and damage) 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 damages. However, even with higher return periods, damages will not increase exponentially. In fact, the expected damages begin to reach a plateau (the curve will 'flatten') as the maximum potential damage is reached and additional water adds little more to significant harm. The relationship between the probability of flooding and a given damage value can also be displayed graphically (see Figure 4-2 - right). 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. However, it is also possible that damages occur multiple times per year in the same area. In that case, a certain set of damages 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 if such floods occur twice or more per year. In that case the right side graph in Figure 4-2 could display frequencies/return periods that are larger than one. The data on damages is collected for each flooding event and the events data note the number of such floods.

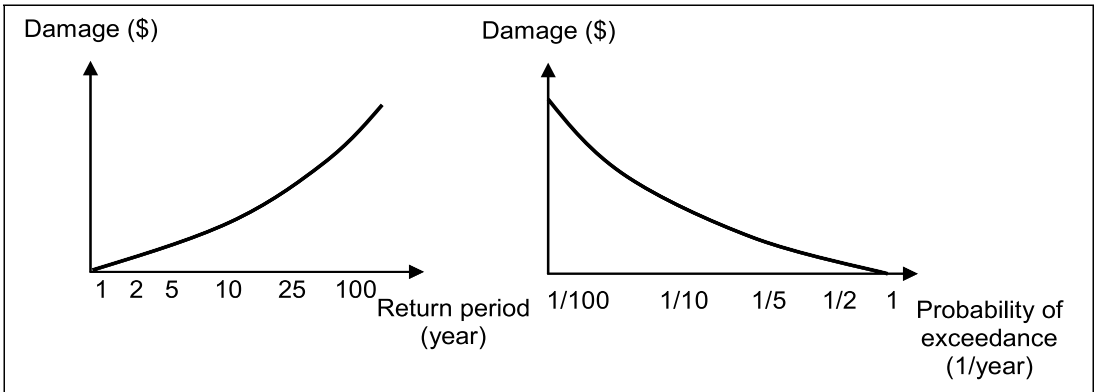


Figure 4-2 Relationship between return period and damage (left) and probability of flooding and damage (right).

Using this information, it is possible to determine the expected value of damages for an area, as presented below. The unit of risk is measured in annual monetary damages and is referred to as expected economic damage. Note that the risk/expected damage can also be determined for a single unit of land[7]; e.g., per hectare. In such case the risk is presented in terms of expected monetary damages per year per land area such as in USD/ha/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 between areas.

[7] It is preferable to estimate the damage per hectare for the actual surface of land that has been flooded. However, the exact size of the flooded area is not always known and the damage needs to be 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 flooding and the damage (Figure 4-3). In the figure the risk can be measured 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 (if the curve cannot be described by an equation for use of a more exact measure using integral calculus).

Note that just multiplying the damages from Table 4-1 with their probability of flooding 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' the area E all the way to the y-axis, overlapping partly A, B, C and D. Instead, one should calculate just the additional risk from each flood (probability of 1/2 – probability of 1/5) x $Damage_{1/2}$. The same applies to the other damages/probabilities.

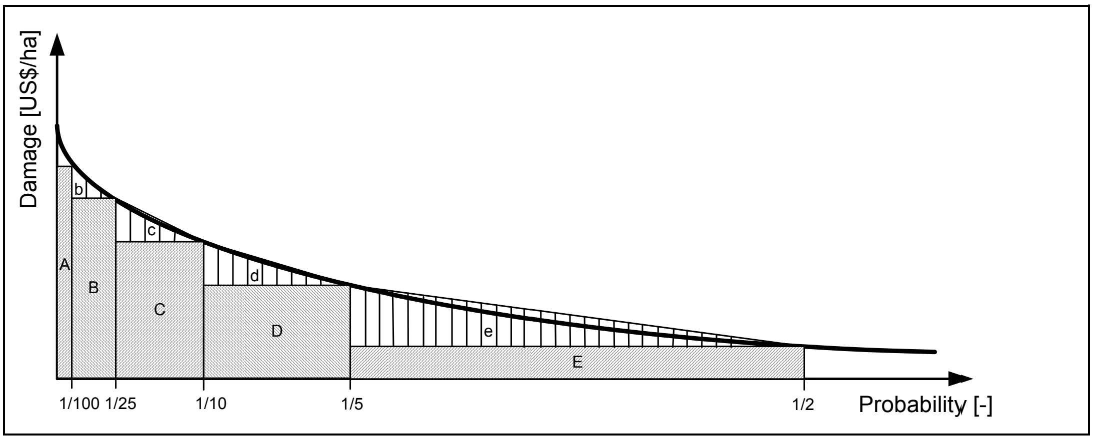


Figure 4-3 The area below the curve, the total risk or expected damage (for example, in USD/year), can be approximated by summing the areas of the rectangles, A, B, b, C, c, D, d, E and e.

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 offer insight in the spatial/geographic 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. Maps can also make it easier to see the relationships between flooding and the presence or absence of flood protection works as well as point to other insights. Examples of risk maps for the LMB 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, mortality 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 can be designed to show the probability of flooding and the loss of life for several events or scenarios (similar to Table 4-1).

The risk to life is generally referred to as societal risk. It can be shown in an FN curve, which shows the probability of flooding leading to 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 an example of an FN curve[8].

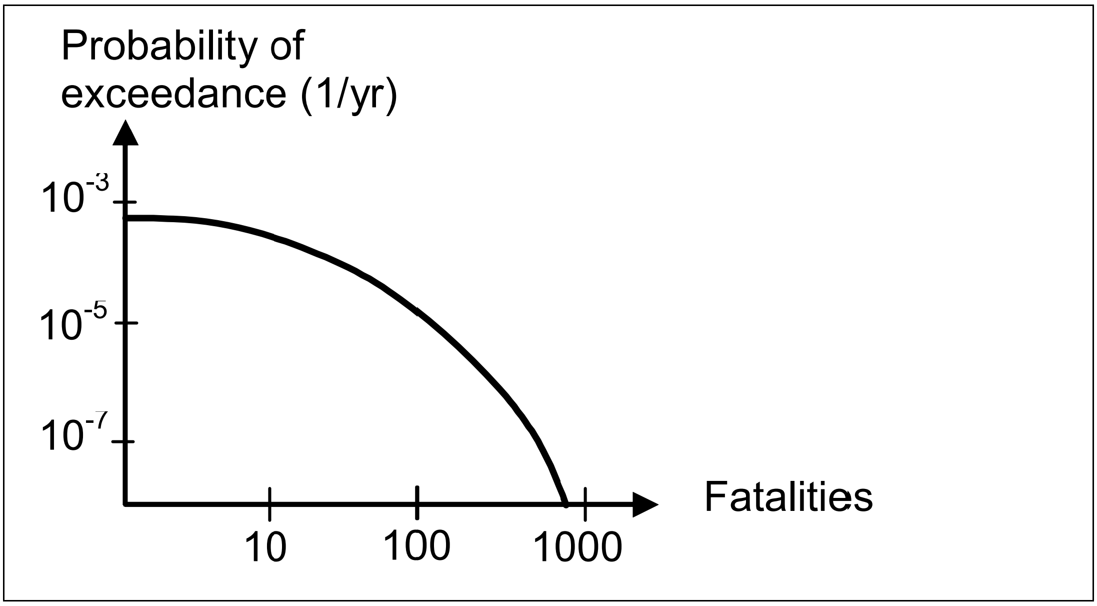


Figure 4-4 Example of an FN curve.

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

4.4 Risk reduction measures and risk evaluation

4.4.1 Effects of anti-flooding and flood preparation measures on risk

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

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

Figure 4-5 offers 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 flooding. In other words, floods with larger probabilities (smaller return periods) are controlled and do not cause any damage.

[8] A FN curve is very similar to the curve that shows the probability of exceedance resulting in 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.

For example, this is the case when dykes or embankments are built to provide protection to an area up to a certain level; e.g., for a major flood of 50 year return period.
Measures to reduce the consequences of flooding such as adaptation of land use controls and building improvements, reduce the consequences of an event (total damages) for a given return period. Measures can be combined, so there will be a combined reduction in risks.

Note that while compensation and insurance are also often mentioned as measures to reduce the consequences, these measures do not reduce the total damages. They are only a financial reallocation of the flood damages costs.

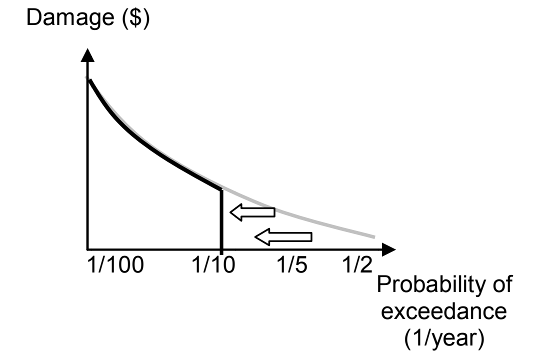
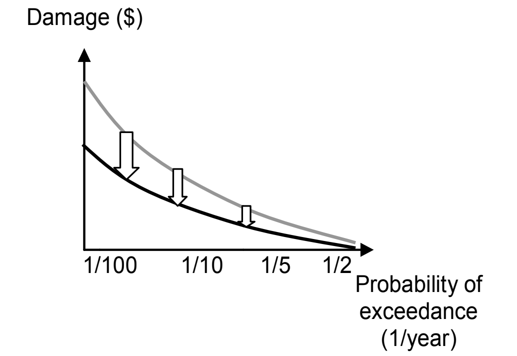
Measures to reduce flooding probability	**Measures to reduce flooding consequences**
- Strengthening of dykes and embankments - River widening ("room for rivers") - Retention and emergency storage	- Land use planning - Secondary flood defences - Flood proof buildings (e.g. raising buildings above ground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

Figure 4-5 Effects of measures on flood risk.

4.4.2 Basics of cost-benefit analysis

Cost-benefit analysis is used to evaluate whether a certain measure achieves enough risk reduction. A project should be undertaken if it results in an increase of economic welfare. In other words, the benefits generated by the project should exceed its costs. Further information on cost - benefit analysis in the context of flood management is given in the work by Penning Rowsell and Chatterton (1977) or in the guidelines for cost-benefit analysis (CBA) developed in the UK (MAFF, 1999, 2000) and Australia (BTRE, 2001).

Investment projects can be systemically analysed with individual effects estimated and, wherever possible, given a monetary value. Cost - benefit analysis provides an overview of distributional effects and uncertainties while pointing to alternatives. In theory, all relevant impacts, including intangible ones, must be taken into account in a competent cost-benefit analysis. Too often, however, in practice, the analysis is often narrowed to tangible monetary effects.

In such a 'limited' cost - benefit analysis, the measurable economic benefits of an activity are compared with the measurable costs of the activity. If the benefits are higher than the costs, the activity is considered attractive (it generates an increase in economic benefit). If the benefits are lower than the costs, the activity is not attractive. In the context of flood management this means that costs of increasing safety against flooding (e.g., dyke strengthening of flood proofing) are compared with the decrease in the yearly expected economic flood damages to determine whether an investment is attractive. 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. The benefit measure is the reduction of the expected economic damage.
Restating this in terms of an equation, a flood risk reduction investment is attractive in the terms of a cost - benefit analysis if:

$$I < \Delta E(D) \qquad (4.3)$$

where: I = investment in project/measure [e.g in USD/yr]
ΔE(D) = reduction of expected economic damages [e.g. in USD/yr]

The Greek letter delta here is used to mean 'the change' but of course the change in expected economic damages here is best described as the reduction in the damages since the investments are designed to result in changes that reduce damages.

The reduction of the risk/expected economic damages can be calculated with a simple equation looking at the before and after changes:

$$\Delta E(D) = E(D)_0 - E(D)_N \qquad (4.4)$$

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

The expected economic damage can be determined through the approaches outlined in Section 4.2.

The change in the expected damage value due to different types of risk reduction 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., USD/yr). In many cases, investments in flood risk reduction are one-time costs where the benefits are expected to continue over a long period, such as for a dyke construction project, whereas the benefits are expressed on an annual basis. To conduct a cost benefit, the time element needs to be standardised for both the investment costs and the benefits. The way to standardise the benefits is to calculate their net present value. Any costs and benefits that occur over future time periods need to be discounted to determine their net present value. The following general formula (as presented in Appendix 3) can be used to do that:

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

where: NPV = net present value [e.g. USD]
Bi = benefits in year i [e.g. USD]
Ci = costs in year I [e.g. USD]
t = time [year]
r' = reduced interest rate [-]

The reduced interest rate r' is generally used for discounting. It is equal to the rate of economic growth minus the rate of 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 economic optimisation. This approach is used to determine an optimal level of protection when both the investments in protection and the risk are dependent on the level of protection. This is the case, for example, for flood prone areas that are protected by dykes. The choice of protection level is dependent on the height of the dyke.

The Delta Committee in the Netherlands has applied economic optimisation to flood protection systems. The Committee began its work to investigate possibilities for new safety standards following a major flood that caused enormous damage in the Netherlands in 1953.

In economic optimisation, the incremental investments in more safety are balanced with the reduction of the risk. In the example of the Netherlands, the investments consist of the costs to strengthen and raise the dykes. This simple approach assumes that flooding can only occur due to floodwaters exceeding the flood defences. Thus, each dyke height corresponds to a certain probability of flooding (the higher the dykes the smaller the probability of flooding) and an associated damage. By summing the costs and the expected damage or risk, the total costs can be plotted as a function of the safety level. A point can be determined where the total costs are minimal. This is considered the optimal point. (See Figure 4-6.) At this optimum point, the corresponding dyke height is known. Because the statistics of the water levels are also known, a corresponding protection level in terms of a probability can be defined.

This approach was 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 throughout the Netherlands. For coastal areas, the optimal level of protection has been chosen with flooding probabilities between 1/4,000 per year and 1/10,000 per year. For Dutch river basin areas, the safety standards were set at 1/1,250 per year and 1/2,000 per year.

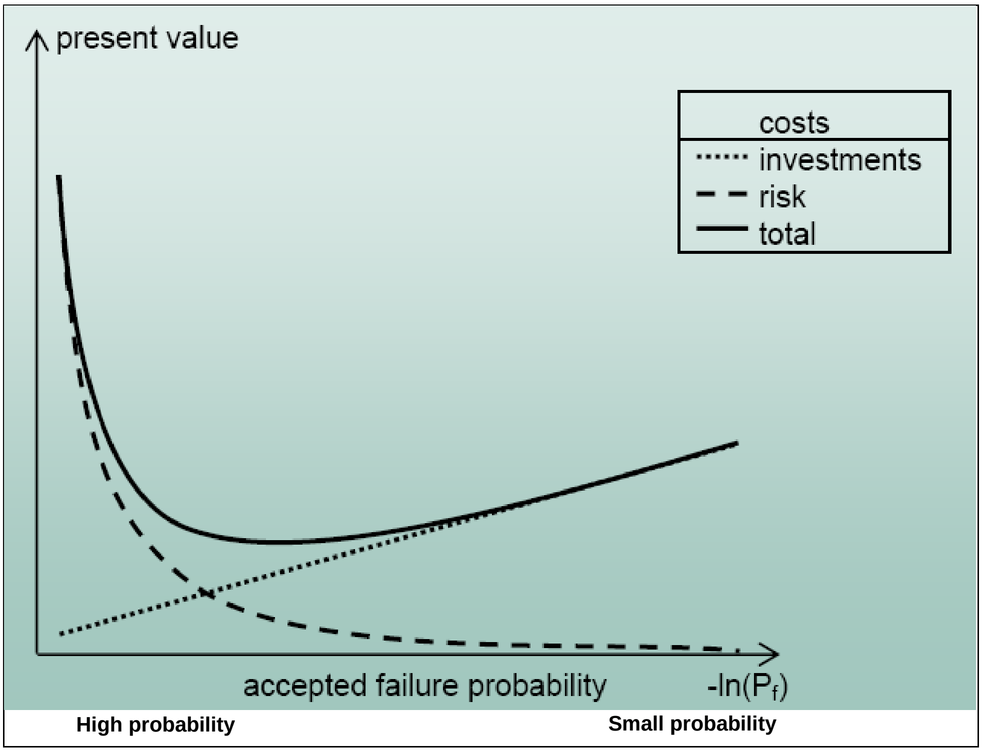


Figure 4-6 Principle of economic optimisation.

Economic optimisation can also be applied to other types of problems of various scales. For example, the optimal level of raising a house to minimise flood damages can be determined by 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 valuation for loss of life

The estimates of risk to life can be included in risk valuation 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 several texts (see 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, such as 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 through use of a limit line in the FN curve (see Figure 4-7). The limit line sets the acceptable number of fatalities versus the probability of a harm such that any number of fatalities beyond this are considered unacceptable. In other words, an event with larger consequences is acceptable only with a smaller probability. In planning protection measures, 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.

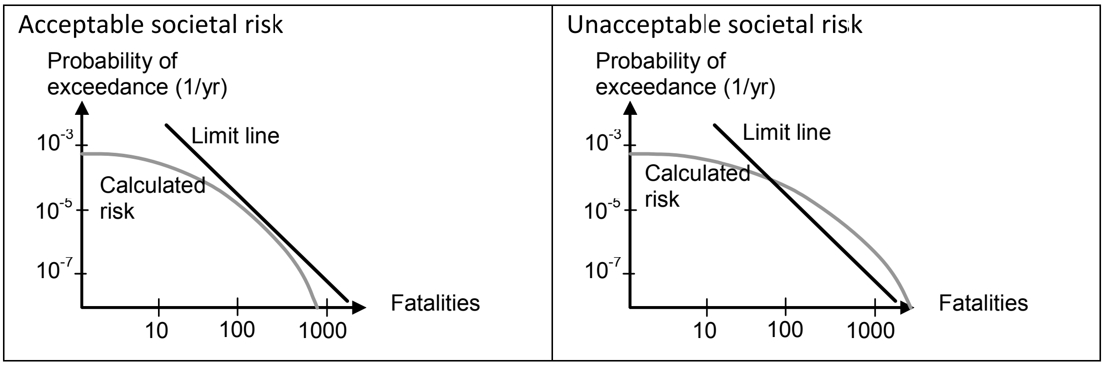


Figure 4-7 Societal risk of fatalities due to flooding and the limit line of acceptable harm.

The above concepts for limits for individual and societal risk are currently explored in the Netherlands where new safety standards are developed that meet society's acceptable limits for risk to life. At present, the Netherlands appears to be the only country that uses this approach to safety standard for flooding.

4.4.5 Risk matrix

A tool used to evaluate risk is the risk matrix (see below). It provides a ranking of the probability (vertical axis) and expected damages (horizontal axis). Based on the magnitude of probability and expected damages, a certain risk can be ranked as acceptable (shown on the chart in green), unacceptable (red) or subject to further discussion on its acceptability (orange) based on subjective determinations regarding the risks. In order to categorise the damages, different damage categories (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 one. The outcomes of risk assessment can only provide information on the level of risk and not on the acceptability, which is a subjective determination.

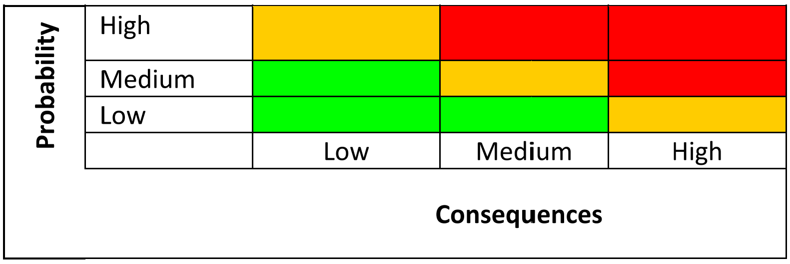


Figure 4-8 Structure of a risk matrix.

4.5 Risk assessment for the LMB

4.5.1 Introduction and approach

This section presents the results of risk assessment within the context of the MRB; combining the results of the flood hazard analyses (Chapter 2) and damage assessments (Chapter 3) from the areas under study. Note that benefits of flooding are not discussed in detail here, but can be relevant in an overall risk valuation.

Figure 4-9 outlines the approach that was followed in this project to estimate risk. From the time series output of the ISIS hydraulic model (the graph in the upper left of the figure), the probability of different water levels can be analysed and presented graphically (shown in the graph in the upper right). The relationship between floodwater levels (or flood depth) and damages (shown graphically in the lower left) is also known. By combining the damage relationship with the flood probability data, the damage probability curve can be derived (shown in the graph in the lower right of the figure).

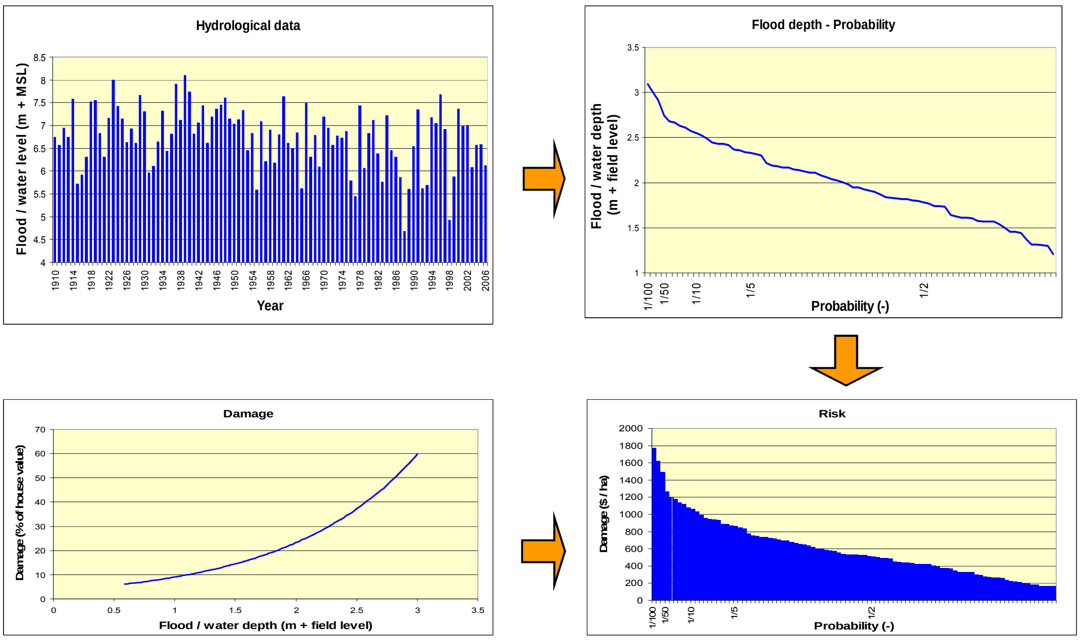
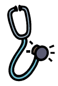


Figure 4-9 Approach for estimation of the risk.

The results obtained using this approach for three districts in Cambodia designated as focal areas in the FMMP Stage 1 are illustrated below. These are the districts of 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 generated. From the figure it can be seen that Koh Andet has the highest damages for most return periods; especially for events with a relatively large probability of flooding (40% - 60%). The Koh Tum district has the lowest overall risk curve.

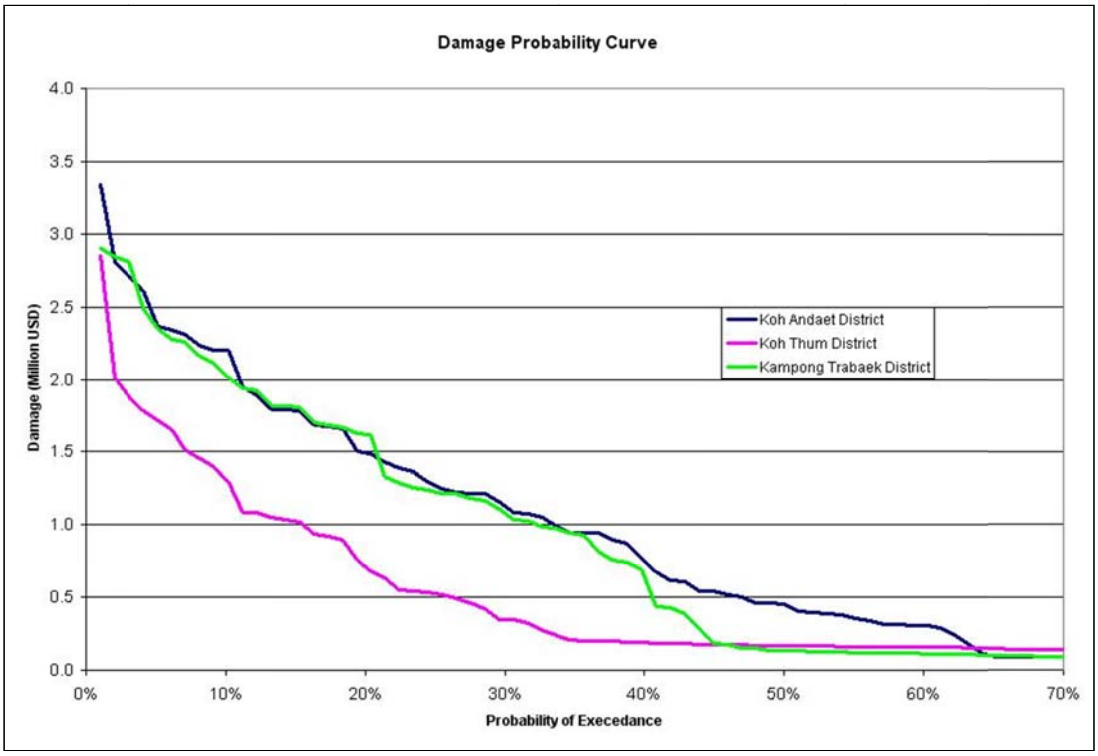


Figure 4-10 Probability damage curve for three Cambodian districts.

The risk (annual expected value of the damages) for the three districts can 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 kilometre. From these results it becomes clear that Koh Andet has the highest risk.

Table 4-2 Results of risk calculations for the three focal areas in Cambodia.

District	**Expected economic damages (million USD/yr)**	**Expected economic damages per ha (million USD/(km^2*yr)**
Koh Andet	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 visualised on maps. Figure 4-11 shows the results for the average flood risk calculations for the focal areas in Cambodia and Viet Nam. The size of each circle shows the magnitude of the risk for the district. The distribution over the three damage categories (housing, infrastructure and relief, agriculture) is shown within each circle. It is clear that the distribution over the damage categories varies between districts. For Koh Andet and Kampong Trabek, the largest part of the risk is to agriculture. For Koh Thom, the largest share of the risk is to infrastructure.

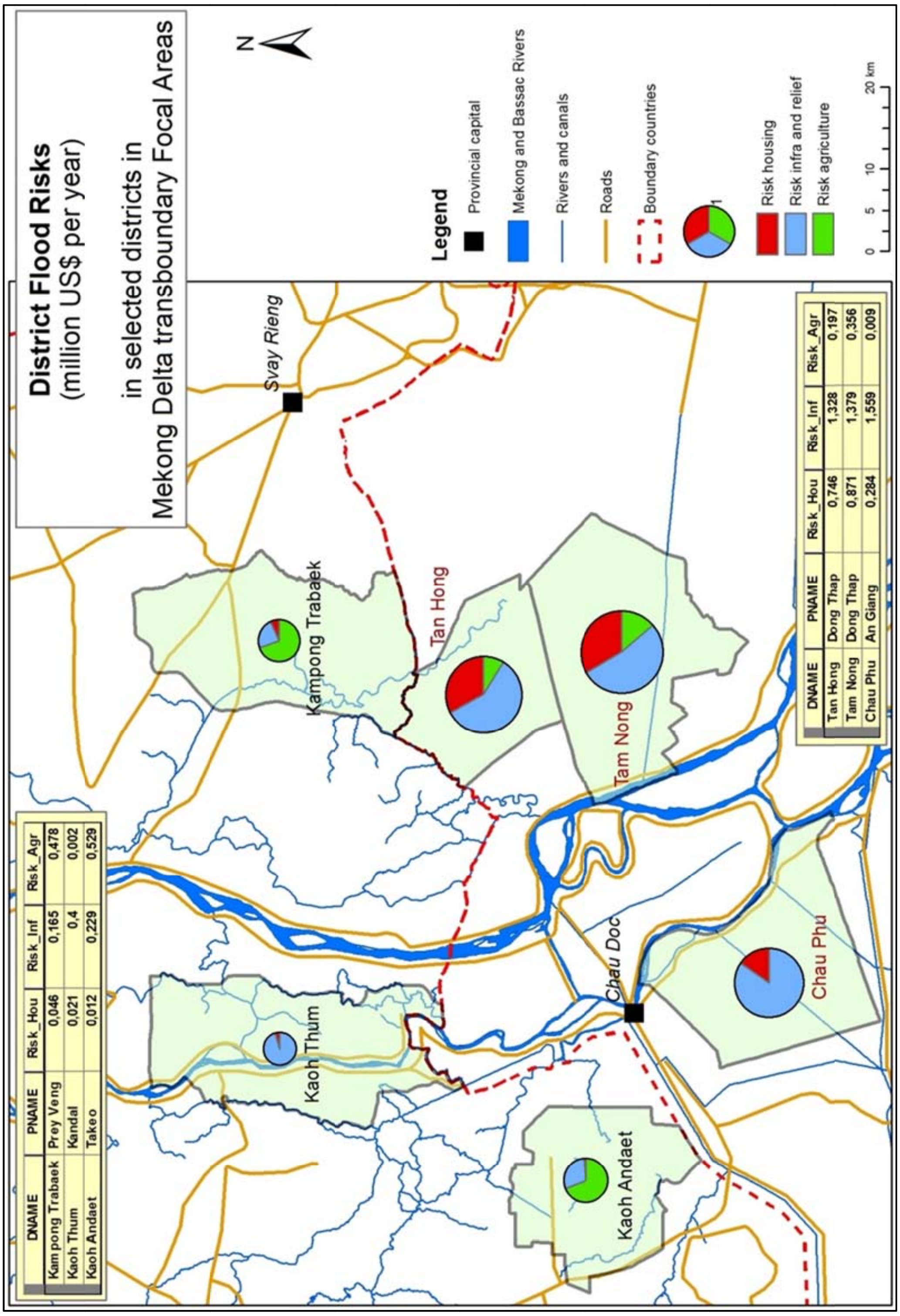


Figure 4-11 Flood risks by district for selected areas in Cambodia and Viet Nam.

The figure shows clearly that the risks 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

This Appendix presents the European Union's Flood Directive along with preliminary studies and guidelines for its implementation produced by the European Exchange Circle on Flood Mapping (EXCIMAP) on behalf of several European countries, the FLOODsite research project that directly follows the EU Directive, and the Dutch Damage and Casualties Assessment (DACA) as an introduction to the management of flood damage and flood risk 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 compelled 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 that may be relevant and applicable to other regions or river basins. These principles include the following:

- Member States shall, for each river basin or portion of an international river sub-basin lying within their territory, undertake a preliminary flood risk assessment along with damage estimates of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity. These should consider as best 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 human developed flood defence infrastructure, the position of populated areas, areas of economic activity and planned long-term developments, and estimates of the 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 concerned competent authorities.
- Flood risk management plans shall take into account 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, and preparedness; including flood forecasts and early warning systems. They should also take 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.

[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 initial steps required by the Directive.

Flood maps are used to indicate the geographical areas which could be covered by flood waters from all natural sources at several levels of probability. The Guideline distinguishes between: (i) river flooding in floodplains; (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; and (vi) lake flooding.

EXCIMAP flood maps can show flood extent according to: (i) probability classifications; (ii) historic events; (iii) flood depths; (iv) flow velocities; (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 for (vi) overall public awareness.

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 and related maps

EXCIMAP directs that flood hazard maps be prepared for low, medium and high probabilities of flood occurrence. For each probability the extent, inundation depth/floodwater level, and where appropriate the water velocity are 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 mapping. The can be used in awareness raining, for follow-up of flood hazard assessment, for the calibration of models, and as an emergency management and planning tool.

Flood vulnerability maps

Flood vulnerability maps show the categories and assets at risk: (i) population, (ii) assets and economic activity, and (iii) potentially affected installations that may release pollution. In the Netherlands, these maps are prepared at the provincial level and are available to the public and specialised services[11].

[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.

The basis of flood risk maps, therefore, is to indicate: (i) the number of inhabitants potentially affected, (ii) the type of economic activities potentially affected, (iii) installations which might create incidental pollution, and (iv) other pertinent information, such as high content of transported sediments and debris and other significant sources of pollution.

Risk may be calculated as:

Risk = C * Ph

where: C = potential adverse consequence and
Ph = the probability of the hazardous process

Risk is expressed as a potential loss in a particular area or unit area (ha) within a given time period (one year) using a second equation:

C = V * S * E

where: V, S and E are called the 'vulnerability parameters' for damage measurement:
- 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., floodwater depth-damage and damage-duration relationship curves (with each 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] was a research project on Flood Risk Analysis and Management Methodologies, designed by the EU to support its Member States in complying with the requirements of the EU Flood Directive, collecting data during 2004-09. FLOODsite research analyses the physical, environmental, ecological and socio-economic impacts 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 research consortium included 37 of Europe's leading institutes and universities and the project hired managers, researchers and practitioners from a range of government, commercial and research organisations, specialising in aspects of flood risk management. FLOODsite research is currently applied in EU Member States in the form of models and technical support for river, estuary and coastal sites in Belgium, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Spain, and the UK.

FLOODsite also prepared a discussion paper[13] reviewing the flood damage evaluation methods applied in the UK, the Netherlands, the Czech Republic and selected German States, followed by a guideline for flood damage assessment[14].

[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]

In the Netherlands, (HIS-SSM), a standard method for flood damage and casualties assessment has been used since its development in 1999. It is used to assess the change of risk following national and regional decisions on water management measures in the Netherlands. Since 2007, regulations require that all Dutch water-projects of national importance 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 'relative approach' described in Section 3.3.4.

These approaches are an advance on traditional flood measures and preparations. Traditionally, flood planning focused on safety standards, such as dyke design levels or reservoir volumes required to ensure predefined protection levels. Protection of the community against floods occurring with a frequency of once in 1,250 years is an example of such an established level under the flood protection law of the Netherlands. What is missing in this approach is the amount of damage protection that the system offers. In other words, the approach disregarded 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. 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 can better be adjusted to the specific circumstances, given that the costs of ensuring an overall safety standard often considerably exceed the benefits in some areas.

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

Appendix 2 Approaches for the Assessment of Structural Damage to Buildings

Flow velocity is an important factor in damage to building since it impacts the hydrodynamic 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 A 1 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.

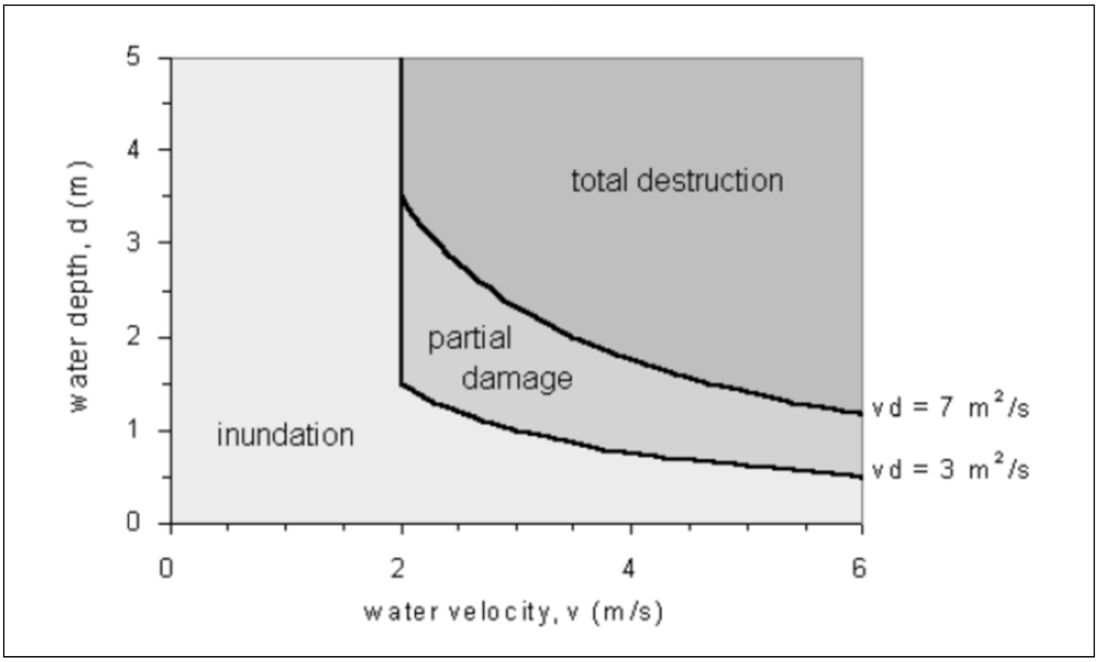


Figure A 1 Damage criterion for brick and masonry houses as proposed by Clausen (figure from Karvonen et al., 2000).

In general the advantage of the above approach is that the actual flood conditions (flood depth, flow 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 have different damage patterns than concrete or brick houses. Measures and construction techniques, e.g. building houses on poles, will also affect the degree of structural damage. This is why existing models and structural damage relationships should not be directly transferred to other regions or to use with different housing types without first conducting a detailed assessment of building types and their vulnerability.

Appendix 3 Fundamental issues in Economic Valuation

There are different rationales for economic valuation. Financial valuations consider 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 bear. Economic valuations have a broader perspective and seek 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 used for public policy.

Several principles of economic valuation need to be considered in order to conduct a comprehensive flood damage valuation study in a consistent way. Some of the most important principles as regards the economic valuation of flood damage are specified in the following sections. The application of the principles of economic valuation 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 points of view

Economic aspects of flood damage valuation 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 goods and services - opportunity cost are used in estimating flood damages and benefits. Thus, anything that reduces national per capita wealth is a “damage” and anything that increases national per capita wealth 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 valuation of damages

The economic valuation 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 distortions. 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 as well as by adjusting for the social value where market values fail to account for social benefits and losses (externalities).

Time value of money

The time value of money is the way of thinking about the choice between holding real goods this year or holding “money” and waiting to purchase those goods in a future year. The “time value” in the future reflects how people generally think about the future and whether they would rather save or have something they will use.

There is a simple way to think about this. If you have USD100 today and lend it to someone or put it in a bank, you expect to be paid interest for the use of the money (for example, 10% per year). This means that from USD100 today you will have USD110 one year later. In another words, the value of USD100 today worth USD110 next year and can buy 10% more (or 10% minus inflation).

In economic analysis the economist compares value of money at a different time instead of the amount of money. To do this, economists use a 'discounting' technique for converting value of money to a specific time/date. A number of terms, presented below, can describe this relationship over time, using mathematical equations.

Compounding factor
This factor is used to determine future value (FV) of a present amount (PV) at the end of the n^{th} period at the interest rate of *i*:

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

An easy way to think about the compound factor is to think of the 'compound interest rate' from bank interest, with the same interest multiple applied to the new amount at the end of a period of time, such as every year. In the example above for USD100 in the bank, if the compound rate is 10%, applied every year, at the end of 2 years, you would have, USD121.

Compounding factor of once per year with annual distributions
This is used to calculate the future accumulated value (FAV) at the end of n^{th} period at an interest rate of *i* with a sequence of equal payments (A).

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

Here, the easy way to think about this is for a period (n) of 2 years, like above. In the example of USD100 in the bank, you would receive USD10 after the first year and USD10 after the second year. Of course, the total amount you would have would depend on what you do each year with the USD10 in interest. If you reinvest it at the same interest rate, then you have USD121 after 2 years as in the example above. But if you spend the interest each time you receive it, your future accumulated value is only USD20.

Capital recovery factor
This 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 income stream (the continual annual payments, A, above, or the benefits or value of a project) generated by an investment. It can be calculated by the following equation:

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

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

Note that this equation doesn't actually use profit but calculates an annual 'net benefit' of the project that is equal to the benefit minus the cost (B less C) in each year. The Greek letter sigma represents that this is a summation from year one to the final year, n.

Constant price

The concept of constant price assures that a monetary sum taken from one year can be compared with a sum from another year. Flood damage evaluation is carried out in a specific year but the cost and damages are always estimated using data from previous years. To keep the values constant, the values from each year (called the 'nominal value' for that specific year) needs to be converted to a constant/fixed value using the current pricing value. To do this means applying the same idea of interest rates as applied in the equations above to the year of the measurement and bringing it up to the current year using information on comparative prices over the years.

'Constant' or 'fixed price' refer to a value from which the overall effect of general price changes has been removed. 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 leading to loss of consciousness and drowning or direct drowning (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 A 1 shows the combinations of depth and velocity that resulted in instability. It shows that people lose stability in flows with limited depth-velocity multiples. The obtained critical depth-velocity multiples 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 (ground surface friction, test configuration) or personal characteristics (weight, height, clothing). Further background information regarding human instability is given in Jonkman and Penning-Rowsell, 2008.

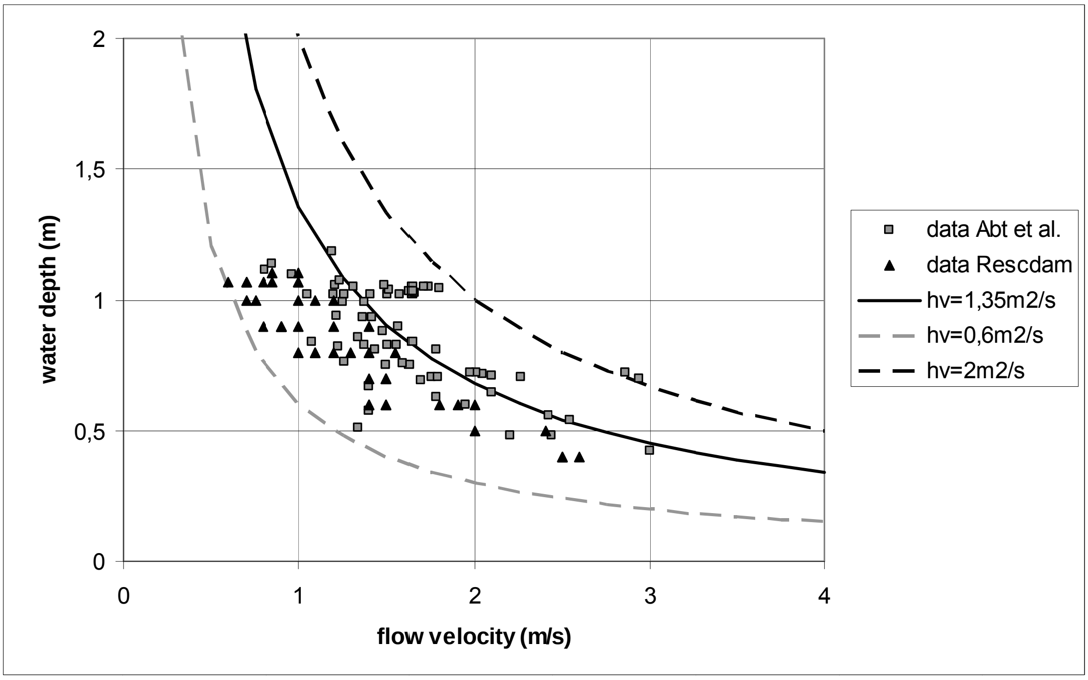


Figure A 2 Observations from experimental series regarding the combination of water depth and flow velocity that resulted in instability.

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 the figure above with floodwater velocity (in meters or in feet per second) on the x-axis and floodwater depth (in meters or feet) on the y-axis. Distinction is made between three 'zones' representing different levels of danger. The above criteria can be used to determine risk zones for certain flood conditions.

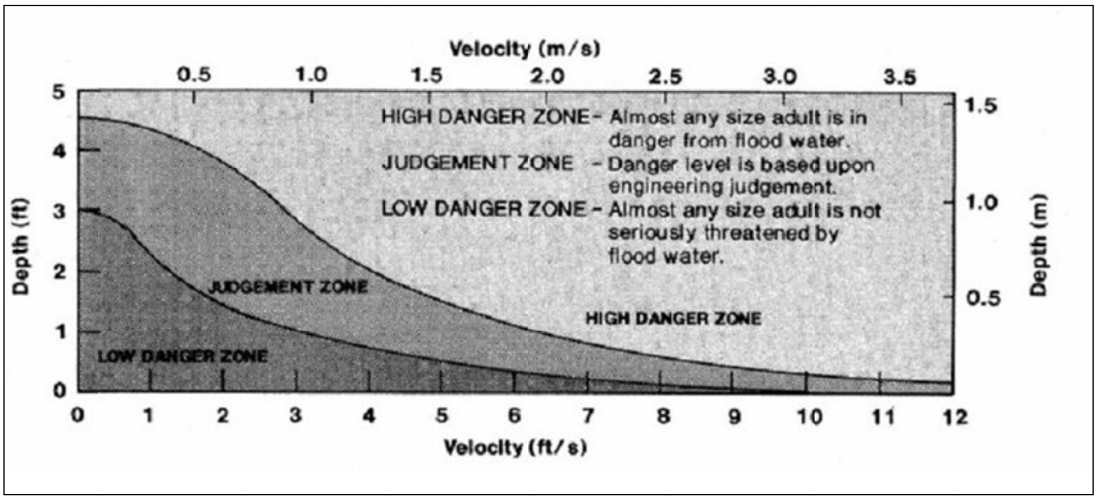


Figure A 3 Criteria for danger to people in flood flows (USBR, 2001). The graph is two dimensional but presents depth and velocity both in measures of meters and feet.

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 estimating the effects of these processes on the loss of life. Such losses should be directly dependent on the area that is affected and the social and economic conditions as well as physical characteristics (safety preparation, government and community self-help infrastructure, demographics, climate and ecology, etc.).

Appendix 5 The Best Practice Guidelines and Project Phases/Stages

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

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

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

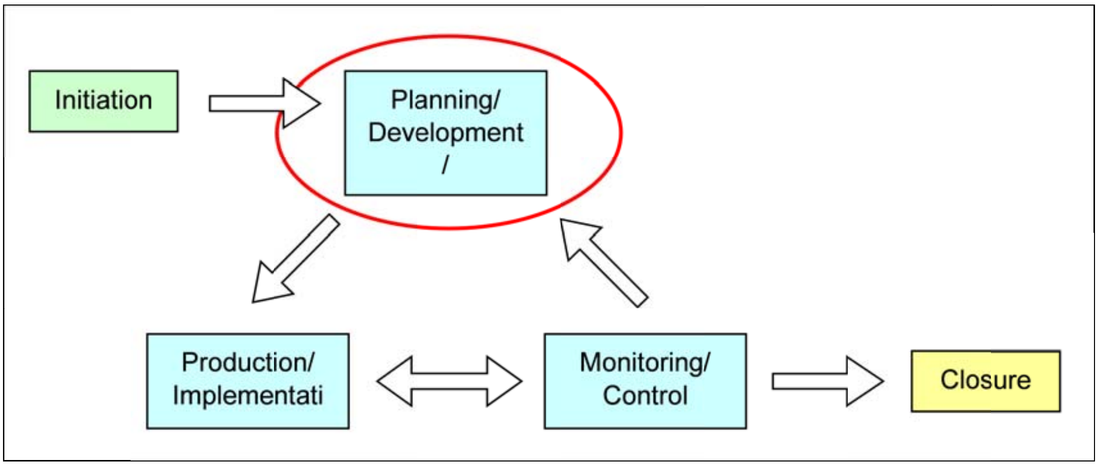


Figure A 4 The phases of an engineering project.

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

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

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

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

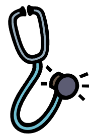
Phase 2 contains all of the following five stages:

a) Preliminary/pre-feasibility study

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

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

b) Feasibility study and overall planning



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

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

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

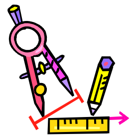
c) Preliminary design

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

- Site surveys and investigations and computer modelling provide the data for preliminary design criteria;
- The design criteria can be translated into the preliminary design of structures and measures in an integrated and balanced system in which the envisaged management activities are linked to one another;
- The cost-benefit analysis (construction and operation) and analysis of environmental, social and political factors demonstrate whether the project is still viable.

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

d) Detailed design and detailed planning

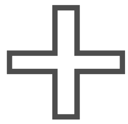


During the final design stage, the detailed architectural and engineering drawings (the blueprints) of all physical components of the project are produced. Virtually all design problems must have been resolved before the end of the final design stage. Sufficient detail must be provided by the drawings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

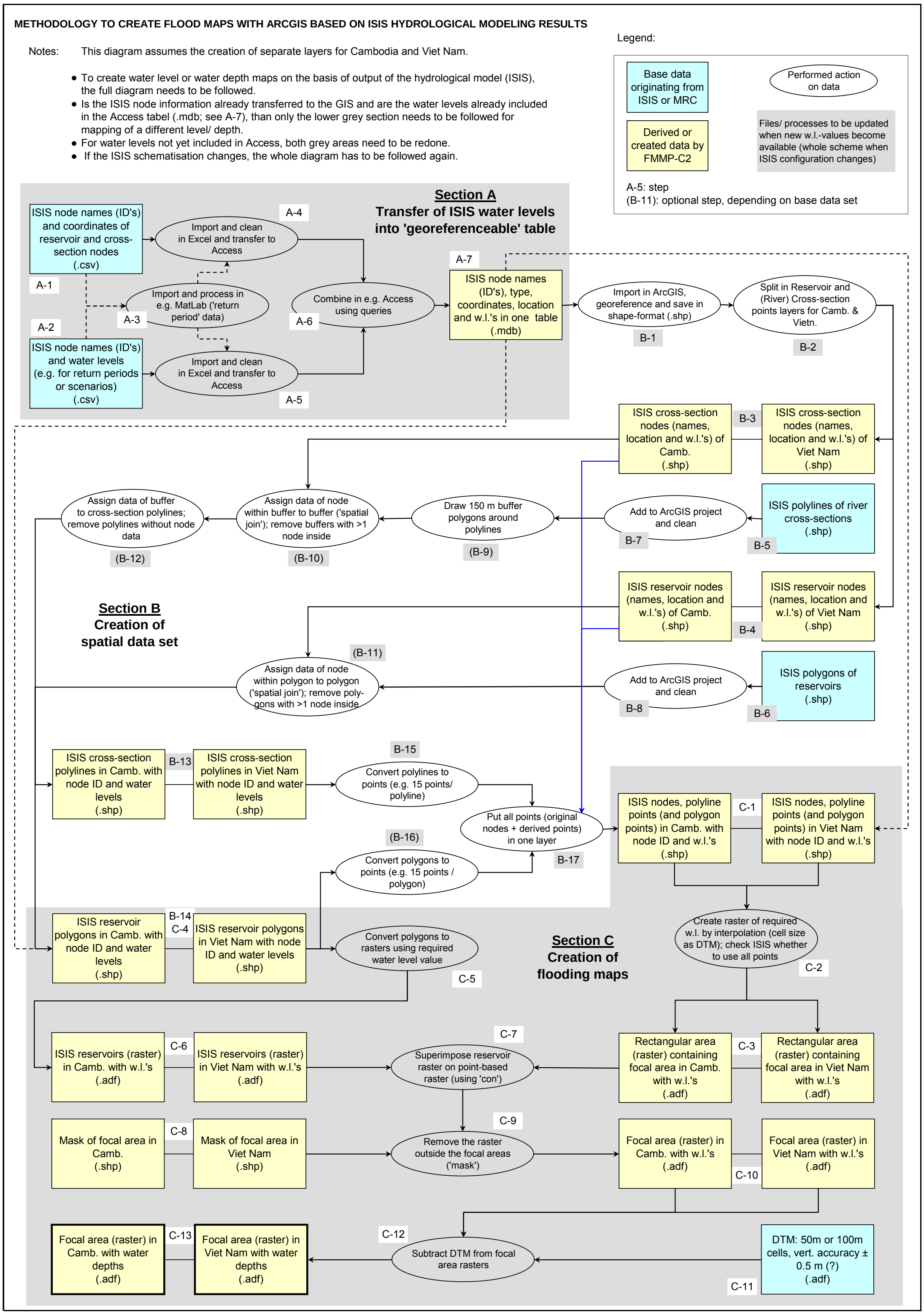
e) Construction documents/bid documents

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

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



Appendix 6 Flow Chart to Create Flood Maps with a GIS



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