Japan-ASEAN Cooperation

Guideline

On Integrating Climate Change Projection Into Flood Risk Assessments & Mapping

At The River Basin Level

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The ASEAN Secretariat is based in Jakarta, Indonesia.

For inquiries, contact:
The ASEAN Secretariat
Community Relations Division (CRD)
70A Jalan Sisingamangaraja Jakarta 12110, Indonesia
Phone: (62 21) 724-3372, 726-2991
Fax: (62 21) 739-8234, 724-3504
E-mail: public@asean.org

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The information and views set out in this report are the author's alone and not necessarily reflect the official opinion of the Government of Japan. Project Website www.aseandrr.org

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ACKNOWLEDGEMENT

The Guidelines was commissioned through a partnership between the Institute for Global Environmental Strategies, CTI Engineering International Co., Ltd, Asian Disaster Preparedness Center and The ASEAN Secretariat. It was made possible by support from The Government of Japan through the Japan-ASEAN Integration Fund (JAIF).

The guideline was authored by the project team, under the oversight of Co-Chairs of the ACDM Working Group on Prevention and Mitigation and the ASEAN Secretariat. The team included Mr Toshihiro Goto (Senior Chief Engineer), Mr Hirokazu Sakai (Professional Engineer), Dr Prabhakar Sivapuram Venkata Rama Krishna (Socio-Economic Assessment Specialist), Dr Binaya Raj Shivakoti (Capacity Building Specialist), Mr Susantha Jayasinghe (Climate Change Modeling Specialist), Dr Senaka Basnayake (Climate Change Adaptation Specialist) and Ms Pimvadee Keaokiriya (ASEAN DRR-CCA Program Manager).

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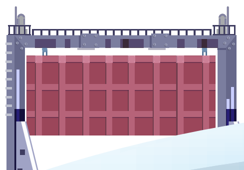

FOREWORD

Southeast Asian countries are diverse in their socio-economic and cultural profiles and yet share some common elements that make the region one of the world's most diverse. Country economies have developed rapidly in the past decade and are projected to continue this accelerated growth. Rapid economic development has led to significant achievements in socio-economic development. However, this rapidly changing socio-economic landscape in Southeast Asia is also generating climate change, disaster risks and vulnerabilities. Countries in the region are especially vulnerable to floods, droughts, typhoons, and landslides. Some of the world's top ten countries most affected by disasters are located in the region. For example, Myanmar reported the largest percentage of losses from extreme weather-related events (0.8% of GDP), followed by the Philippines (0.6%), Vietnam (0.5%), and Thailand (0.9%). The Global Climate Risk Index lists Myanmar, Philippines, and Vietnam in the top ten most affected countries by extreme weather events.

Recognizing the importance of addressing climate change and disaster risks, countries have implemented overarching disaster risk reduction and climate change adaptation plans, regulations and laws at regional and national levels and are rapidly progressing towards localizing them in specific sectors. One important element that still requires significant progress is integrating climate change projections into disaster risk assessments; support and enhance related knowledge and skills at all levels so that climate-proof risk assessments are implemented, shared and implemented. These forward-looking assessments will equip planners and decision-makers to manage rapidly the changing risk profiles due to climate change and related uncertainties.

The project captured the essence of these regional climate-related needs and has developed two set of guidelines designed to assist relevant agencies and sectors to plan and prepare for climate induced risks. This is based on the implementation in pilot river basins in Lao PDR and Myanmar, through series of interactive hands-on training, data collection, field exercises and surveys. – addressing on-the-ground disaster risk planning challenges and potential climate change impact, also taking into account the existing institutional set up, human resources, data capacities and limitations that are applicable to Southeast Asia countries. These guidelines and their tools are recommended for beginners and middle-level experts in the field of disaster management, natural resources and environment, water resource planners, climate change adaptation, urban planners and public works. They are unique as that they are targeted at the watershed level, multi-disciplinary in nature, and espouse principles of integrated risk assessment and integrated planning.

Last but not least, we congratulate the RBPs and host countries, national counterparts and consultant teams from IGES, CTII and ADPC for their valuable efforts. These guidelines are living documents and are expected to be revised at regular intervals by incorporating new and emerging knowledge with regards to climate change and disaster risk reduction. We highly recommend that all relevant national and regional stakeholders promote and disseminate these guidelines to foster their adoption to the location-specific contexts in ASEAN region demands.

Vilayphong Sisomvang

Director-General
Social Welfare Department
Ministry of Labour & Social Welfare
Lao PDR

Usec. Ricardo B. Jalad

Executive Director
National Disaster Risk Reduction and Management Council and Administrator,
Office of Civil Defense
Philippines

Boontham

Boontham Lertsukekasem

Director-General
Department of Disaster Prevention and Mitigation
Ministry of Interior
Thailand

Co-Chairs of the Working Group on Prevention and Mitigation, ASEAN Committee on Disaster Management (ACDM)

MESSAGE FROM MISSION OF JAPAN

Increasing climate change impacts and more frequent natural disaster events in these years have led to growing awareness of the need for accelerating climate change adaptation (CCA). Southeast Asia is said to be the most disaster-ridden region in the world, and is no longer free from unprecedented challenges caused by global climate change.

Because of geographical, topographical and meteorological conditions, Japan is also prone to natural disasters such as torrential rain, floods, landslides, earthquakes and tsunami. As a disaster-prone country, Japan is keen to support ASEAN's efforts to enhance regional mechanisms under the framework of the ASEAN Agreement on Disaster Management and Emergency Response (AADMER). In this regard, the Government of Japan is proud to support the development of guidelines for flood and landslide risks through the Japan-ASEAN Integration Fund (JAIF), which has played a vital role in Japan's cooperation to support ASEAN's community-building and integration efforts.

The Guidelines for flood and landslide risks were developed with the intention to assist ASEAN Member States in conducting flood and landslide risk assessment. The Guidelines contribute to mapping of flood and landslide risks by integrating climate change impacts at river basin level. It is expected that flood and landslide risks as well as associated vulnerabilities to extreme hydrological events are identified more easily by conducting the Guidelines.

I am confident that the risk assessment methodology presented in these Guidelines will be useful for planning and appropriate decision-making.

Last but not least, I wish to convey my gratitude to everybody who was involved in this valuable project. We are committed to further enhancing Japan's cooperation with ASEAN through the activities of JAIF.

千葉明

H.E. CHIBA Akira

Ambassador of Japan to ASEAN

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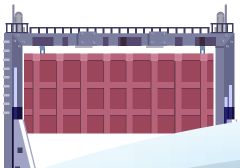

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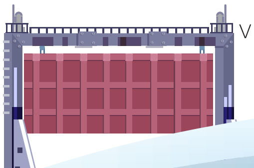
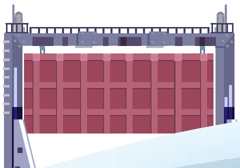
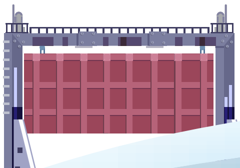




GLOSSARY

Terms	Definitions
Area Drainage Master Plan	A plan which identifies the preferred alternatives of those identified in an ADMS. An ADMP provides minimum criteria and standards for flood control and drainage relating to land use and development.
Area Drainage Master Study	A study to develop hydrology for a watershed, to define watercourses, identify potential flood problem areas, drainage problems and recommend solutions and standards for sound floodplain and stormwater management. The ADMS will identify alternative solutions to a given flooding or drainage problem.
Arithmetic method	This technique calculates areal precipitation using the arithmetic mean of all the point measurements considered in the analysis.
Base Flow	Discharge which enters a stream channel mainly from groundwater, but also from lakes and glaciers, during long periods when no precipitation or snowmelt occurs.
Calibration	In terms of simulation model calibration, calibration means adjusting model's parameters to get more realistic results.
Channel Flow	Flow of water with a free surface in a natural or artificial channel
Climate Change	Changes in climate that are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. (Source: United Nations Framework Convention on Climate Change/UNFCCC)
Cross Section	Section perpendicular to the main direction of flow bounded by the free surface and wetted perimeter of the stream or channel. (ISO 772)
Curve Number	Empirical parameter ranging from 0 to 100 which is used to estimate the runoff coefficient of a given rainfall event from precipitation depth and basin drainage properties.
Digital elevation model (DEM)	Computerized representation of land surface elevation.
Digital Terrain Model (DTM)	In this Project, DTM means the ground elevation excluding height of buildings, houses, trees etc.
Flash Flood	A flood of short duration with a relatively high peak discharge
Flood Control	Various activities and regulations that help reduce or prevent damages caused by flooding. Typical flood control activities include: structural flood control works (such as bank stabilization, levees, and drainage channels), acquisition of flood prone land, flood insurance programs and studies, river and basin management plans, public education programs, and flood warning and emergency preparedness activities.
Flood risk	The level of flood risk is the product of the frequency or likelihood of the flood events and their consequences (such as loss, damage, harm, distress and disruption).

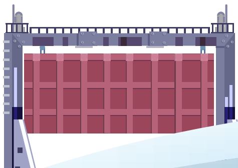
Flow Model	Mathematical or numerical tool that describes and quantifies the various components of the flow of water in a hydrosystem, such as a groundwater flow model, a river flow model or a coupled flow model which contains all components simultaneously.
Gumbel Distribution	Double exponential probability distribution of extreme values of a random variable
Hydrologic Modeling System	Designed to simulate the precipitation-runoff processes of dendritic drainage basins. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.
HEC-RAS	Computer program that models the hydraulics of water flow through natural rivers and other channels. The program was developed by the United States Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction.
Hydrograph	Graph showing the variation in time of some hydrological data, such as stage, discharge, velocity and sediment load.
Hydrology	The scientific analysis of rainfall and runoff, its properties, phenomena and distribution; as well as water dynamics below the ground and in the atmosphere.
Hydrological Model	Estimates the flow in a river arising from a given amount of rainfall falling into the catchment. Such models typically account for factors such as catchment area, topography, soils, geology and land use.
Integrated Flood Management	Integration of land and water resources development in a river basin, within the context of Integrated Water Resources Management (IWRM), with a view to maximizing the efficient use of flood plains and minimizing loss to life.
Integrated Water Resources Management	A process which promotes the coordinated management and development of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
Log-normal distribution	Probability distribution in which the natural logarithm of the random variable is normally distributed.
Model Calibration	Process whereby the parameters of a model are adjusted to obtain a satisfactory agreement between model-generated results and measured variables.
Peak Discharge	Maximum instantaneous discharge of a given stream, shown by the discharge hydrograph, for a specific event.
Probability	A measure of degree of certainty with a value between zero (impossibility) and 1.0 (certainty) that estimates occurrence likelihood, or the magnitude, of an uncertain future event.
Runoff	Surface water resulting from rainfall or snowmelt that flows overland to streams, usually measured in acre-feet (the amount of water which would cover an acre one foot deep). Volume of runoff is frequently given in terms of inches of depth over the drainage area. One inch of runoff from one square mile equals 53.33 acre-feet.



SCS curve number	The runoff curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area.
Ishinara Takase method	One of probability density functions to evaluate the occurrence probability of the event such as rainfall, discharge, etc. based on statistical observation data.
Structural and non-structural measures	Structural measures are defined as physical construction to reduce or avoid possible hazard impacts, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Non-structural measures are those not involving physical construction that use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, and training and education.
Thiessen method	Graphical method for estimating areal rainfall by forming polygons from the perpendicular bisectors of the straight lines joining adjacent rainfall station locations.
Vulnerability	The degree to which a system is susceptible to [damage], or unable to cope with, adverse effects of [climate change], including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (Source: IPCC)

ACRONYMS AND ABBREVIATIONS

Abbreviations	Description
1D	One Dimension
2D	Two Dimensions
AADMER	ASEAN Agreement on Disaster Management and Emergency Response
ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
AMS	ASEAN Member States
APHRODITE	The Asian Precipitation Highly-Resolved Observational Data Integration Towards Evaluation
AR4	The Fourth Assessment Report
CCA	Climate Change Adaptation
CCI	Climate Change Impact
CMIP5	Coupled Model Intercomparison Project Phase 5
CN	The SCS (The US. Soil Conservation Service) Curve Number
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DDM	Department of Disaster Management
DEM	Digital Elevation Model
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DTM	Digital Terrain Model
ENSO	El Nino Southern Oscillation
FIA	Flood Impact Assessment
GCMs	Global Climate Models
GHG	Greenhouse Gases
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HEC-FIA	The Flood Impact Assessment by Hydrologic Engineering Center of US Army Corps of Engineers
HEC-HMS	Hydrologic Modeling System by Hydrologic Engineering Center of US Army Corps of Engineers
HEC-RAS	River Analysis System by Hydrologic Engineering Center of US Army Corps of Engineers or "RAS Mapper"
HEC-SSP	Statistical Software Package by Hydrologic Engineering Center of US Army Corps of Engineers
IFM	Integrated Flood Management
IFRMP	Integrated Flood Risk Management and Planning
IGES	Global Environmental Strategies
IOD	The Indian Ocean Dipole
IPCC	The Intergovernmental Panel on Climate Change



JAIF	Japan ASEAN Integration Fund
JICA	Japan International Cooperation Agency
LS	Lateral Structure
MJO	The Madden-Julian Oscillation
MRI/JMA	Meteorological Research Institute of the Japan Meteorological Agency
NDMO	National Disaster Management Office
RBP	River Basin Pilot
RCMs	Regional Climate Models
RCPs	Representative Concentration Pathways
RIHN	Research Institute for Humanity and Nature
RMSE	Root Mean Squared Error
SCS	The US. Soil Conservation Service
SLSC	Standard Least Squares Criterion
SST	Sea Surface Temperature
XS	Cross Section

Photo: Shutterstock / Phoutthavong Souvannachak

1

INTRODUCTION

The rise in extreme floods, and resultant losses and damage to lives and property, is an indicator of the changing profile of natural disasters in the ASEAN region. Natural disasters in ASEAN, the majority of which are related to water, cost on average in excess of USD4.4 billion each year. This figure would be higher if unprecedented large-scale natural disasters such as Typhoon Haiyan that hit the Philippines in November 2013 were also taken into account[1]. Existing structural and non-structural flood risk management measures are clearly insufficient to cope with these emerging disasters.

The changing intensity, frequency and timing of precipitation is due in part to the effects of climate change. Combined with other human-driven factors such as dense settlements and socio-economic activities in high exposure areas, these calamities are becoming increasingly more severe. A review of global rainfall data by Westra, Alexander, and Zwiers (2012), concludes "rainfall extremes are increasing on average globally." At both the global and regional (Asia and the Pacific) scale, extreme hydrometeorological events are dominant (UNESCAP 2017). Extreme hydrometeorological disasters in Asia and the Pacific accounted for 72 percent of intense natural disasters recorded from 1971–2010 in the region and made up more than half of the increase in frequency of extreme hydrometeorological disasters recorded globally during the decades 1971–1980 and 2001–2010 (Thomas et al., 2013). According the IPCC 1.5°C Special Report on Global Warming, Southeast Asia is a hotspot for heavy precipitation increases. Southeast Asia has significantly stronger increases in projected changes in

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[1] AADMER Work Program 2016-2020

heavy precipitation, runoff and high-water flows at 1.5°C as opposed to 2°C of warming.

Existing flood mitigation structures are outdated or largely ineffective for today's climate induced flood events. A lack of reliable risk assessment of increased rainfall intensity hinders appropriate flood mitigation measures. Flood risk assessment must be multi-dimensional and account for a variety of new factors in today's changing environment. Many recent catastrophic deluges, including the 2011 Thailand floods and those triggered by typhoons such as Haiyan, have revealed that existing river, channel and waterway drainage capacities are inadequate to accommodate the increasing intensity of rainfall runoff events. Water storage dams are limited in number and storage capacity, while natural wetlands are shrinking due to rapid urbanization. Exposure to flood events is further increasing due to unplanned land development and higher concentrations of people in hazard-prone areas, especially cities.

Intensification of climate change impacts and the changing context of extreme floods pose a number of challenges to ASEAN Member States (AMS). Agencies in ASEAN dealing with flood risk reduction face the challenge of inadequate understanding of the nature and scale of disaster risks due to not only the numerous extreme floods over the past decade, but also the likely intensification of the scale of hazards under climate change scenarios. Therefore, questions that must be urgently addressed include:

- What would be the scale and extent of future floods under the changing climate caused by human induced global warming? How can we utilize downscaled climate change projections to assess climate change impacts at the local level?
- How will the decision-making capacity of agencies involved in flood risk management improve to meet the new challenges posed by climate change?
- What kinds of disaster preparedness and planning would be necessary to respond to extreme floods and minimize risks? How can integrated flood management (IFM) as a framework for planning against future risks be adopted and improved?


Photo: Shutterstock / Akarat Phasura

- How are the huge capacity gaps in data availability, tools and human resources for flood risk assessment and implementing integrated flood management addressed?

Climate change challenges mandate a significant overhaul of existing flood risk management systems in order to build a more disaster resilient ASEAN community. Agencies tasked with disaster risk reduction cannot make effective decisions on flood mitigation planning without reliable knowledge on risk levels and factors that contribute to the scale of hazards and damages from recent extreme events, as well as their likely intensification due to climate change. Decisions should take into account resource allocation for reinforcement, upgrading and expansion of hydrometeorological observation systems, improvements in modeling and flood prediction capacity, design of structural and non-structural measures to mitigate floods, and revitalization of preparedness and response systems.

The rapid increase in extreme disaster events and sheer magnitude of resulting losses and damage has come to the attention of the ASEAN community. ASEAN is addressing these new challenges through the ASEAN Agreement on Disaster Management and Emergency Response (AADMER), which provides regional direction on disasters through enhanced cooperation and improvement of joint capacities. Article 5.1 of AADMER asks parties to take appropriate measures to identify disaster risks through addressing natural and human-induced hazards, risk assessment, monitoring of vulnerabilities, and disaster management capacity. The AADMER Work Program 2016-2020 emphasizes, as one out of eight priority actions, the enhancement of risk assessment and improvement of risk awareness in ASEAN through strengthening its risk and vulnerability assessment capacity, improving regional risk and vulnerability data and information and enhancing mechanisms on risk data utilization and information sharing.

In keeping with the AADMER program of work, the Japan International Cooperation Agency (JICA) identified a need for practical guidelines on assessing flood and landslide risks that incorporate climate change impacts at the river basin scale in its project concept note "Strengthening Institutional and Policy Framework on Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) Integration" 20 (hereinafter, CN20 Project). The CN20 Project is one of 21 flagship and priority projects identified by the AADMER Work Program Phase 2 (2013-2015). Building on the outcomes of CN20 project, the ASEAN project Disaster Risk Reduction by Integrating Climate Change Projections into Flood and Landslide Risk Assessment was initiated with financial support from the Japan ASEAN Integration Fund (JAIF) (hereafter referred as ASEAN DRR-CCA Project). The project's goal is to enhance AMS risk assessment capacity through climate risk integration. Two sets of guidelines, for flood and landslide risk assessment, have been developed through the ASEAN project. This volume addresses flood risk assessment.

1.1 Objectives and scope

Extreme hydrological events are on the rise across ASEAN and are expected to intensify in scale and frequency in the future due to climate change. The main objective of these guidelines is to assist AMS conduct flood risk assessments and mapping at the river basin level by integrating projected climate change impacts. These guidelines will enhance AMS decision-making capacity and supplement existing flood risk assessment guidelines. Current guidelines are limited in scope and focus mainly on recurring flood events, with reference to historical trends. These guidelines specifically cover the ASEAN region and should be applied at the river basin level for integrated flood risk management and planning (IFRMP). They will be useful to:

- Identify flood vulnerabilities and risks due to extreme hydrological events and future climate impacts.

- Conduct climate change impact assessments and develop realistic scenarios using hydrological and flood inundation modeling and geospatial tools.

- Identify new, as well as hidden, vulnerabilities and conduct vulnerability and damage assessments.
- Assess and map flood risks under different climate change scenarios.
- Carry out risk planning using the principles of integrated flood management.
- Assist in the application of community-based flood risk management and planning.

1.2 Guidelines structure

These guidelines are divided into three parts (Figure 1.1): preparation, assessment and planning. They provide a holistic overview of risk assessment to assist in decision-making and IFM implementation.

Flood risk assessment starts with preparation, a vital step considering the current lack of readily available data incorporating climate change scenarios for this exercise. Part one introduces preparatory steps for a flood risk assessment, beginning with an outline of flood characteristics and how to identify the key factors responsible for heightened flood impacts. This part defines needed data (such as hydromet, geo-spatial, downscaling of climate scenarios, vulnerability and damages), identifies sources of this data and the agencies and stakeholders involved (their capacities and coordination), and discusses how to organize these sources to develop a flood risk assessment strategy. Preparatory steps are fundamental in order to identify capacity gaps, choose appropriate measures according to local conditions and capacity, and obtain missing information through steps such as primary surveys or monitoring infrastructure installation. This part additionally guides users on improving data monitoring, storage, processing and information sharing among agencies critical for flood risk assessment.

Figure 1.1 Three main parts of the guideline

Part two introduces flood risk assessment and mapping methods and strategies. It is divided into four sections. The first section explains the climate change impact assessment and scenario development process. It is geared toward understanding the basic and recent advances in climate science and effective use of climate predictions for the development of realistic scenarios for planning and implementation. The second section explains the hydrological analysis process, including rainfall, runoff and inundation in order to estimate the severity of hazards or inundations under different rainfall and runoff conditions and climate scenarios. The third section focuses on the key components of a vulnerability assessment, consisting of a damage estimation (tangible and intangible) and vulnerability analysis (including new types). The fourth and final section outlines the process of risk assessment and mapping through integration of climate assessment, hazard analysis and vulnerability assessment results.

Part three of these guidelines covers planning based on the principles of IFM. This part details how to apply risk assessment and mapping for planning and decision-making. It is divided into three sections. The first section details a basin-wide plan that incorporates potential structural and non-structural measures to assist intervention from relevant agencies at the river basin level. These measures might include: structure development for water storage and retention, drainage improvements, dike development, use of natural infrastructure, including vegetation management, hydromet station installation, water level monitoring, organizational reforms, and more. The second section describes local level planning, with a focus on preparedness and response. The third section provides recommendations to relevant line agencies and sectors in regard to roles and responsibilities for short and long-term river basin and flood risk management and planning.

1.3 Guidelines development and target users

These guidelines were developed through a collaborative effort that is an integral part of the ASEAN Project design. The development process adopted both bottom-up and top-down approaches to ensure its applicability and relevance across AMS. It was co-developed with relevant AMS agencies from the local to national level under the direct supervision of a project steering committee headed by the co-chairs of the ADCM Working Group on Prevention and Mitigation. River Basin Pilot (RBP) sites in Myanmar and Lao PDR were used to demonstrate the risk assessment process. The Bago River Basin in Myanmar and Xedon River Basin in Lao PDR were selected as RBPs for flood risk assessment after consultation with relevant stakeholders and upon the recommendation of the disaster agencies the National Disaster Management Office (NDMO) in Lao PDR and Department of Disaster Management (DDM) in Myanmar. Both RBP sites suffer from frequent floods, and have experienced an increase in extreme flood events in recent decades. RBP risk assessment processes are guided by local conditions and existing capacity gaps such as lack of data, human resources and institutional capacity. A dedicated team nominated by a national project committee completes each RBP (Figure 1.2).

The RBP team consisted of technical experts from the Institute for Global Environmental Strategies (IGES), CTII International Co. Ltd., and the Asian Disaster Preparedness Center (ADPC), as well as experts from relevant AMA agencies. Local agencies and stakeholders at each RBP site were involved in the risk assessment process, including risk mapping and flood management plan development. The methodology followed an adaptive approach guided by local conditions, available resources and current constraints. Open source geospatial and modeling tools were used for knowledge management to ensure adoption and continuity of the methodological steps after pilot completion. Each pilot site established an RBP team consisting of members from key line agencies based on host country and project co-chair recommendations. The RBP team gathered necessary data, coordinated with agencies at pilot sites, and assigned staff dedicated to the risk assessment. The RBP team also took the lead in each field survey while the project team (IGES, CTII, ADPC) provided technical support and facilitation. Field surveys concluded with a seminar to review findings, progress, and lessons learned. Experience and outcomes from the RBP site exercise inform these guidelines. Experts from relevant AMS line agencies took part in the risk assessment process and shared their experiences and suggestions for risk assessment and mapping.

The guidelines development process was further complemented by carefully designed case visits in the Philippines, Malaysia, and Japan to gain first-hand experience of flood risk management best practices. This work (Figure 1.3) was integral to the project's flood risk assessment capacity development efforts. This 'learning-by-doing' approach to capacity development was focused on two outcomes: 1) ensuring the transfer of the key knowledge to AMS, and 2) gathering inputs and feedback for development of these guidelines. The Regional Workshop for Development of Guidelines Integrating Climate Change Projections into Flood and Landslide Risk Assessment was held on 13-15 February 2020 in Vientiane, Lao PDR. Participants included the RPB team and experts from relevant agencies. Participants determined the scope of these guidelines and provided suggestions for value addition and revision. These guidelines were also peer-reviewed by agencies and experts from AMS and project co-chairs.

Figure 1.2 Structure of a River Basin Pilot (RBP) in the Project

LAO PDR

Landslide

NDMO
National Disaster Management Office, Social Welfare Department Ministry of Labour and Social Welfare

PTRI
Public Works and Transport Research Institute Ministry of Public Works and Transport

DCCM
Department of Climate Change Management, Ministry of Natural Resources and Environment

Flood

NDMO
National Disaster Management Office, Social Welfare Department Ministry of Labour and Social Welfare

DMH
Department of Meteorology and Hydrology Ministry of Natural Resources and Environment

DWR
Department of Water Resources Ministry of Natural Resources and Environment

MONRE INSTITUTE
Natural Resources and Environment Research Institute Ministry of Natural Resources and Environment

National Project Management Committee

River Basin Pilot (RBP) Team

National Project Management Committee

MYANMAR

Landslide

DDM
Department of Disaster Management Ministry of Social Welfare, Relief and Resettlement

DGSE
Director of Department of Geological Survey and Mineral Exploration Ministry of Natural Resources and Environmental Conservation

DMH
Department of Meteorology and Hydrology Ministry of Transport and Communications

Flood

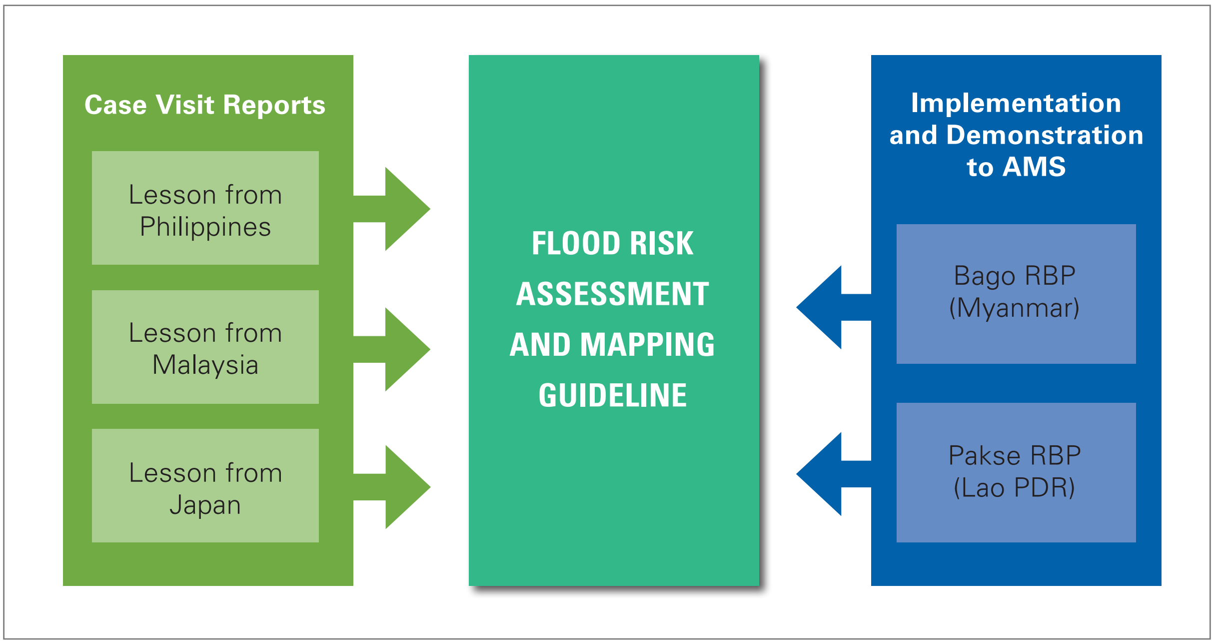
DDM
Department of Disaster Management Ministry of Social Welfare, Relief and Resettlement

IWUMD
Irrigation and Water Utilization Management Department, Ministry of Agriculture, Livestock and Irrigation

DWIR
Directorate of Water Resources and Improvement of River Systems, Ministry of Transport and Communications

DMH
Department of Meteorology and Hydrology Ministry of Transport and Communications

Figure 1.3 The two main information sources used in these guidelines' development



These guidelines are useful for relevant disaster management agencies in the AMS either to conduct a risk assessment or as a reference to design or oversee flood risk management projects outsourced to contractors or consultants. They can also serve as a handy reference for disaster risk management practitioners, including the private sector and development agencies. Their use is expected to improve inter-agency coordination on data organization, management, and sharing for risk assessment, which was a common issue identified during project implementation. In order to address gaps in data, capacity (technical and human resources) and financial resources, these guidelines will advise relevant implementing agencies on choosing the best available approaches for risk assessment under a given situation. These guidelines, together with the methods and results of flood risk assessment in the RBPs and lessons from the case visits, can serve as a risk assessment model for other AMS river basins.

PART I: PREPARATION

Flood risk assessment can be divided into four steps (see box): 1) Gain an understanding of flood characteristics; 2) Identify institutions, tools, resources and team formation; 3) Collect dataset and information; 4) Compile the dataset. These steps will lead to a comprehensive understanding of the risk profile in a given situation and then guide users to adopt the most practical approach for the assessment under given constraints such as dataset, information and tool availability, lack of financial resources, and lack of human, technical and institutional capacity.

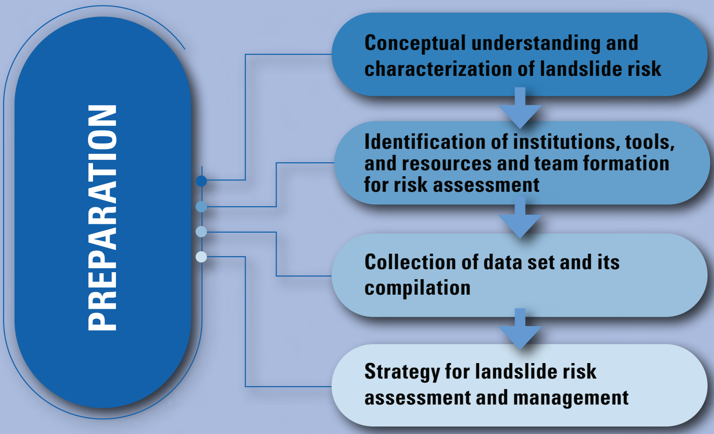


Photo: Township watching based on flood hazard/risk maps in Bago, ASEAN DRR-CCA

2

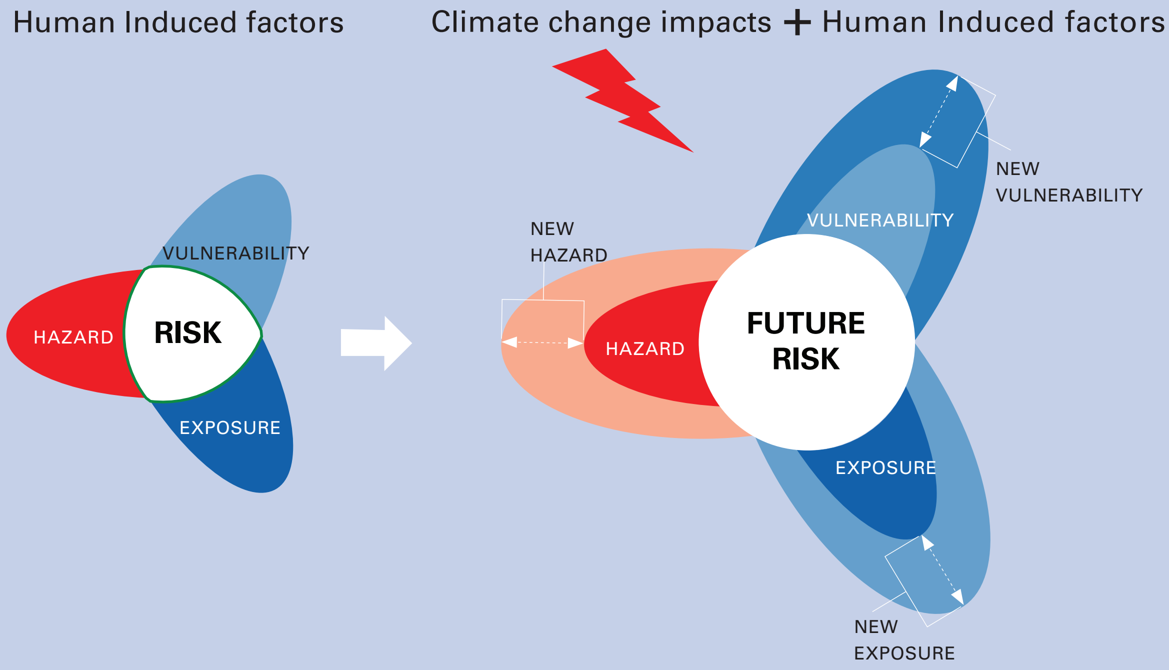
FLOOD RISK ASSESSMENT PREPARATION

2.1 Understanding flood characteristics

Flood characteristics in target river basins or probable flood areas should be clarified and classified at the first stage of risk assessment and mapping. This process starts with a timeline analysis to date of historical major floods and their impacts. A comparison between historical and recent factors and knowledge from floods caused by extreme rainfall events can help create a baseline for the assessment and help identify new risks. For example, the Xedon River Basin (the selected RBP in Lao PDR) experienced large floods from 2008-2020, including in 2008, 2011, 2013, and more recently 2017, 2018 and 2019. Similarly, the Bago River Basin (the selected RBP in Myanmar) suffered from large floods in 2011, 2015 and 2018. The 2018 flood was the most severe in historical recorded.

The current extreme floods mark a shift in hazard characteristics, and thus necessitate a renewed approach to risk assessment. While both RBPs have been experiencing floods on a regular basis and people living there are well adapted for "living with floods", the valuable lessons from historical floods events are not necessarily adequate in the context of recent extreme events that have become more common and are likely to intensify due to climate change impacts. These guidelines stress the need to identify new vulnerabilities and redefine the risk profile with reference to changing flood characteristics (Figure 2.1)

Figure 2.1 Disaster risk as a function of hazard, exposure and vulnerability without (left) and with climate change (right). Climate change impacts are expected to increase disaster risk due to increases in new hazards, exposure and vulnerabilities.



Source: Project Team

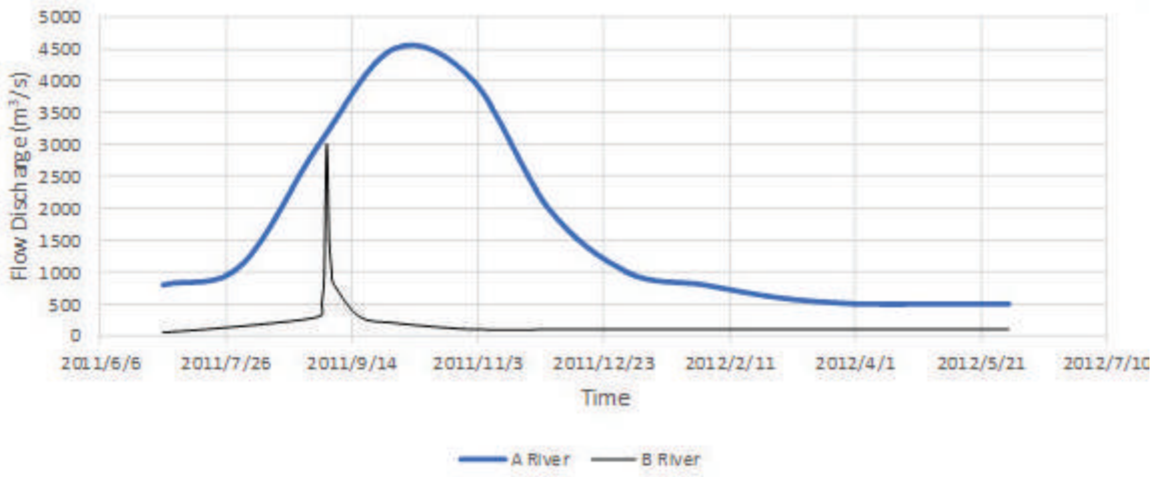
The 2018 Bago River Basin flood was used as a baseline for risk assessment at both RBP sites. Flood characteristics were examined in detail. These included probability, rainfall intensity, inundation type (diffusive or confined, deep or shallow), duration (long or short) and arrival speed (flash or slow-moving). Flood history, local topography, existing mitigation measures, land-uses, socio-economic settings and other factors were also taken into account. For example, observation of flood arrival time and duration characterizes the effect of a rainfall event on a basin in addition to the selection of appropriate response and mitigation strategies (Box 1.1). Further details can be found in the RBPs risk assessment and mapping technical report.

Though the focus of the information above is for floods resulting from meteorological conditions, not all floods fit this scenario. Floods resulting from human infrastructure, such as those caused by backed-up sewer systems, dam breaks, etc. are prevalent in ASEAN. To prevent these floods, flood and water resource facilities should be planned, designed, maintained and operated properly. Current laws and codes that regulate building structure and land use (including forestry and natural water bodies), as well as the absence of these regulations, will impact the severity of flood damage.

Local conditions and characteristics identified in baseline surveys can inform an efficient and effective assessment strategy. This will allow for adherence to procedures during assessment activities that include data collection, inundation and hazard evaluations, climate scenario development, vulnerability and damage assessment, risk analysis, establishment and verification of risk maps, disaster risk management planning, and other activities.

Box 1.1 Flood duration (long or short) and arrival time (flash or slow moving)

The below figure illustrates long and short duration floods using a discharge hydrograph of two hypothetical rivers (A and B). The flow discharge of River A reaches its peak at approximately three months and reduces to normal discharge gradually, with total flood duration at approximately six months. River B takes just one day to reach peak discharge, with a total flood duration of two to three days. In terms of arrival time, River A would generally be categorized as slow moving and River B as flash. The Mekong River and Chao Phraya River that runs through Bangkok in Thailand are categorized as River A types, taking longer to hit their peak and having longer flood duration, while the Xedon (a tributary of the Mekong) and Bago (in Myanmar) Rivers can be categorized as B River types, with floods moving from upstream to downstream rapidly.



Source: Project Team

2.2 Institutional arrangements, information sharing, tools and resources, and risk assessment team formation

An understanding of institutional arrangements at different agency and policy levels, as well as their coordination mechanisms and capacity, is essential for flood risk assessment and mapping. The current state of key institutions and agencies determines the level of effort needed for conducting the risk assessment as these institutions might be the only source of critical information for a number of important evaluations, including those on location, range and degree of past flood damage, current land use conditions, hydro-meteorological data, topological and geological data, public infrastructure, agricultural areas and products, and buildings and houses. These entities often have the capacity to allocate resources and engage relevant staff, in addition to holding decision-making authority. Similarly, they are responsible for risk assessment coordination and facilitation through provision of data, resources and technical and support staff. Therefore, a robust information sharing policy should be implemented among relevant ministries and authorities to systematically share and provide data for the risk assessment.

The formation of the RBP team for this project was designed to engage key institutions and ensure the participation of relevant staff for the entirety of the risk assessment and mapping. Implementing agencies' understanding of roles and responsibilities division will guide and define the requirements and evaluation for key experts or specialists that carry out the risk assessment, even if that expertise is outsourced to consultants or outside firms.

Examining existing capacity and gaps in the collection and sharing of information such as hydro-meteorological, geospatial, waterways and channels, flood mitigation infrastructure and facilities, exposure and damage data should run parallel to the institutional knowledge attainment process. In addition to information, the risk assessment and mapping will require tools such as hydrological models and GIS systems. Data, information, tools and resources are often spread across line agencies and stored and retained at different hierarchical levels by more than one of the agencies. Failure to identify and streamline these components before undertaking the analysis will result in time, cost and effort waste, and potentially create friction among agencies.

After relevant institution and agency identification and capacity mapping, the next step is to form a team with clear demarcation of roles and responsibilities. Ideally, the team should include technical experts, representatives of concerned agencies (such as water resources, water works and river engineering, meteorology, agriculture, forestry, local authorities responsible for DRR, etc.), local stakeholders and community members from at-risk populations, including vulnerable groups such as the elderly, women, children, and the differently abled. However, team members should be able to work flexibly, and if necessary, individually, or in different group settings depending on the activity and responsibility. For example, technical members in most cases will lead and execute the entire risk assessment, while the involvement and inputs from stakeholders or agencies could be limited to specific processes. The intent is to ensure inclusiveness and meaningful participation so that all necessary factors and criteria are incorporated in the risk assessment process. The team should be need-based and agile, with a clear understanding of individual roles and responsibilities at each stage of the assessment. The RBP team and active involvement of stakeholders and vulnerable groups in this project serves as a useful example of team formation for risk assessment, mapping and planning.

2.3 Dataset and information preparation

The preparation of the dataset and information such as long-term hydrological, climatology, topography and socio-economic data is the core of the risk assessment and mapping process. Assessment results will largely depend on dataset quality. Essential data and information for the


Photo: Baseline survey in Bago, ASEAN DRR-CCA

hydrological analysis, risk analysis and simulation modeling must be itemized and follow the means and objectives of the risk assessment and mapping process. Missing or unavailable data or information must be found through alternative approaches by using either reference data, or if possible, by conducting surveys. Recommendations on how to obtain and observe data/information are provided in the relevant sections of these guidelines.

The three flood risk dimensions – hazard, vulnerability and exposure – are illustrated in in the Venn diagram in Figure 2.1 above. These dimensions can be used to categorize assessment data and information. Additional data needs for hydrological and hydraulic modeling to evaluate flood hazard conditions in accordance with procedures for flood risk mapping are explained below in this section. The hydrological and hydraulic models and geospatial tools serve as a platform to assess the flood risk.

Data collected for hazard analysis is classified into three categories: spatial data, hydrological data, and hydraulic data. Other data types are used for exposure analysis, vulnerability assessments, and global data. For example, the construction cost for buildings, income for agricultural products, labor fee, indirect cost rate etc. are also necessary for vulnerability analysis. This is explained in the chapter of vulnerability analysis.

2.3.1 Spatial data

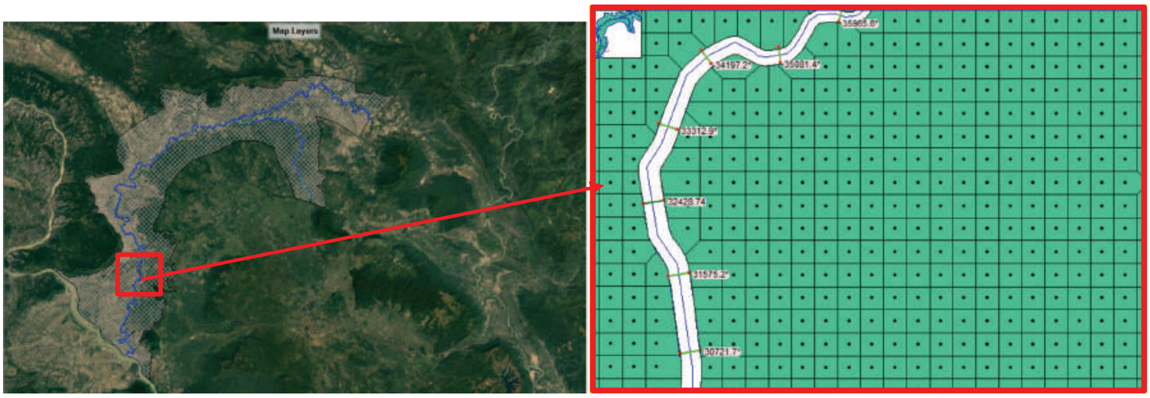
Information that includes catchment boundaries and land cover and use, as well as results from digital elevation (DEM, see Box 1.2), and digital terrain (DTM) models, is necessary to set modeling parameters such as catchment system size, water flow direction, slope gradient, permeability, run-off coefficients, and other measures. DEM and DTM are important for establishing hydrological and hydraulic simulation models to delineate basin boundaries, extract river systems and calculate surface water flow directions and amounts. Spatial data must be digitized for organization and processing in a GIS environment (such as QGIS). The data will then be fed into flood risk assessment tools such as the HEC series software used at the RBP sites for demonstration.

2.3.2 Hydrological data

Hydrological data (Table 1.1), especially on discharge and, most importantly, rainfall, is essential for hydrological analysis and modelling. Discharge and rainfall data is also utilized for statistical analysis to estimate the probability of flooding. Discharge and water level data is employed to calibrate and validate the hydrological model by comparing observed and estimated

Box 1.2 Digital elevation model (DEM) concept

The grid area identified in the left satellite image shows a flood plain area of the Xedon River Basin in Lao PDR. Elevation data is assigned to each grid as shown in the figure on the right. This data is essential for determining slope gradient and flow direction.



Source: Project Team

(simulated by the model) data. The intervals between data collection should be decided according to the timing and duration of past floods in the target area. In cases where there are few or no hydro-meteorological stations, satellite image data can be utilized for support.

2.3.3 Hydraulic data

Hydraulic data is defined as information about river structures that may affect river hydraulic conditions. Hydraulic data is incorporated into the simulation model to determine the effect of hydraulic factors on flows. Relevant data to collect for this process is listed in Table 1.2. Structural information such as location, dimensions and plan views, as well as function and roles, should be collected and summarized before the analysis.

2.3.4 Exposure Data

Exposure data collection involves the identification and quantification of elements exposed due to a specific hazard condition. This data is based on the distribution and magnitude of recent and historical flood impacts. Exposure data is necessary for delineating the flood risk area and estimating flood damages. Table 1.3 shows data types and variables.

Table 1.1 Hydrological Data

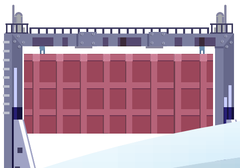
Category	Type of Data	Typical Data
Hydrological Data	Water level and discharge	Long-term daily time series data for statistical analysis and hourly level time series data to calibrate models during flooding.
Meteorological Data	Rainfall	Long-term daily time series data for statistical analysis and hourly level time series data to calibrate models during flooding.
Observatory	Hydrological station and meteorological station	Meta data such as location, observation period, monitoring parameters, record intervals, etc.

Table 1.2 Data for Hydraulic Conditions

Category	Type of Data	Typical Data
Rivers, channels, lakes and ponds	Main river, tributaries and artificial channels, bathymetry data	Condition of river and channel networks, cross-sections, longitudinal profiles, etc.
River structures	River crossing structures	Bridges, dams, weirs, levees
	Lateral structures	Dykes, overflow dykes, drainage outlets, water intake gates, structures hampering water flow, etc.
	Channels	Diversion channels, spillways, dewatering channels, short-cut channels, etc.
	Other structures	Retention ponds, pumping stations, etc.

Table 1.3 Exposure data

Types	Type of Data	Typical Data
Past flood records	Location and number of affected people Location and number of affected houses or buildings, agriculture, livestock, industry, service and trade sector assets Flooded (damaged) areas House, building and infrastructure flood damages (costs)	
Spatial distribution and number	Houses, other buildings (including cultural heritage) and farmland Infrastructure (bridges, roads and railways, hydrotechnical works, electricity, water, gas and oil networks)	



2.3.5 Vulnerability assessment data

A vulnerability assessment is a complex process as it involves both quantitative and qualitative variables. The quantification of loss and damages for each exposure variable in a specific flood event (i.e., hazard) can then be used as input for a vulnerability assessment. Qualitative input, on the other hand, relies on factors that are difficult to quantify and express directly, such as perception, priorities, sensitivity and adaptive capacity.

One common approach to a flood risk assessment is development of a damage function. Data for this approach can be collected from both primary sources (such as an household survey, Appendix 4), or secondary sources (published data). Several precautions should be taken during the damage function development process. The most important precaution is to clean up units and missing or misused decimals (for example, commas in place of periods) as these mistakes can lead to data errors. Additionally, it is important to check the reported depth and duration values with the flood simulation results. This can help identify erroneous results or assumptions made in the flood simulations. Another important check to perform is whether same-year data has been reported in different flood severity categories. If several years of data are being collected, the respondent should be informed and the data must be entered to capture the temporal variations in flood and damage characteristics.

If there are multiple flood events in a single year, it is important to include the highest and longest floods in the depth-duration-damage analysis since the emphasis is on planning for the worst-case scenario. It is possible that the data for some damage or depth classes is missing from the sample. To avoid such a situation, survey data should be checked on a daily basis and cover additional samples, if necessary. Finally, damage rates can be expressed as a percentage of the physical structure damaged by eliminating limitations associated with economic valuation, such as changes in costs, inflation, quality of material, etc.

2.3.6 Global Data

If data for the assessment is missing or not available, global data could be used to help fill this gap. Table 1.4 shows a selective list of data available from different sources. This table should serve as a beginning reference point. ASEAN member states are encouraged to maintain and expand an updated list of common use data sources.

Photo: Interviews and hearing about the flood conditions in Bago, ASEAN DRR-CCA

Table 1.4 Global data and information sources[1]

Data type	Source	Open database example
DTM	USGS (United States Geological Survey)	SRTM Global DEM, ASTER G-DEM
Land cover and land use	National Cartographic Institute (US)	Global Land Cover from different organizations (NASA, FAO), GlobeCover from Envisat/Meris, MODIS GlobeCover
	USGS	GLCC (Global Land Cover Characterization)
	SERVIR MEKONG Project (funded and implemented by USAID, NASA, ADCP and ICIMOD)	Land cover portal
River hydrography	USGS	Hydrosheds
Rainfall data	National hydro-meteorological services	Gauge data sets, satellite-only data sets and merged satellite-gauge products
	JAXA	JAXA global rainfall watch
	NASA	Experimental Real-Time TRMM Multi-Satellite Precipitation Analysis
Stream flow	National hydro-meteorological services	Global Runoff Data Centre
Geologic/ pedologic/soil parameters	National cartographic institute	Harmonized world soil database
Dams	National dam regulation body	Global reservoir and dam database

[1] Data sources, including web address, are subject to changes. This list may not be fully inclusive.

2.4 Compilation of necessary data

Before utilizing the collected data, each data type, including historical and recent, should be checked for reliability based on correctness, consistency, and completeness. The reliability check and corrections are critical to ensure accuracy in the risk assessment and mapping process. For example, the temporal and spatial distribution of rainfall and discharge is key data for the modelling. Temporal is the main input data. Spatial data is used as an indicator to evaluate the model's accuracy. The relationship between rainfall and discharge in a basin should be consistent. Hydrological analysis results, such as the single mass-curve, double mass curve and run-off coefficient, will be helpful in determining the reliability of rainfall and discharge data. If the rainfall and discharge data is inadequate or missing, (1) the discharge data should be deselected to verify the simulated discharge hydrographs, and (2) the rainfall data can be compensated for or corrected by a gap-filling method based on other rainfall station data or satellite rainfall data.

Information often comes from different formats and widely distributed sources. Data compilation and prepressing are basic steps that need to be taken before embarking on the assessment process. Typically, there are two types of data: (1) observed raw data that must be preprocessed before use, and (2) processed data for factors such as rainfall and discharge that can be used directly after basic checks for accuracy and missing data. Processed data is a derivative of raw data and often the result of a more complex process to ensure accuracy.

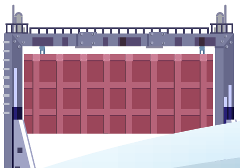
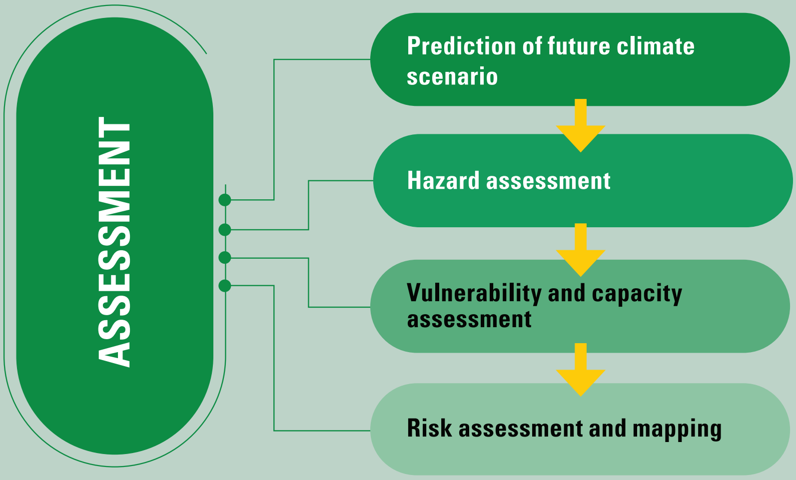


Photo: Interviews and hearing about the flood conditions in Bago, ASEAN DRR-CCA

PART II: ASSESSMENT

A flood risk assessment can be divided into four sections: (1) Prediction of future climate scenarios, (2) Hazard assessment, (3) Vulnerability assessment, and (4) Risk assessment and mapping. Based on purpose and data and resource availability, an appropriate and achievable strategy for the assessment will need to strike a balance between required effort and available capacity.



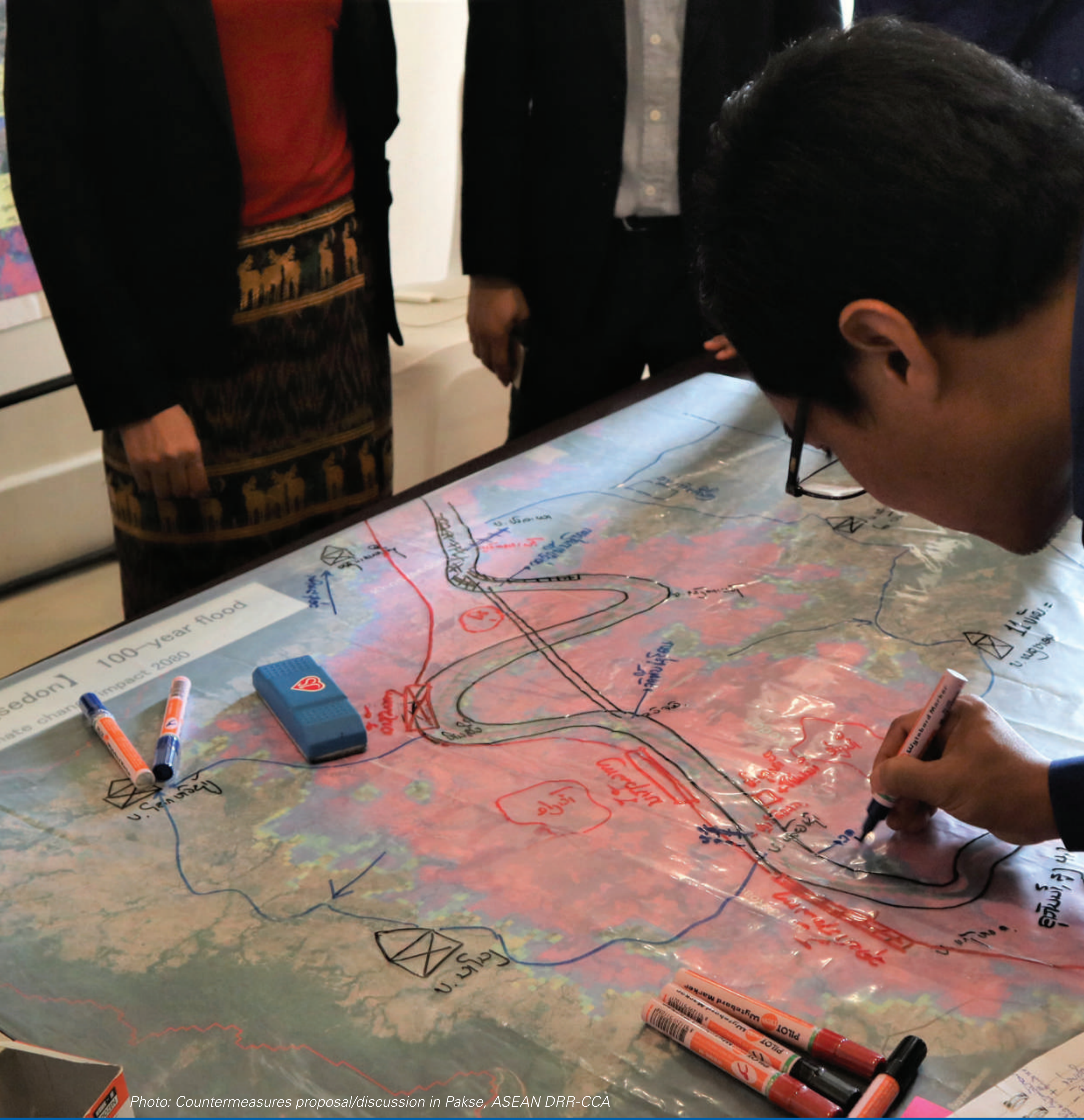


Photo: Countermeasures proposal/discussion in Pakse, ASEAN DRR-CCA

3

PREDICTING FUTURE CLIMATE CHANGE SCENARIOS

The objective of an impact analysis is to assess the effects of climate change on social, ecological, and physical systems by using current trends in applicable climate parameters and observed impacts of these trends on social, ecological, and physical systems, as well as development of climate scenarios for the appropriate time frame, and at appropriate temporal and spatial scales (ADB, 2017). This section introduces recent advances in climate scenario development and explains its application for flood risk assessment and mapping.

One of the critical challenges for climate change scenario development for flood risk assessment is downscaling global and regional projections to a river basin. This process is often fraught with high degree of uncertainty, and utilizing these downscaled projections at the local or river basin level is not straightforward. A cautious approach to the process should be adopted, ensuring results reflect the local context. A good understanding of data and climate simulation and projection mechanisms and uncertainties is essential in order to properly assess risks in a given local context and develop realistic scenarios. The whole process should be designed so that decision makers will be able to understand, interpret and use the results from climate simulations and projections, and then develop realistic scenarios for planning, design of mitigation measures and implementation.

A changing climate may lead to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate-related events, and can result in unprecedented extremes (Seneviratne et al., 2012). Weather or climate events that are not extreme statistically can still cause extreme conditions or impacts, either by crossing a critical threshold in a social, ecological, or physical system, or by occurring simultaneously with other events. Some climate extremes may not be the result of a single event but rather the accumulation multiple single events (Seneviratne et al., 2012). In a changing climate, determining whether a rise in recurring extreme events is natural, or an indication of a changing profile for weather related events, is indispensable. This leads to three types of challenges: (1) to understand and attribute the contribution of global warming for triggering extreme hydrological events at a given scale, intensity and frequency, (2) to predict by how much global warming induced climate change is going to escalate the extreme hydrological events of the future, and most importantly, (3) how to correctly predict abnormal changes in a hydrological event at a given spatial scale and use this prediction for decision-making.

3.1 Dataset for predicting future climate scenarios

Climate projections are widely used to understand climate extremes and the probability of extreme events occurring in the future. The construction, assessment, and communication of climate change projections, including regional projections and extremes, is drawn from four sources (Seneviratne et al., 2012; Christensen et al., 2007; Knutti et al., 2010):

(1) Global Climate Models (GCMs)
(2) Downscaling of GCM simulations
(3) Physical understanding of the processes governing regional responses
(4) Recent climate change history

The Fourth Assessment Report (AR4) of the IPCC used GCMs as the main source of regional information on the range of a possible future climate, including climatic extremes (Christensen et al., 2007). The AR4 concluded that extreme event statistics from the present-day climate, especially those regarding temperature, are well simulated by current GCMs at the global scale, though extreme precipitation events are not (Randall et al., 2007). Improvement in GCM spatial resolution and complexity could be useful for investigating smaller-scale events, including changes in extreme weather.

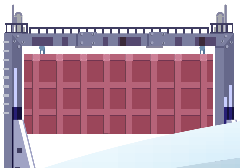
Global and regional historical meteorological datasets are available from several sources. Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) precipitation data from 1981 to the present is available from the Climate Hazard Group (CHG) with 5x5 km2 resolution. The Asian Precipitation Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) project precipitation data from from the Research Institute for Humanity and Nature (RIHN)/ the Meteorological Research Institute of the Japan Meteorological Agency (MRI/JMA), from 1951 to 2007 with a 25x25km2 resolution is also available. For temperature, fifth generation ECMWF atmospheric re-analysis of the global climate (ERA5) re-analysis temperature data from 1950 to the present is available.

In addition to these information sources, meteorological data (rain gauge and tem perature) over a longer period is also needed to verify results.

3.2 Developing Climate Change Projections

Future climate change studies, including flood risk assessments, will require projection of climate variables such as rainfall, temperature, wind, sea

The Intergovernmental Panel on Climate Change (IPCC)'s Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA) also provides general guidelines on the use of data and scenario in impact and adaptation assessments.
http://www.ipcc-data.org/guidelines/#ClimScenSD

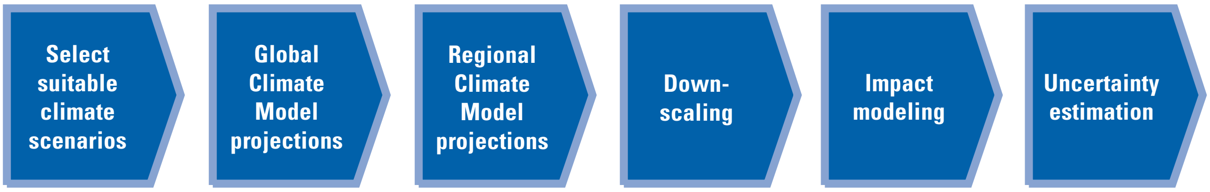


level rise, etc. For flood risk assessments, the change in rainfall is the key study variable.

Climate projections provide a prediction of a future climate using assumptions on future human activities such as socioeconomic and technical developments based on current activities, lifestyles and progress. Projections usually stem from global climate models (GCMs) or regional climate models (RCMs).

Before using climate projections for a flood impact model, they should be processed and downscaled to characterize the assessment area climate. Figure 3.1 illustrates the process of developing a climate change projection based on project methods. A detailed process and resulting outcomes can be accessed in the adjoining flood risk assessment technical report in the RBPs.

Figure 3.1 Proposed climate projection development process

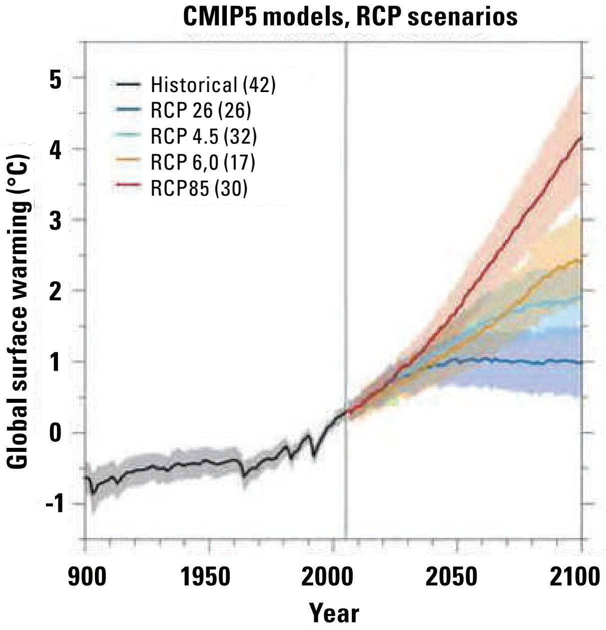


3.3 Selecting suitable climate scenarios

A Climate scenario is a representation of the future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change (IPCC, 2018). Here it refers to Representative Concentration Pathways (RCPs) that project the atmospheric concentration of greenhouse gases.

Climate scenarios drive input into General Circulation Models/Global Climate Models (GCMs). RCPs describe different climate futures, all of which are the result of consideration for future emission greenhouse gas (GHG) volumes. There are four RCP pathways: RCP8.5 (high emissions), RCP6.0 (intermediate emissions), RCP4.5 (intermediate emissions) and RCP2.6 (low emissions).

The goal of a climate scenario is not to predict the future but to better understand uncertainties and possible alternatives to probe the feasibility of decisions or options under a wide range of possible futures.



Source: ccii.org.nz

For more information: https://www.ipcc-data.org/guidelines/pages/glossary/glossary_r.html

3.4 Global Climate Model projections

Global Climate Models (GCMs) are mathematical representations of the climate system that are run on high-performance computers. GCMs are coupled ocean, atmosphere, sea ice and land surface systems that use emission scenarios (RCPs) for projecting the future climate. The Coupled Model Inter-comparison Project Phase 5 (CMIP5) is the latest dataset group with simulation available from the new generation of GCMs (Rupp et al., 2013). The 40 plus GCMs in the CMIP5 archive have different spatial resolution and have been developed by various meteorological organizations and other agencies. In the fifth assessment report of the IPCC, climate simulations for the 21st century have been completed according to RCPs based on four greenhouse gas concentration trajectories (Demirel and Moradkhani, 2016).

More info: https://www.ipcc-data.org/guidelines/pages/gcm_guide.html

GCMs may have significant biases that vary between models, climate variables and regions. To address this variability for an impact assessment, a mix of GCM model results is recommended. At least three GCMs that fall into low, medium and high scenario projection should be used. For assessments that focus on extreme events, GCMs that represent the highest and lowest extremes should be selected to fully capture climate change variability.

How to select suitable GCMs for a study

Not all GCMs in the CMIP5 are applicable for all global regions. GCMs that are selected should be based on region or area of interest. The GCM can be based on published reports and journal papers, as well as a historical climatological analysis. Following are descriptions of these two methods.

- ***Literature review:*** A comprehensive review of published reports and peer-reviewed journals can help to identify a GCM suitable for the region or area of interest. For the RBPs in Myanmar and Lao PDR that inform these guidelines, the report Evaluating the Performance of the Latest Climate Models Over Southeast Asia published by CSIRO Australia for the Asian Development Bank (ADB) was used to identify and select suitable models for the Southeast Asia region (Table 2.1) (Hernaman et al., 2017). A subset of CMIP5 models in the report was identified based on metrics that left out the least realistic models but included models that captured the maximum possible range of change with satisfactory performance across all the metrics [67].

GCM data can be accessed from:
IPCC Data Distribution Centre: https://www.ipcc-data.org/index.html

The Earth System Grid - Center for Enabling Technologies (ESG-CET)
http://esgf-node.llnl.gov/

The following 11 GCMs are considered to be satisfactory for Asian and Southeast Asian countries
Hernaman V, Grose M and Clarke JM (2017) Evaluating the performance of the latest climate models over Southeast Asia. CSIRO, Australia

bcc-csm1-1, BNU-ESM, CanESM2, CMCC-CM, CSIRO-Mk3-6-0, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, IPSL-CM5A-MR, MPI-ESM-LR, MPI-ESM-MR

Some countries have selected GCMs suitable for their local context.

Vietnam: CNRM-CM5, CCSM4, NorESM1-M, ACCESS1.0, MPI-ESM-LR, GFDL-CM3
Technical report on High-Resolution Climate Projections for Vietnam published by IMHEN (2014)

Indonesia: MIROC5 (BMKG-Indonesia)

Thailand: IPSL-CM5A-MR, GFDL-CM3 and MRI-CGCM3 [Thailand-Third National Communication]

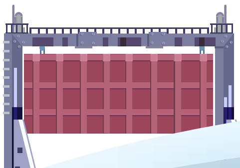


Table 2.1 Selected Global Climate Models for the Southeast Asia Region

GCM	Modeling Group
ACCESS1.0	CSIRO and BoM, Australia
bcc-csm1-1	Beijing Climate Center, China
BNU-ESM	Beijing Normal University, China
CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada
CMCC-CM	The Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy
CNRM-CM5	National Centre for Meteorological Research, France
CCSM4	National Center for Atmospheric Research, USA
CSIRO-Mk3-6-0	CSIRO Atmospheric Research, Australia
GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, NOAA, USA
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France
MIROC5	Center for Climate System Research, Japan
MPI-ESM-LR, MPI-ESM-MR	Max Planck Institute, Germany
NorESM1-M	Norwegian Climate Center, Norway

- ***Climatological analysis:*** A historical climatological analysis can be completed for the area or region using key weather and climate processes such as monsoon patterns, the Madden-Julian Oscillation (MJO), the El Nino Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), tropical cyclones, sea surface temperature (SST) and surface rainfall and temperature patterns and trends. As with the literature review, this analysis will help identify a subset of CMIP5 models based on metrics that left out the least realistic models but included models that capture the maximum possible range of change with satisfactory performance across all the metrics.

3.5 Regional Climate Model projections

Regional climate models (RCMs) (Table 2.2) are widely used to produce climate information on a regional scale to support regional climate variability and change studies. While GCM simulations drive RCMs, they have advantages in that they cover a specific geographical area and have better resolution than GCMs. RCMs can also realistically simulate climate parameters as they capture the regional topography and land surface features well. RCMs have their own biases, in particular in relation to the physical

Table 2.2 Common Regional Climate Models

RCM	Developer
PRECIS	Met Office, UK
RegCM	International Centre for Theoretical Physics (ICTP), Italy
WRF	National Center for Atmospheric Research (NCAR), USA

parameterization used for describing sub-grid scale climate features. RCM projections therefore also suffer from variability.

To address this variability when completing an impact assessment, a mix of RCM model results is recommended. At least three RCMs that fall in the low, medium and high scenario projections should be used. In studies focused on extreme events,, the RCMs representing the highest and lowest extremes should be selected for the impact assessment to fully capture climate change variability.

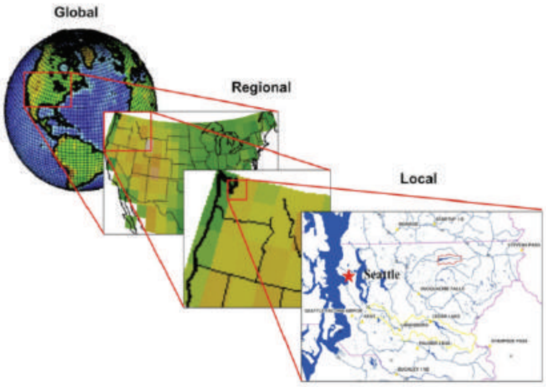
3.6 Downscaling

Assessments of climate variables that are simulated by the GCMs are global in scale and are not generally appropriate for assessing climate change impacts at regional and local levels for decision-making processes in sectors such as agriculture, health, transportation, energy and water resource management. Scientists have therefore taken steps to translate the global data from GCMs for use in regional and local impact analyses (Figure 3.2). This process is known as 'downscaling'.

There are two general approaches: statistical and dynamical downscaling. Statistical downscaling uses statistical relationships from GCMs to predict local climate variables [Benestad et al., 2008; Wilby et al., 1998]. Dynamical downscaling uses RCMs to dynamically extrapolate the effects of large-scale climate processes to regional or local scales of interest.

Statistical downscaling was used for the RBPs in these guidelines. A straight bilinear univariate resampling method has been used to convert 25km x 25km resolution precipitation data into a 1km x 1km resolution grid. The APHRODITE data set is used as the reference surface to resample precipitation surface. This resampling process can generate approximate patterns as per the reference data surface and it doesn't disturb the pattern of the original GCM. Downscaling to 1km x1km was carried out in selected GCMs using the above process. Downscaled 1km x 1km resolution datasets were used for developing future climate projections and hotspot analyses for target areas.

Figure 3.2 Downscaling Approach



RCM driven downscaled data can be accessed from:
CORDEX East Asia: https://cordex.org/domains/region-7-east-asia/

Bias correction and statistical downscaling dataset:
NASA Earth Exchange Global Daily Downscaling Projections:
https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp

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National Level Approaches:

Indonesia: HadGEM2-ES (RegCM4 RCM Driven) [Indonesia-Third National Communication]

Philippines: HadCM3Q (PRECIS RCM Driven)

Thailand: MPI-ESM-MR and EC-Earth (RegCM4 RCM Driven) [Thailand-Third National Communication]

Vietnam: CNRM-CM5, CCSM4, NorESM1-M, ACCESS1.0, MPI-ESM-LR, GFDL-CM3, HadCM3Q
(CCAM, RegCM4, PRECIS RCM Driven) (Technical report on High-Resolution Climate Projections for Vietnam published by IMHEN (2014))

It could also be possible to get locally downscaled dataset accessed from mandated national institutes such as National Hydro-meteorological Services, Climate Change Studies Institutes, and similar organization of each country.

3.7 Impact modeling

Climate projections provide a range of possible future climate scenarios and are not climate predictions. Projections should therefore be used for guidance only for impact assessment, planning and decision-making. Below is a summary of the key actions for climate projection data preparation for an impact assessment.

- Based on the region or area of interest, select an applicable subset of GCMs from those available.
- Use your selected models to capture the full range of potential future climate change. Adoption of a multi-model approach for both GCMs and RCMs is preferable. For probing future extreme conditions, GCMs and RCMs that generate extreme conditions using a stable scientific method are recommended.
- To ensure climate variation and variability are correctly accounted for in climate change projections, use an appropriate length of time, for example 20-30 years for the baseline period and the same number of years for the future period. Downscaled projections using RCMs or other methods should be combined with relevant GCM information, as the downscaling may not have the same reliability as the GCM projections.
- For comparing projections with different emission scenarios, use the same set of selected models (GCMs and RCMs), for example comparing outputs for RCP4.5 against outputs for RCP8.5. Similarly, since there is no internal consistency, do not mix the results of different climate variables obtained from different models. For example, do not use temperature projection from one GCM or RCM and precipitation projection from another GCM or RCM.
- It is important to address biases in model results. This can be done by converting results to changes with respect to a baseline period, or by using an applicable bias correction approach.
- Emission scenario selection depends on the timeline being used. For near-future predictions, it may not be necessary to use a full range of emission scenarios, as these scenarios may not have significant differences. On the other hand, medium and distant future projections – those for adaptation and planning purposes – should utilize multiple scenarios.

3.8 Estimating uncertainties and flexible decision making

Uncertainties in climate projection development are inherent as this action involves downscaling of global climatic phenomena to a regional and then local scale (for example, RBP sites). Knowing the factors responsible for uncertainty helps users understand and interpret the results of impact modeling for decision-making.

Two factors should be considered when addressing uncertainties in climate modeling. First is the uncertainty related to the GCM itself, for example, that related to climate system response and natural variability. Second is uncertainty in future emissions and concentration of greenhouse gases (GHGs). GCM uncertainty can be adjusted and minimized using projections from a range of GCMs with different initial conditions. The uncertainty in future GHG emissions and emissions concentration can be addressed using a number of carbon cycle and atmospheric chemistry models and climate models with a range of emission scenarios.

The selection of best available approaches or strategies for climate modelling and projections does not indicate completeness as uncertainties can never be eliminated in their entirety. Results are therefore not meant to be adopted directly, and instead should be used to provide a range of possible future climate. Projection values are useful for guiding thinking and the overall impact assessment. Users should be flexible in their planning and adopt an adaptive management approach to allow for change as more information becomes available through observational-based monitoring, scientific research, and evaluation.

Photo: Philippines Case Visit (PAGASA), ASEAN DRR-CCA

4

HYDROLOGICAL AND HYDRAULIC ANALYSIS FOR FLOOD HAZARD ESTIMATION

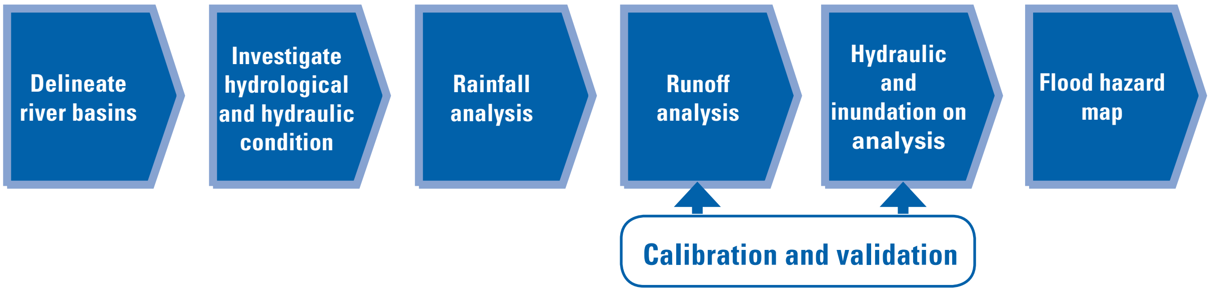
A hydrological analysis is the core component of a risk assessment as it allows for identification of inundated areas and an estimation of flood extent. The analysis assesses likely changes in the scale of flooding in the future and can be conducted with and without climate change impact conditions. For the project, a flood analysis model using the HEC series – a free software program produced by US Army Corps of Engineers – was used to demonstrate the hazard assessment process. The HEC series is already used by AMS agencies responsible for flood and water resource assessments. The models are applied to confirm flood hazard indicators and flood damage and risks. This holistic hydrological analysis procedure and its processes, including methodology and expected outputs, is further explained in this section.

The RBP hazard assessment main steps are illustrated in Figure 4.1. The functions of the HEC series as hydrological analysis tools, as well as the detailed process of hazard assessment adopted in the RBP, will be shared for cross-reference in a separate technical report.

4.1 River basin delineation

A river basin is an area of land characterized by surface water draining into the same outlet through a major river and its tributaries. Delineating the boundary of a river basin is a fundamental step in hydrological modeling used to understand catchment areas and estimate the amount of water conveyed at the basin outlet.

Figure 4.1 Proposed hazard assessment steps



Digital Elevation Models (DEM) or Digital Terrain Models (DTM) are used as inputs for common GIS software. For the project, QGIS was used for processing the spatial information, including the DEM/DTM. However, the integrity of the delineated boundary depends on the resolution and accuracy of the DTM data. A manually delineated boundary based on topographic maps is often recommended in addition to the DEM to confirm integrity. To conduct a flood inundation analysis, a DTM is better than a DEM to collect ground elevation data because a DEM sometimes includes the height of trees and buildings.

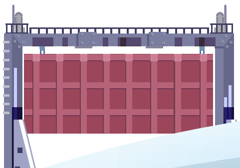
After identifying the basin boundary, another important step is to delineate the sub-river basin drainage system. Important drainage systems such as tributaries should be selected for delineation using variables that include regional rainfall distribution, sub-basin size, average elevation, monitoring station location, etc. DEM or DTM resolution largely dictates the accuracy of the drainage system delineation, which is critical for run-off analysis. Irrespective of DEM or DTM quality, some level of biasing and field verification is always necessary. For example, in areas where the elevation gradient is small, determining drainage direction is very difficult and requires field verification. A drainage system at the plains level, especially in the lower river basin, is sometimes hampered and controlled by artificial structures. The influences of existing structures should be considered when dividing sub-river basins in plain areas.

The methods for delineating a basin boundary in a GIS environment (by Arc-GIS or Q-GIS) can be found in the following YouTube videos.

- How to Use a DEM to Delineate a watershed/basin in ArcGIS: https://youtu.be/1dJvvk85n1k
- Stream and Catchment Delineation in QGIS 3: https://www.youtube.com/watch?v=Ro-RRzMMw-c

Table 3.1 Hydrological and hydraulic conditions information collection

Category	Type of Data
River-canal-lake networks	Length, width, cross-sections, location and bathymetry data for lakes and ponds
River structures	Bridges, dams, levees, dikes and structures hampering water flow
Topology	Topological maps, DEM and DTM
Land cover maps	Vegetation and land use, surface geological maps
Other structures	Infrastructure affected by hydraulic and hydrological conditions
Hydrology	Isohyetal maps, hydrogeological maps, temporal runoff patterns during floods, extreme values of daily and hourly rainfall, rainfall intensity curves, typhoon and cyclone courses, flood experience maps



4.2 Investigation of hydrological and hydraulic conditions

To attain the characteristics of a target river basin before the analysis and modeling, baseline information from the basin should be collected from relevant agencies, in particular those charged with disaster management, water resources management and flood control. Table 3.1 lists key information to be gathered and reviewed. Meteorological information, in particular that pertaining to rainfall, is also necessary and covered in section 4.3.

4.3 Rainfall analysis

The temporal and regional distribution of rainfall is an essential boundary condition to input into the hydrological model. Rainfall conditions (especially temporal and regional distribution of rainfall) should be properly defined in order to establish an accurate model. The methods of rainfall analysis employed therefore need to ensure data reliability. Furthermore, alternative methods to procure missing data must be considered as some ASEAN Member States lack a sufficient amount of viable data.

For the flood runoff analysis, hourly rainfall data is often essential to identify flood occurrence mechanisms via hydrological and hydraulic simulation models. In cases where the target river basin can provide only daily observed data, satellite rainfall data (hourly level data that has been stored as archive data) may be useful to measure temporal rainfall distribution based on daily observed rainfall amounts. A hythergraph – a climatic diagram with coordinates using some form of temperature versus a form of precipitation – depicting satellite rainfall can be modified to show daily rainfall amounts observed in hydrological stations (See Appendix 4).

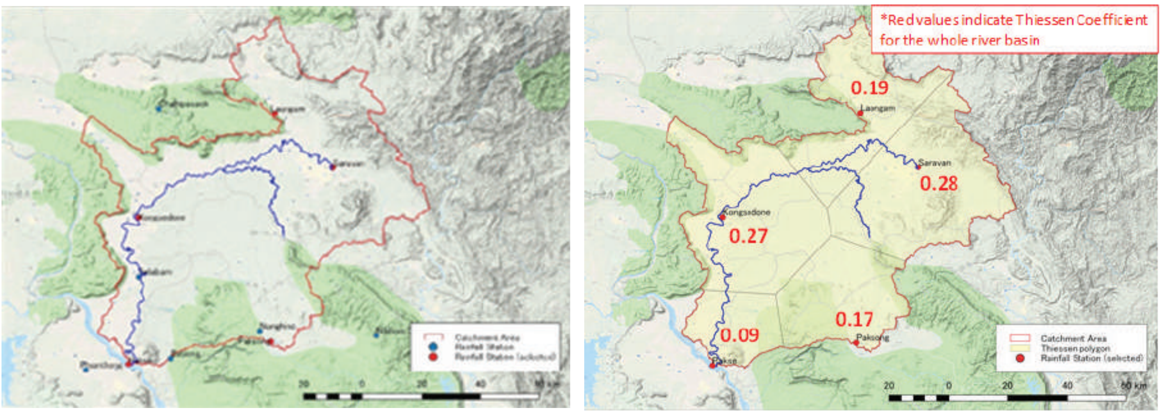
4.3.1 Preparing time series data for average basin rainfall

Average basin rainfall time series data should be input into the hydrological model by delineated sub-basin. Average basin rainfall estimates typically use three methods: the Theisen polygon, isohyet line and arithmetic methods. For the RBP, average basin (watershed) rainfall is estimated using a weighted mean average method based on the occupation ratio (Theisen coefficient) of each rainfall station (Figure 4.2). This method was adopted due to an insufficient amount of observed data.

4.3.2 Flood duration investigation

Past flood event duration, including the most recent extreme events, should be analyzed to understand the characteristics of flood conditions, which will contribute to setting the number of hydrological model parameters and

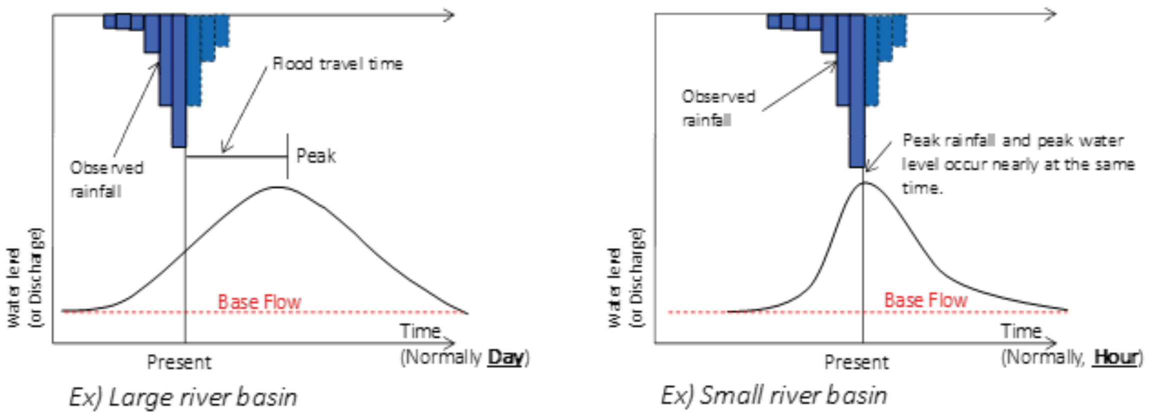
Figure 4.2 Thiessen Polygon preparation and station weight occupation



Source: Project Team

preconditions. Past flood event duration can be used as a reference for setting the flood simulation period. Flood duration can normally be clarified through comparison of observed flow discharge hydrographs. Flood discharge hydrographs are divided into two parts: a flood portion showing precipitation increase and a base flow portion, defined as normal conditions before precipitation. The degree and balance of those portions can be seen in the discharge hydrograph and rainfall hyetographs in Figure 4.3. Flood duration can be measured when observed discharge exceeds the base flow level and the point when flow recedes back to that base level. The simulation period can be set in consideration of the above-mentioned flood duration based on the rainfall and runoff response characteristics of the basin. To cover the inundation in the surrounding river channels, an extension of the duration period may be necessary.

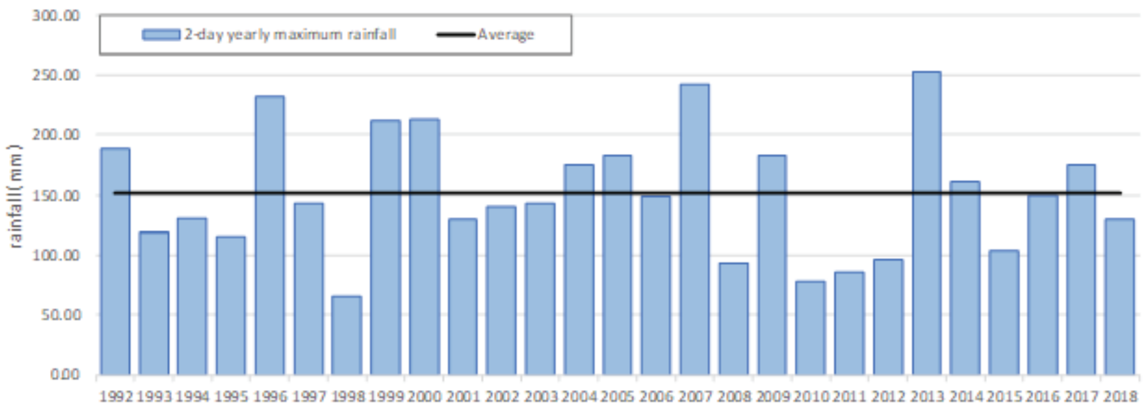
Figure 4.3 Examples of rainfall and flood duration



*Hyetographs (blue bar graphs) express mean basin rainfalls in the area upstream of reference points. Hydrographs (black line) express discharge or water level, and base flow (red dotted line) represents the average minimum discharge or water level before precipitation.

Source: Project Team

Figure 4.4 Example of rainfall extreme value series data

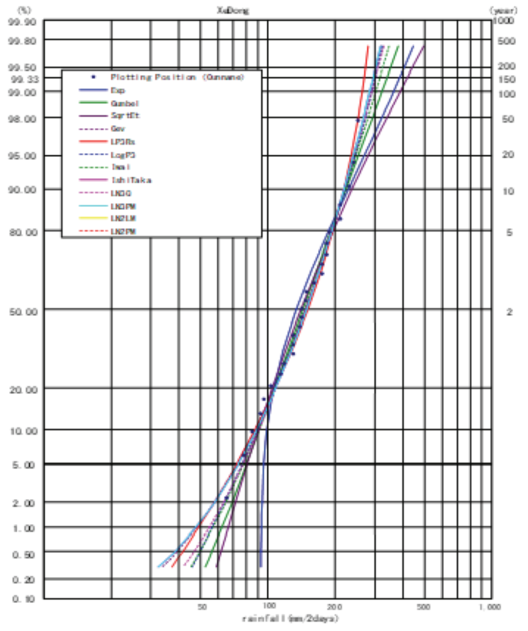


Source: Project Team

4.3.3 Rainfall probability

A representation of rainfall probability is commonly used by engineers for modeling and planning in order to understand not only the scale of floods, but also to set the necessary preconditions to conduct flood mapping control planning. ASEAN countries have regularly used extreme rainfall (concentrated heavy rainfall for several days) for their probability analyses. This exposes the degree of flooding, but does not normally include huge transboundary river basins that have long-term flooding issues. The extreme rainfall series data (Figure 4.4) can be collected from the observed rainfall data: the extreme data is the average basin rainfall estimate based on the observed data. In most cases, the probability analysis will use “annual maximum values” that are extracted from extreme values.

Figure 4.5 Example of two-day rainfall probability regression curves



Source: Project Team

Box 2.1 Duration of Extreme Rainfall Data

The probability analysis duration of extreme rainfall data should be examined for correlations between peak discharges and rainfall amount in different durations in past floods. A dominant duration against peak discharge should be selected for extreme value estimation. In addition, river basin size, flood duration and rainfall causes should be considered for a set duration. Current and planned flood control facilities in the target river basin must also be taken into account.

There are multiple extreme value distribution functions, including the Gumbel Distribution, square-root, exponential type maximum distribution, generalized extreme value distribution, Log-Pearson Type III Distribution, Iwai method, Shihara Takase method, log-normal distribution, etc. that can be employed after the evaluation of applicability based on regression correction. The regression correction can be analyzed by the least SLSC (Standard Least Squares Criterion), estimated error (Jack Knife method) and so on.

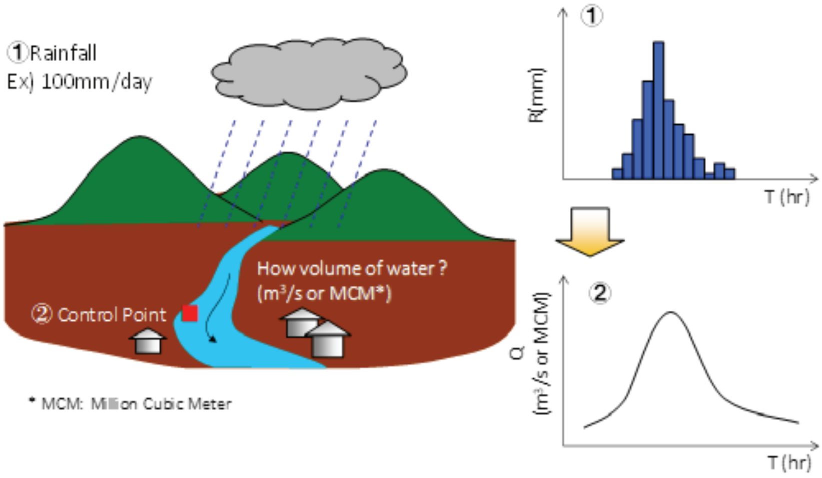
After the identification of extreme values, the probability analysis outlined in the two preceding paragraphs can be executed and visualized in graphs (Figure 4.5) with freeware, such as Hydrological Statistical Utility version 1.5 developed by the Japan Institute of Country-ology and Engineering (JICE), the HEC-SSP (Statistical Software Package) by the Hydrologic Engineering Center of US Army Corps of Engineers, etc.

4.4 Runoff analysis

Runoff is the process of rainwater flowing into channels and rivers, and then to the sea. Runoff estimation and analysis uses a simulation model. The project used the HEC-series runoff simulation model freeware to conduct the runoff analysis. The runoff simulation model was used to convert rainfall input data, both observed as well as that resulting from downscaling the GCM, to surface discharge flows in the river channels (Figure 4.6).

The common practice for this modeling is to use the observed flow data for calibration and verification by comparing it to the simulated

Figure 4.6 Runoff analysis outline



flow discharge. After calibration and verification, the simulated flow discharge data will be fed into the flood inundation model to conduct the inundation analysis.

4.4.1 Runoff analysis model (HEC-HMS)

Before modelling, the target basins and sub-basins may be further divided in consideration of natural conditions and hydrology station distribution (Figure 4.7). This will contribute to model accuracy. For example, the project pilot river basin is divided for accuracy according to tributary confluence, hydrology (water level gauge) station and planning design location (flood reference points to confirm the effects of flood control countermeasures).

4.4.2 Model framework structure

The model framework structure consists of three parts: a basin model, meteorological model and control specification (Figure 4.8). Data setting

Figure 4.7 Example of river basin division

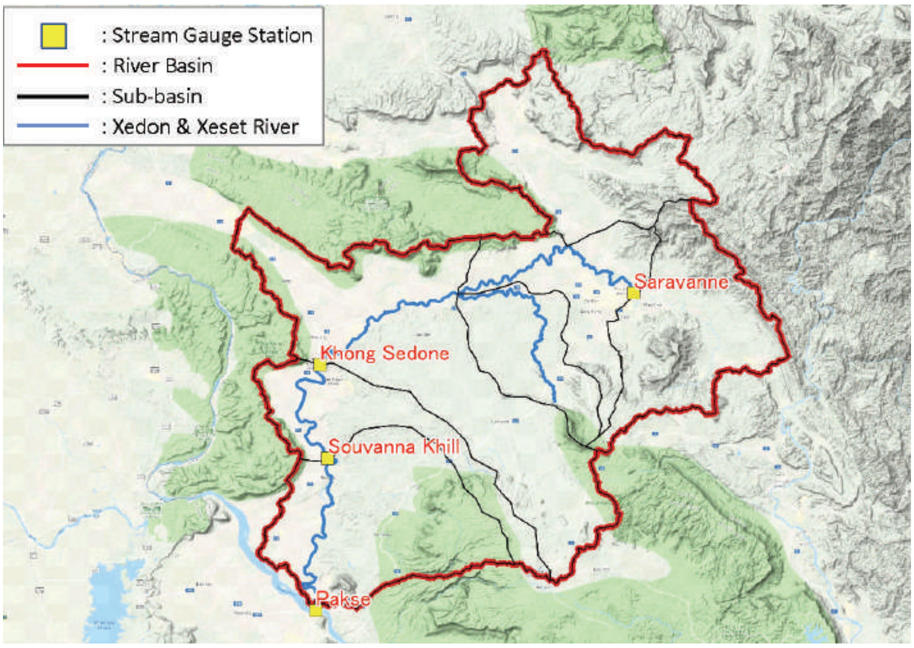
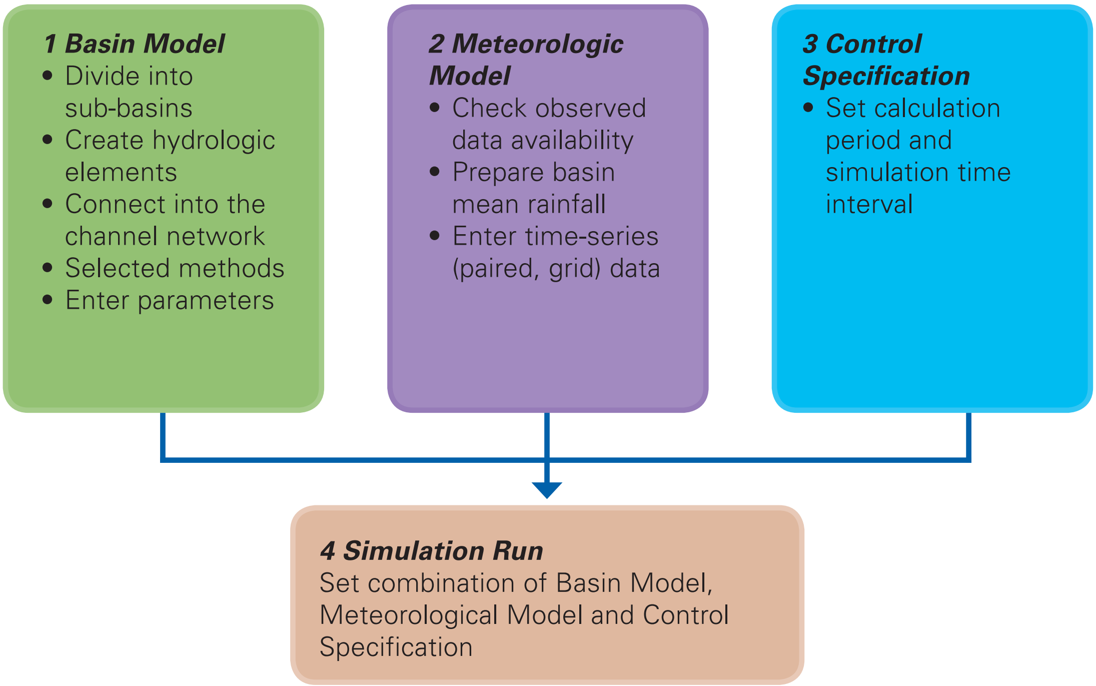


Figure 4.8 Framework structure flowchart



1 Basin Model
- Divide into sub-basins
- Create hydrologic elements
- Connect into the channel network
- Selected methods
- Enter parameters

2 Meteorologic Model
- Check observed data availability
- Prepare basin mean rainfall
- Enter time-series (paired, grid) data

3 Control Specification
- Set calculation period and simulation time interval

4 Simulation Run
Set combination of Basin Model, Meteorological Model and Control Specification

can be displayed through the HEC-HMS user interface. Collected and processed information and data is incorporated into the models as shown in boxes 1, 2 and 3 of Figure 4.8.

Data setting is displayed through the HEC-HMS user interface shown in Figure 4.9.

Procedures for creation of a basin model, metrological model and control specifications, in addition to steps to set-up an HEC–HMS, are detailed in the technical report in Annex 1 of these Guidelines.

4.4.3 Running a simulation

After establishment of the basin model, hydrological simulations can be run in accordance with the other conditions detailed in Section 4.4.1 and 4.4.2. To run the HEC-HMS simulation, a "simulation run" data set should be built according to the following steps.

Step 1: Create a "simulation run dataset platform" by opening the simulation run manager.

Step 2: Set the information for each simulation case in the platform. Provide inputs for the three major datasets: scenario name, basin model and "meteorological model".

The results can be displayed through the HEC-HMS user interface shown in Figure 4.10.

Figure 4.9 A river basin model in HEC-HMS

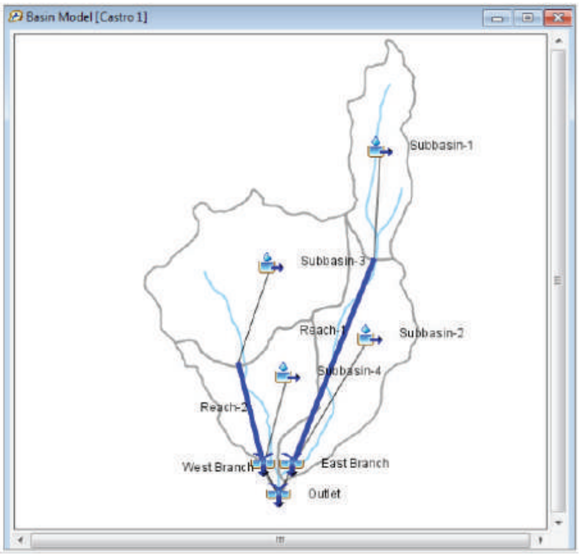
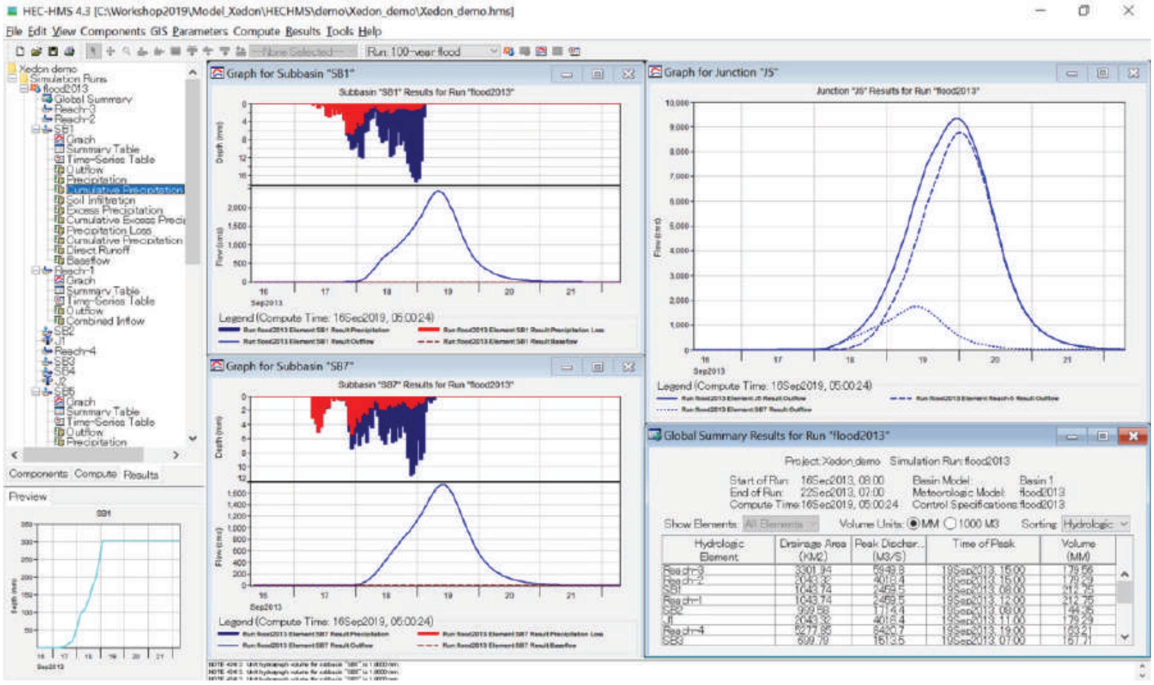


Figure 4.10 Example of visual simulation results



Global Summary Results for Run "flood2013"

Project: Xedon_demo Simulation Run: flood2013

Start of Run: 16Sep2013, 08:00 Basin Model: Basin 1
End of Run: 22Sep2013, 07:00 Meteorologic Model: flood2013
Compute Time: 16Sep2019, 05:00:24 Control Specifications: flood2013

Show Elements: All Elements Volume Units: ● MM ○ 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Reach-3	3301.94	5949.8	19Sep2013, 15:00	179.56
Reach-2	2043.32	4018.4	19Sep2013, 15:00	179.29
SB1	1043.74	2459.5	19Sep2013, 08:00	212.75
Reach-1	1043.74	2459.5	19Sep2013, 12:00	212.75
SB2	999.58	1714.4	19Sep2013, 09:00	144.35
J1	2043.32	4018.4	19Sep2013, 11:00	179.29
Reach-4	5277.85	6420.7	19Sep2013, 19:00	163.21
SB3	699.79	1513.5	19Sep2013, 07:00	157.71

Source: Project Team by using HEC Software

4.5 Hydraulic and inundation analysis (by HEC-RAS)

A hydraulic and inundation analysis involves flow modeling and routing in both one (1D) and two (2D) dimensions. The HEC series has a river analysis system (HEC-RAS) for building an inundation simulation. HEC-RAS has the ability to perform 1D and 2D unsteady-flow modeling as well as combined 1D and 2D unsteady-flow routing. A combined 1D and 2D unsteady-flow routing model can be developed to analyze a flood hazard area and its conditions.

The unsteady-flow model procedure and establishment method will be detailed in Section 4.5.1. The inundation simulation model will generate flood indicators such as inundation areas, depth, flow velocity/direction, duration in the target river basin, etc. The indicators reveal vulnerability in the flooded areas through flood damage calculation and risk analysis.

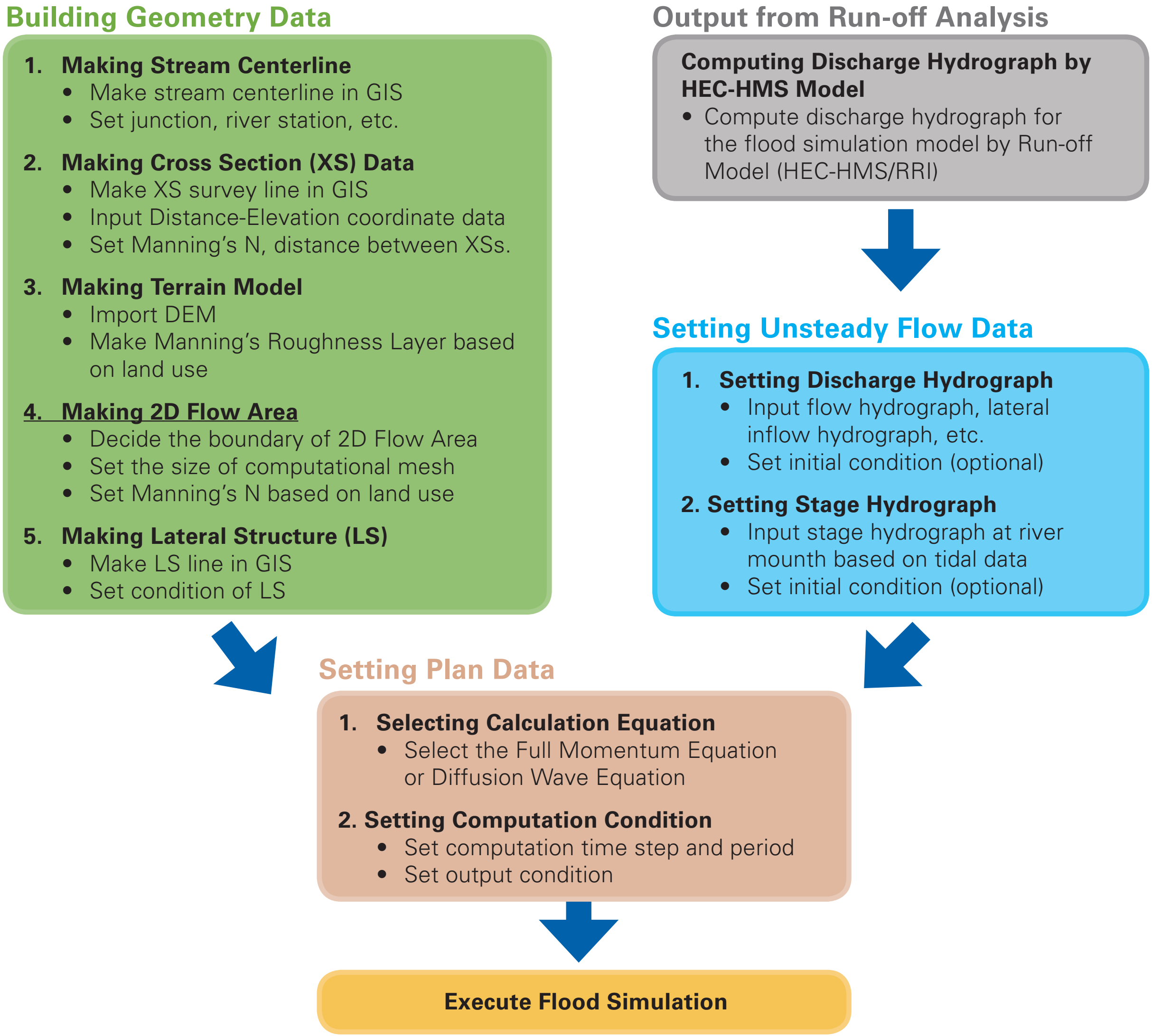
4.5.1 Hydraulic and inundation analysis dataset

The information and data described in this section serves as input into hydraulic and inundation modeling such as in the HEC-RAS model as shown in Figure 4.11.

The simulated output by HEC-HMS (simulated discharge hydrograph data). The geometry data in the left box should be newly prepared from routine flood calculations in river channels and other drainage canals, as well as flood inundation calculations from flood plains. Both sets of data make up the boundary conditions for input into the model in order to run a hydraulic and inundation simulation.

Steps to set conditions for the HEC–RAS are detailed in the RBP technical report (as an attachment to these Guidelines). Steps from (a) to (g) are conducted for the hydraulic simulation while steps from (h) to (k) are conducted for the inundation simulation.

Figure 4.11 Flowchart for HEC-RAS data setting



(a) Define a stream center line.
(b) Define a cross-section.
(c) Input river stations, reach lengths and junctions.
(d) Create a project (platform) file and select data input or link to HEC-RAS.
(e) Compile information sets such as those related to river network GIS information, cross-sectional information and geometry information.
(f) Check data import and input results.
(g) Optimize data.
(h) Create a digital terrain model.
(i) Scrutinize the association between geometry data and the digital terrain model.
(j) Create a two-dimensional (2D) flow area.
(k) Input river structure information.

4.6 HEC-HMS and RAS model calibration and verification

To optimize settings and parameters, the model should be calibrated and verified. Methods and procedures for this exercise are detailed below.

4.6.1 Model calibration

Model hydrographs and simulated discharge values should be adjusted after comparison with verified observations in the same periods and locations (especially key floods and locations for flood control planning). To assist the calibration, HEC-HMS has an auto-calibration function to adjust the SCS curve number (CN) that is based on land use conditions. However, the number automatically adjusted by the function should be confirmed in accordance with the range of experimental thresholds corresponding to land use (see the HEC-HMS official manuals technical references). On the other hand, HEC-RAS is not equipped with an auto-calibration function for roughness coefficients for riverbeds, channels and confluence lag time. When the simulated results require high accuracy, an evaluation of the wave of both hydrographs is therefore recommended. It should be based not only on visual comparison, but also the use of evaluation indicators such as the Nash-Sutcliffe Efficiency, Root Mean Squared Error (RMSE), etc..

Errors and gaps in input data should spur users to follow trial and error for model calibration in varying degrees based on their river engineering experience, even though there are automatic functions in the software to set parameters such as CN, roughness coefficient, time lag of water confluence, etc.

4.6.2 Model Verification

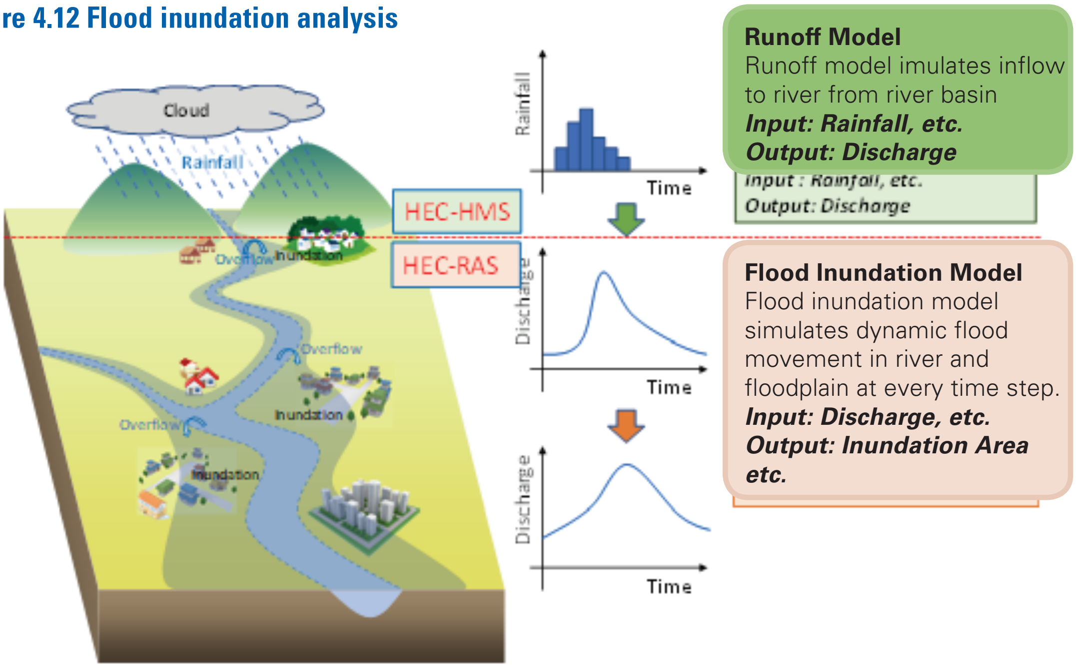
The calibrated model should be verified by testing on floods that were not used in calibration. Model verification aims to validate the model's robustness and ability to characterize the catchment's rainfall runoff response. Verification can also detect any biases in the calibrated parameters (Gupta et al., 2005), as model performance is usually better during calibration than verification, a phenomenon called model divergence (Sorooshian and Gupta, 1995). If the degree of divergence between simulated and observed discharge is unacceptable, the modeler must go back and examine the model structure and calibration procedures, or assumptions, and revise accordingly.

4.7 Flood hazard mapping

4.7.1 Flood inundation simulation

As detailed in section 4.5, the HEC-RAS flood inundation model simulates dynamic flood movement (unsteady flow routing) in river channels and floodplains. This one-dimensional flow model can express river overflow through comparison between the calculated water level of a river channel and riverbank height at any time and point in the river (Figure 4.12). When the water level breaks the riverbank, the spilled water will inundate the flood plain, allowing the HEC-RAS two-dimensional flood flow model to simulate floodplain diffusional flows that are combined, as shown in Figure 4.13.

Figure 4.12 Flood inundation analysis



Runoff Model
Runoff model imulates inflow to river from river basin
Input: Rainfall, etc.
Output: Discharge

Flood Inundation Model
Flood inundation model simulates dynamic flood movement in river and floodplain at every time step.
Input: Discharge, etc.
Output: Inundation Area etc.

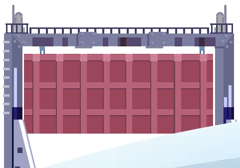
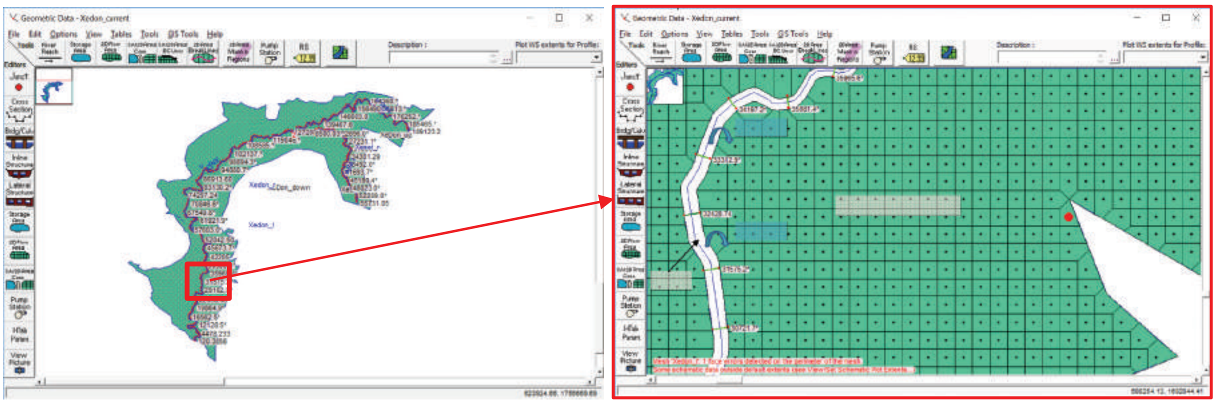


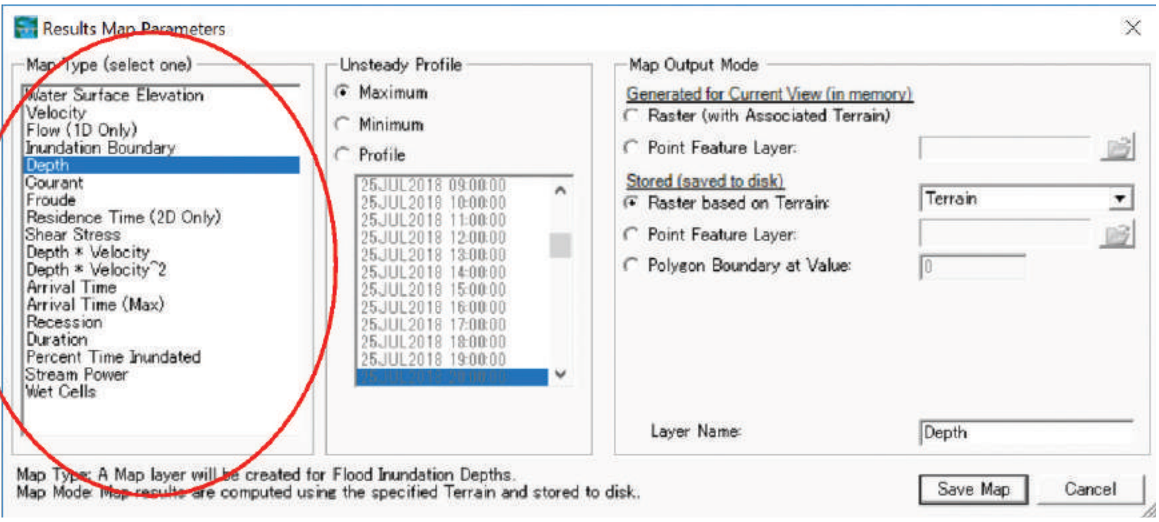
Figure 4.13 Flood inundation area setting



4.7.2 Flood hazard mapping

After running the flood inundation simulation, flood hazard maps can be accessed through the HEC-RAS "RAS Mapper". Flood indicators such as flood depth and duration, water direction and velocity, etc. as shown in Figure 4.14 are necessary hazard information for the flood risk analysis. They are calculated at each HEC-RAS simulation time step and are accumulated in the user's computer as time series data. Animations based on the accumulated data of these variations can be seen on the RAS Mapper as shown in Figure 4.15.

Figure 4.14 RAS Mapper available flood indicators



Results Map Parameters

Map Type (select one)
Water Surface Elevation
Velocity
Flow (1D Only)
Inundation Boundary
Depth
Courant
Froude
Residence Time (2D Only)
Shear Stress
Depth * Velocity
Depth * Velocity^2
Arrival Time
Arrival Time (Max)
Recession
Duration
Percent Time Inundated
Stream Power
Wet Cells

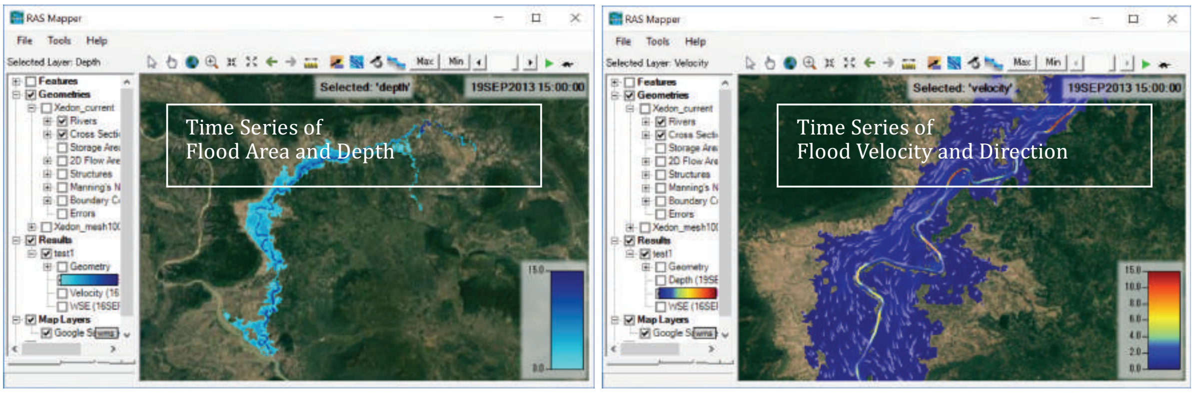
Unsteady Profile
● Maximum
○ Minimum
○ Profile
25JUL2018 09:00:00
25JUL2018 10:00:00
25JUL2018 11:00:00
25JUL2018 12:00:00
25JUL2018 13:00:00
25JUL2018 14:00:00
25JUL2018 15:00:00
25JUL2018 16:00:00
25JUL2018 17:00:00
25JUL2018 18:00:00
25JUL2018 19:00:00

Map Output Mode
Generated for Current View (in memory)
○ Raster (with Associated Terrain)
○ Point Feature Layer:
Stored (saved to disk)
● Raster based on Terrain: Terrain
○ Point Feature Layer:
○ Polygon Boundary at Value: 0

Layer Name: Depth

Map Type: A Map layer will be created for Flood Inundation Depths.
Map Mode: Map results are computed using the specified Terrain and stored to disk.

Figure 4.15 RAS-Mapper time series values of flood indicators



Time Series of
Flood Area and Depth

Time Series of
Flood Velocity and Direction

Photo: Baseline survey in Bago, ASEAN DRR-CCA

5

VULNERABILITY ASSESSMENT

The third step of the risk assessment is a vulnerability assessment (Figure 2.1). This section outlines flood vulnerability methods and provides a guide to their selection for a damage assessment. While the importance of both qualitative and quantitative approaches is discussed, this section mainly focuses on the quantitative approach that will serve as input for the risk assessment and mapping demonstrated by the HEC series model. The suggested vulnerability assessment process is shown below in Figure 5.1.

5.1. Understanding the concept

Vulnerability is subject to multiple interpretations and connotations and has no single agreed upon definition. For example, from an engineering standpoint, the definition of vulnerability is "…a measure of the damage suffered by an element at risk when affected by a hazardous process" (Guzetti, 2008).[2] The social definition of vulnerability states it is the "the presence or lack of ability to withstand shocks and stresses to livelihood" (Adger, 2000).[3] In general, vulnerability has been defined as "the degree to which human and environmental systems are likely to experience harm due to perturbation or stress" (Luers et al., 2003). Vulnerability can

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[2] Guzzetti, F. 2008. Measuring vulnerability to natural hazards. Natural Hazards and Earth System Sciences, 8: 521.

[3] Adger, N. 2000. Institutional adaptation to environmental risk under the transition in Vietnam. Annuls of Association of American Geographers, 90(4): 738-758.

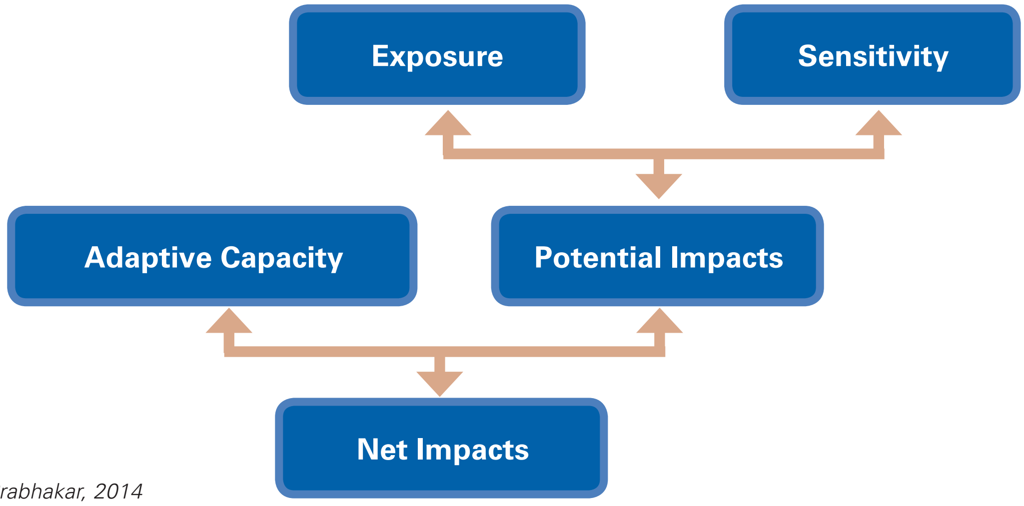
Figure 5.1 Suggested flood vulnerability assessment process (Source: Authors)

be understood as a concept, as a state of a system, and as a process (Prowse, 2003). The vulnerability concept can be considered dynamic as it recognizes and captures changes happening around the system in question. As a state, vulnerability can be understood as a condition that predisposes a particular system to be affected by hazards. Vulnerability factors could be intrinsic to the system as well as exogenous, consistently testing the system's ability to withstand external pressures. Vulnerability can manifest in economic, social, institutional and natural (biological, biophysical and environmental) systems with which communities interact regularly.

Both climate change adaptation (CCA) and disaster risk reduction (DRR) scholars have proposed definitions of vulnerability. According to the United Nations Office for Disaster Risk Reduction (UNDRR), vulnerability is defined as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNDRR, 2015). UNDRR further highlights that vulnerability can originate from a range of physical, social, economic and environmental factors. It is often regarded as the characteristics of a system of interest (for example a community, society or asset), and is independent of the exposure to which that system is subjected. Vulnerability concepts have also been widely applied in other fields, including sustainable development, health, poverty reduction and environmental management.

The IPCC defines climate change vulnerability as "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change." (Schneider et al., 2007). IPCC concludes that vulnerability is a function of exposure, sensitivity and adaptive capacity.

Figure 5.2 Relationship between vulnerability, adaptive capacity and net impacts



Source: Prabhakar, 2014

The methodology outlined in these Guidelines adheres to this definition. Figure 5.2 depicts the relationship between exposure, sensitivity, and adaptive capacity. Vulnerability is determined by exposure and sensitivity, while net impacts are determined by adaptive capacity.

Exposure refers to the people and assets in a hazard area as estimated in Section 4. Sensitivity, as a component of vulnerability, is defined as "the degree to which a system will respond to a given change in climate, including beneficial and harmful effects" (McCarthy et al., 2001). Sensitivity is the major factor that determines the consequences of exposure to flood hazards. A system's sensitivity is determined by factors that predispose it to the losses from the flood hazard. Flooding does not equally impact individual households on a flood plain. Impacts differ according to the socio-economic conditions (for example, sensitivity) that define their predisposition to hazard impacts. Exposure is a necessary but not sufficient factor to fully define disaster impact (Cardona et al., 2012). It must be combined with sensitivity. Communities located in low-lying areas can have high sensitivity to floods compared to those living in elevated areas due to factors that include location elevation, poor transportation infrastructure and lack of disaster preparedness. Other factors that render communities sensitive to disaster impacts include poverty, governance capacity and vulnerability of livelihoods to weather and climate fluctuation.

Community sensitivity to a hazard such as a flood produces what is called potential impacts. The impacts must be termed "potential" as the net impacts (shown in Figure 5.2) will be dependent on another critical factor – a society's adaptive capacity. Adaptive capacity plays a vital role in buffering the shocks of a hazard event, and therefore contributes to determining its net impacts. The methodology developed for these guidelines therefore also includes a community's existing capacities for flood response.

Vulnerabilities are actualized only when hazards, exposure and sensitivities meet. They can therefore be concealed for several years until individuals or communities are exposed to hazards, such as the 2018 extreme floods in the RBPs. Conducting regular vulnerability assessments could help unearth hidden vulnerabilities before hazards occur so that both preparedness and mitigation measures are in place to address potential impacts. It is also important in a vulnerability assessment to factor in climate change, answering questions such as how sensitivities, capacities and hazards change as a result of climate change and the variability associated with it.

Adaptive capacity refers to the ability of an entity to address and negate disaster impacts. Adaptive capacity can be considered a denominator to sensitivity and may help reduce vulnerability. For example, factors such as the presence of strong social bonding, protective natural vegetation and flood protection dikes, flood escape boats and strong leadership indicate capacity to reduce overall flood impacts on a range of time scales. Certain capacities can be mobilized immediately while others may take more time. Communities will be able to mitigate potential hazard impacts sooner with capacities that are closer at hand, in terms of both geographical and time proximity.

The effects of flood event exposure are a result of the combination of sensitivity and adaptive capacity. Hence, adaptive capacity plays a vital role in buffering shocks. Therefore, these guidelines also take adaptive capacity elements into consideration.

5.2. Understanding the nature of vulnerabilities and flood impacts

The nature of flood impacts depends on the elements at risk and the underlying factors contributing to their vulnerability. These risk elements in turn determine the types of flood impacts on which to focus in the flood vulnerability analysis and the following risk assessment.

5.2.1 Risk elements

The vulnerability assessment team must have a thorough understanding of risk elements. Risk elements are the physical, biological and economic systems that are exposed to flood related damages. Elements can be broadly categorized as economic, social or cultural. Economic elements include public infrastructure, housing, agriculture, trade and transport, etc. Social elements include population, health, and food supply, as well as gender, inequality, age, access to services, education, governance, institutions, political economy, and social and institutional networks. Cultural elements include temples and other related cultural heritage structures and organizations. Some of these elements, such as roads, water supplies, hospitals and health facilities, and communications infrastructure, can be considered essential lifelines.

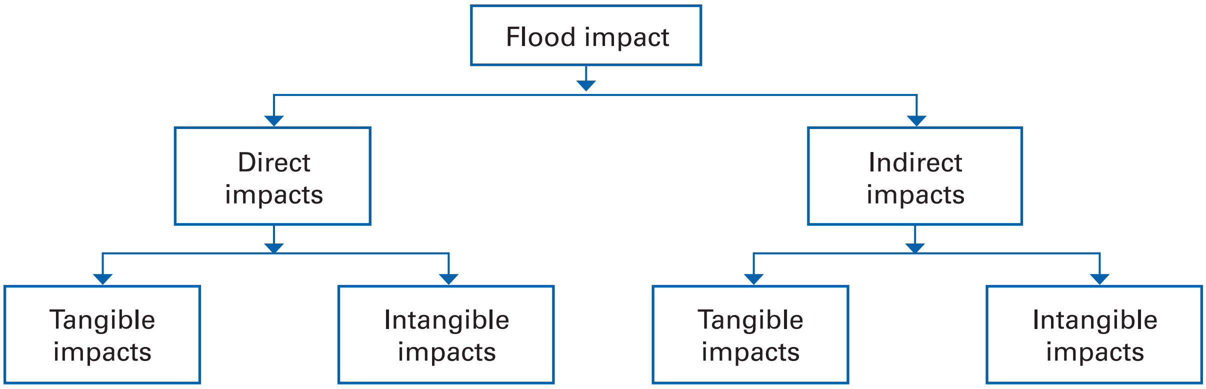
Risk element classification depends on local priorities, customs and governance systems. For example, some assessments recognize the overlap between social and economic elements and combine them as one broad socio-economic category. Environmental elements include forests and related ecosystems and ecosystem services, including biodiversity. This also commonly includes other land categories such as pasture, wetlands, etc. Impacts on one sector can have implications for other sectors, for example road disruption or closure leading to a shortage of essential supplies such as water, food, and medicine. Another example is agricultural flood damage that reduces the purchasing power of a rural population that in turn impacts goods and services, prices, and supply and demand beyond the river basin boundary where the floods occurred. It is therefore important for the assessment team to understand the interconnectedness and complexity of these elements and assess their risk implications beyond the spatial domain of the river basin.

Addressing multiple risk elements requires deeper understanding of the sectors they make up, and how these sectors are predisposed to flood damages (vulnerability) and the underlying factors responsible for that vulnerability. Focusing on these diverse elements additionally has implications for data collection and analysis resources. Though having diversified expertise in the risk assessment team is a necessity, it is often difficult and costly. The team must therefore take a stock of complexities to decide the scope of the assessment according to available time and human and financial resources.

5.2.2 Flood impacts

After identification of risk elements, the next step is a systematic understanding of the impacts or damages to those elements according to the scope of the flood vulnerability and risk assessment. Flood damage can be tangible and intangible based on the ability to measure and quantify it (Figure 5.3). Tangible and intangible impacts can also be identified as economic

Figure 5.3 Impacts to be considered for flood vulnerability and risk assessment design



Source: Authors

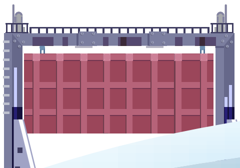


Photo: Field survey and data collection in Bago, ASEAN DRR-CCA

and non-economic damages, or direct and indirect damages. Based on how the damages occur over time, they can be further classified as direct, or primary, impacts and indirect, or secondary, impacts. For example, physical damage to a house due to direct physical force from floodwaters could be categorized as a direct impact. On the other hand, loss of rental income on the house due to damage could be categorized as an indirect, or secondary, impact. Impact on the wider economy over time would also be considered a secondary impact.

Loss of health, building and infrastructure damage and loss of income are categorized as tangible impacts (Table 4.1). Intangible impacts, often referred to as non-economic impacts, refer to those that cannot be reliably estimated or that do not have direct economic market value. Some intangible impacts, however, may eventually be classified as tangible as the ability to measure and value them progresses. For example, a reduction in crop yield or livestock numbers due to inundation might be considered intangible, but after development of a methodology for more accurate measurement (such as standardization or proxy indicators), a figure can be attached to the loss, such as for a crop insurance payment or government compensation.

Different methods are used for tangible and intangible impact assessments. Tangible impacts such as infrastructure damage to buildings, houses and bridges often undergo assessment through development of damage or vulnerability functions as outlined in these Guidelines in Section 5.4. Measurement of both impacts can be difficult as they are often not verifiable and tend to rely on proxy indicators, resulting in constraints for their use in vulnerability and risk assessments. However, intangible damages

Table 4.1 Tangible and intangible impacts

Risk element	Tangible impacts	Intangible impacts
House	Physical damage to the building	Loss of quality of life
Human	Health damage (due to treatment cost)	Psychological trauma, loss of peace
Infrastructure	Physical damage	Disruption of services
Social	Loss of livelihood, including loss of jobs, livestock, etc.	Loss of social cohesion, insecurity, loss of human life
Natural resources	Loss of timber, loss of ecosystem services	Negative impacts on ecosystems and biodiversity
Agriculture	Physical damage to crops, agriculture equipment and inputs	Physical hardship on farmers and their families in restoring flood damaged fields and infrastructure

Source: Authors

cannot be ignored as they play an important role in the long-term recovery of those affected by flood events, as well as the sustainability of flood risk reduction interventions.

5.3 Flood vulnerability assessment steps

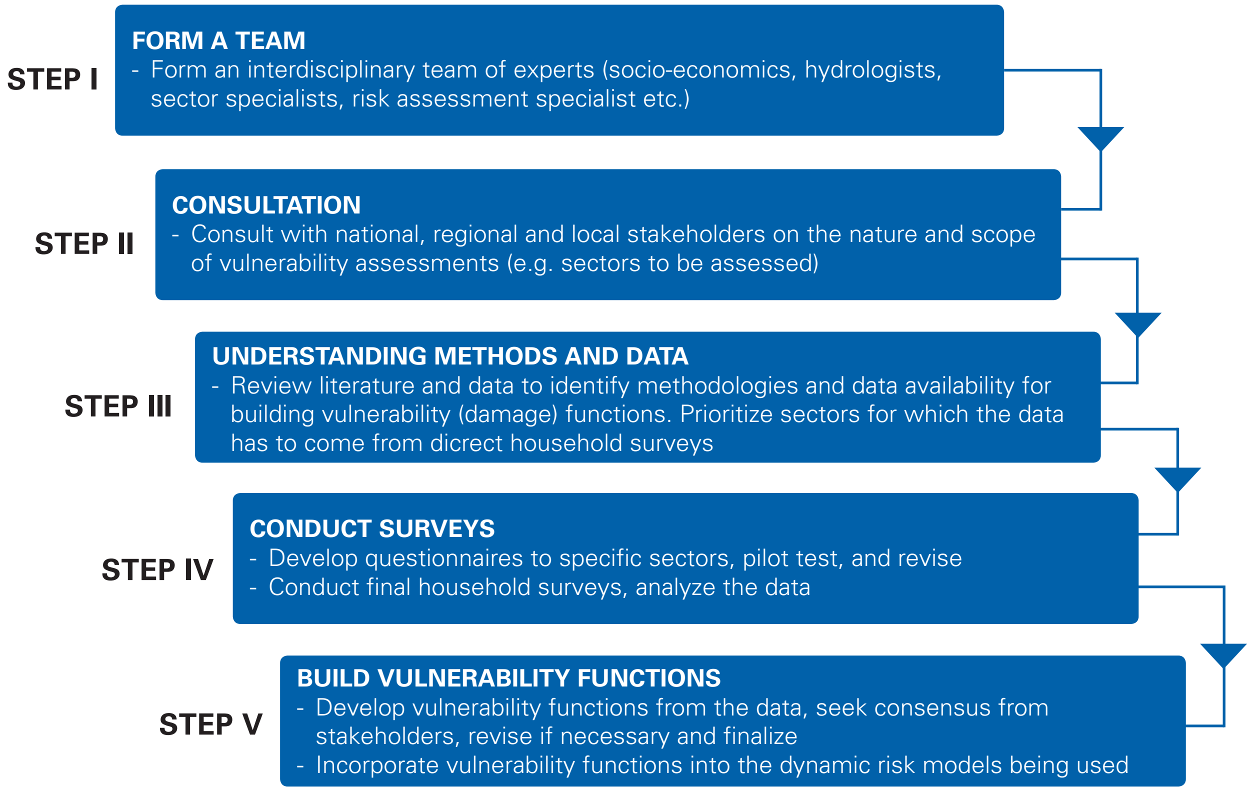
The project followed a clear set of steps to conduct the flood vulnerability assessments, as shown in Figure 5.4.

As vulnerability assessments are an inter-disciplinary activity involving several sectors and related expertise, a team of experts may need to be formed to decide the nature and scope of vulnerabilities to be assessed and the appropriate methodology. As indicated in Figure 5.4, conducting a vulnerability assessment involves a series of consultative processes. These consultations may need to be organized to fine-tune the scope of the vulnerability assessment, for example identifying important sectors to cover, or developing impact functions to seek consensus on their relevance to the assessment location.

Building vulnerability or flood damage functions specific to an assessment has become a norm as some current models utilize them for quantitative risk assessments due to their reliability under known conditions. A location-specific damage function is therefore important in order to characterize various elements at risk such as infrastructure (houses, bridges, roads, etc.), livelihoods (agriculture, businesses, etc.), and human health. If social elements such as migration emerge as significant, they may also be included. A location-specific flood vulnerability assessment is important for three reasons.

1. Certain elements may not be equally relevant at different scales or locations. For example, agriculture income percentage can be a highly relevant indicator in rural areas but might not be for urban areas.

Figure 5.4 Flood vulnerability assessment steps



STEP I

FORM A TEAM
- Form an interdisciplinary team of experts (socio-economics, hydrologists, sector specialists, risk assessment specialist etc.)

STEP II

CONSULTATION
- Consult with national, regional and local stakeholders on the nature and scope of vulnerability assessments (e.g. sectors to be assessed)

STEP III

UNDERSTANDING METHODS AND DATA
- Review literature and data to identify methodologies and data availability for building vulnerability (damage) functions. Prioritize sectors for which the data has to come from dicrect household surveys

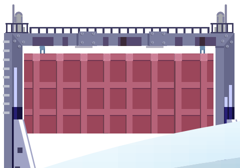
STEP IV

CONDUCT SURVEYS
- Develop questionnaires to specific sectors, pilot test, and revise
- Conduct final household surveys, analyze the data

STEP V

BUILD VULNERABILITY FUNCTIONS
- Develop vulnerability functions from the data, seek consensus from stakeholders, revise if necessary and finalize
- Incorporate vulnerability functions into the dynamic risk models being used

Source: Authors



2. Data availability can vary at different locations.
3. Decision-making needs and resources can vary at different scales or locations.

A literature review focused on risk assessment needs, geographical area environmental and socio-economic conditions and targeted decision-making stakeholders will help understand which important vulnerability functions were used by others under what contexts, and if those functions are relevant for the assessment location. This initial set of vulnerability functions may be discussed and finalized in a series of stakeholder consultations that are made up of local communities, local, regional and national governments and other related stakeholders. If the available data or vulnerability functions are insufficient, the team may decide to build vulnerability functions using the methodology described in these guidelines.

After the vulnerability functions have been solidified, the next step is to develop a questionnaire (example provided in Appendix C) to collect data from affected households for building impact functions for specific sectors in the studied location. The completed questionnaires are then analyzed to develop damage functions using the methodologies in these guidelines.

5.4 Selecting vulnerability assessment methods

The methods used in vulnerability assessment can be broadly grouped as either qualitative or quantitative. A wide range of indicators that identify vulnerabilities and that are difficult to quantify are used in qualitative methods. These methods often provide opportunities for the assessors to gain better understanding of a range of underlying factors that are otherwise difficult to identify and assess. Qualitative methods allow consideration of experiential, perceptual and cultural conditions in a much more nuanced manner than what quantitative methods can allow. Qualitative methods also carry inherent subjective biases. It is often difficult to pinpoint an exact level of vulnerability and the resultant flood damage, though a range of damage possibilities can be identified.

Quantitative methods help the flood vulnerability team establish a relationship between the level of vulnerability and the extent of flood damage. This is due to quantitative methods relying on a relationship between depth and duration of flooding to the level of damage on a particular risk element. Unlike controlled laboratory conditions, quantitative vulnerability assessments can be difficult because not all underlying vulnerabilities may have a clear relationship with damages incurred in a flood event. Establishing a damage function is labour intensive. Flood impacts could be obscured by complications due to poor data quality or large sample size requirements.

The suitability of qualitative and quantitative methods for a vulnerability or risk assessment also varies according to a wide range of economic and other dimensions that must be considered. These could include physical, socio-economic, socio-cultural, environmental, political and institutional dimensions.

As a result, reliance on a quantitative approach over qualitative, or vice-versa, could lead to missing key risk determinants and result in flawed outcomes. As both approaches have strengths and limitations, it is often recommended to follow a synergistic mixed methods approach to maximize flood vulnerability information. It is always beneficial to understand the underlying factors contributing to flood risks, irrespective of whether their relationship is used in risk assessments. This information will come in handy when risk assessments are used to decide risk mitigation interventions.

5.4.1 Damage assessment methods

A range of quantitative and qualitative damage assessment methods are available for application in flood risk and vulnerability assessments. These methods can be broadly grouped into four categories: heuristic methods, economic methods, empirical methods and probabilistic methods. These methods are mostly applied to tangible damages as they follow the quantitative approach to damage assessment, but they have also been applied to tangible damages in qualitative approaches using, for example, heuristic methods. A better understanding of these methods will help risk and vulnerability assessment teams better identify an appropriate assessment method to employ. Though the details of these methods are beyond the scope of these guidelines, a brief explanation of each with relevant references is provided below.

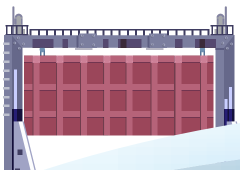
Heuristic methods comprise expert judgements that help classify the damage in qualitative or descriptive terms. Heuristic methods can quickly provide a strong understanding of the nature of flood damage and are usually applied to assess both physical and social elements. When applied to physical elements, or structures, experts usually judge the damage by expressing it as aesthetic, functional or structural in nature. When applied to people (social elements), heuristic methods can help to assess vulnerabilities in a qualitative manner. Heuristic methods are usually applied during post-disaster reconnaissance surveys for a quick assessment of damage for designing a more detailed damage assessment at a later date, as well as to identify needed resources for various post-disaster assessments and interventions.

Economic methods aim to quantify damages in economic or monetary terms. For example, when an asset has been destroyed, the damage is assessed in monetary value: its price or cost of its reconstruction, or the monetary value of a similar asset. Economic methods can also be used to assess the intrinsic value of an asset, for example by evaluating its cultural and heritage importance, and whether it is replaceable or irreplaceable. Another means of economic valuation is based on an asset or structure's utility by calculating the income it generates, or the value of services it provides over its lifespan. Quantified economic losses can be further categorized into direct and indirect losses. Direct losses describe the costs of physical damage to the asset whereas indirect losses are linked to loss in services, such as rental value.

Empirical methods consist of approaches that provide an understanding of the nature and degree of interaction between a hazard and risk element. Empirical methods rely on developing damage function curves (also called vulnerability function curves) using hazard characteristics – depth and duration of flood – and damage to risk elements, for example damage to houses or crops expressed in economic terms. Since developing empirical methods requires careful and detailed observations, or is based on historical data, they tend to be data intensive and require detailed assessments in order to develop reliable results. Empirical approaches express the vulnerability of the risk element as a damage ratio – the ratio of repair (or damage) cost to that of total asset cost. A higher damage ratio will result in higher flood-related damage vulnerability.

Probabilistic methods measure the probability of a damage outcome by examining a range of possibilities associated with the hazard and risk elements response. Probabilistic methods imply that damage resulting from interaction between a hazard and its characteristics (intensity and duration) and a risk element may not necessarily be a single value but can be a range of values depending on hazard and risk element characteristics that are often difficult to understand and attribute. The economic and empirical methods described above can integrate these probabilistic estimations. For example, the probability of occurrence of a specific damage outcome each time a hazard occurs can be affected by the return period of that particular hazard, the resilience of physical structures, and resilience of social and institutional structures that respond to a hazard in different ways due to a lack of standardized response and mitigation measures. The probability of intensity and duration of a flood event determines the probability of a particular magnitude of damage. This is opposed to deterministic approaches that assess flood damages based on traditional methods, such as basing probability on information and data from a single flood event in the past. Deterministic approaches do not take into consideration the inherent randomness of hazards, and our limited understanding of risk elements. Probabilistic methods are gaining in popularity as they tend to break away from the limitations posed by historical understanding of risks, and take into consideration future hazard simulations. Simulation models such as HEC-RAS are commonly employed in probabilistic methods.

Selection of any of the above-mentioned methods depends on the purpose and scope of the assessment, expected assessment



accuracy, and available resources. The Project used the empirical method to develop the flood vulnerability function. This is detailed in sub-section 5.4 immediately below.

5.4.2 Developing damage functions for quantitative vulnerability estimation

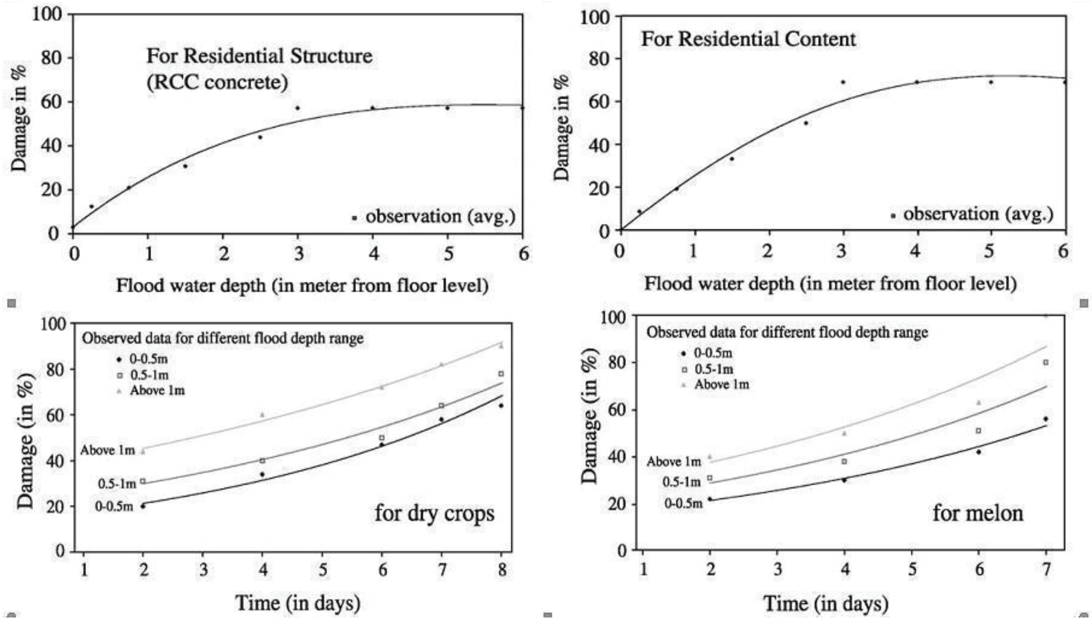
This section covers a vulnerability assessment using the damage function employed in this project. If damage functions are readily available for a study location, they can be used after checking the age of the data and if any changes have occurred in the location. Damage function development can employ various methods. These include conducting experiments under controlled conditions, historical analyses of damage data, structured household surveys (Appendix 4), literature reviews, and combinations of these methods. This section provides vulnerability assessment details using damage functions.

Flood damage and vulnerability functions show the empirical relationship between exposed elements, for example, buildings or human health, and hazard characteristics, for example, flood depth and duration, etc. There are two types of hazard (depth and duration) functions: empirical functions based on damage data collected immediately after the flood event, and synthetic functions based on theoretical assumptions, historical data and expert judgement on different presented scenarios.

Damage functions (Figure 5.5) can be developed by simulated flood events conducted under controlled conditions that help researchers collect damage data on buildings and crops. These experiments, however, are costly, and the results might not always reflect the range of conditions in real world situations, such as building age and associated wear and tear.

Damage functions can be developed with the use of historical damage data. However, the reliability of these functions depends on data quality, including data collected during past events. This can include data on depth, duration and velocity of flooding, as well as various risk element characteristics such as asset age, type, damage cost and value. Since such data is often not systematically collected in many countries, this type of damage function development is not always practical.

Figure 5.5 Example of damage functions for buildings and crops



(Source: Dutta et al., 2003)

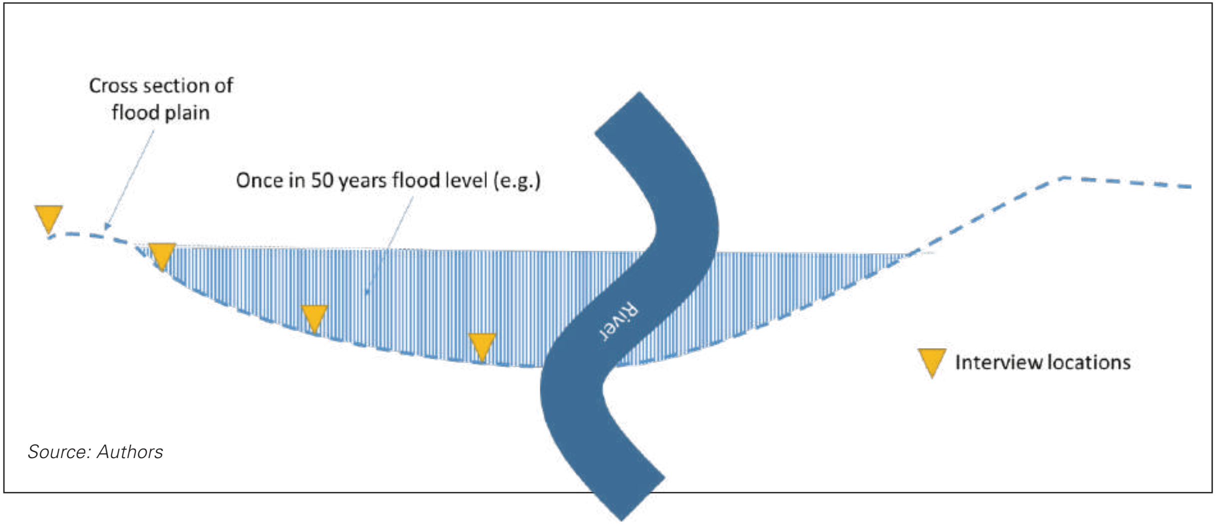
As in the RBPs, damage functions can also be developed using sample survey techniques with structured questionnaires designed to collect data on a historical flood event, or events. Data collected can include depth, duration and velocity of floods, as well as assets (risk elements). Since surveys (Appendix 4) depend on respondents' experiences and memories, this method is often riddled with challenges such as inaccurate recollection that can lead to weak or inaccurate outcomes.

To attain representative sampling and reduce errors, the number of collected samples should be increased substantially if significant time has passed after the flood event occurs. To obtain the most representative sample, random sampling techniques that are stratified based on spatial location on the flood plain (Figure 5.6) are recommended. Data to collect includes building type and age and crop characteristics (Table 5.2).

Characteristics to include in the sample survey questionnaires are shown in Table 4.2 below.

When conditions do not allow experiments or field surveys, damage functions can be formulated using published sources from past investigations in the same or similar locations. The major limitation to this approach is that building characteristics could be different due

Figure 5.6 Example of a stratified random sampling location in a flood plain to cover various flood depths and durations



Source: Authors

Table 4.2 Flood, building and crop characteristics for inclusion in damage function questionnaire surveys (Appendix 4)

Flood characteristic	Building characteristic	Crop characteristic
Occurrence time of year	Building age	Crop age
Flood depth	Roof type (thatched, RC, etc.)	Input costs (fertilizers, labor, etc.)
Flood duration	Wall types (wooden, brick, mud, stone, etc.)	Output price (farm gate price)
Flood velocity	Asset value (Value of the building and land)	Transportation costs (from farm to point of sale)
Sediment/debris load	Cost of repairs (damage)	

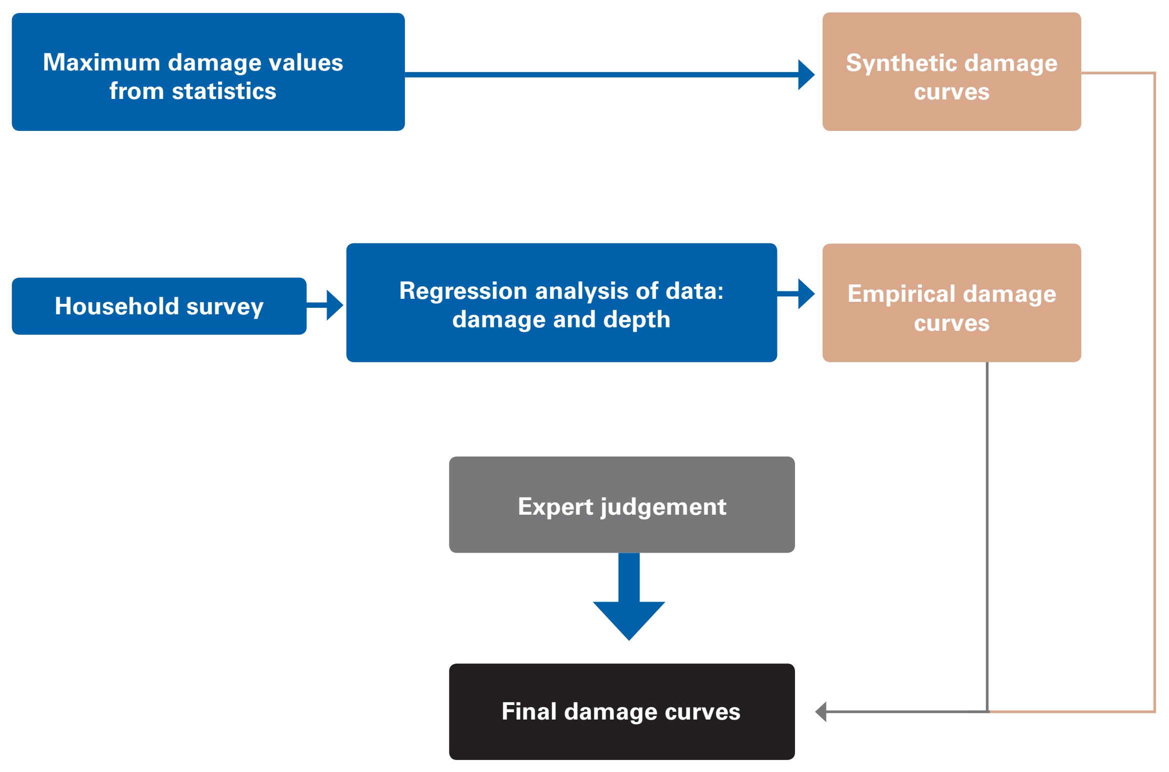
Source: Authors

to different target and literature locations. Additionally, building characteristics may have changed from the time cited in the literature to the current survey time.

Damage functions can be developed using a combination of the methods discussed above, as shown in Figure 5.7. In this ensemble approach, the team typically collects the historical damage data, conducts a literature review and develops the synthetic damage curves. The curves are further refined by collecting additional information from recent flood events through structured household surveys (Appendix 4), or discussions with water sector experts at consultation workshops. Though intensive, this process provides relatively reliable damage functions and helps to address uncertainties.

As flood damage functions are sensitive to space and time factors, these factors must be considered as and when needed. Space and time factors that affect damage function validity include building age and depreciation, new construction standards and material use, new flood response and early-warning measures, nature of building usage according to type and pace of economic activities, and physical space density and resultant human use changes.

Figure 5.7 An ensemble approach to damage function development



Source: adopted from ADB,2020

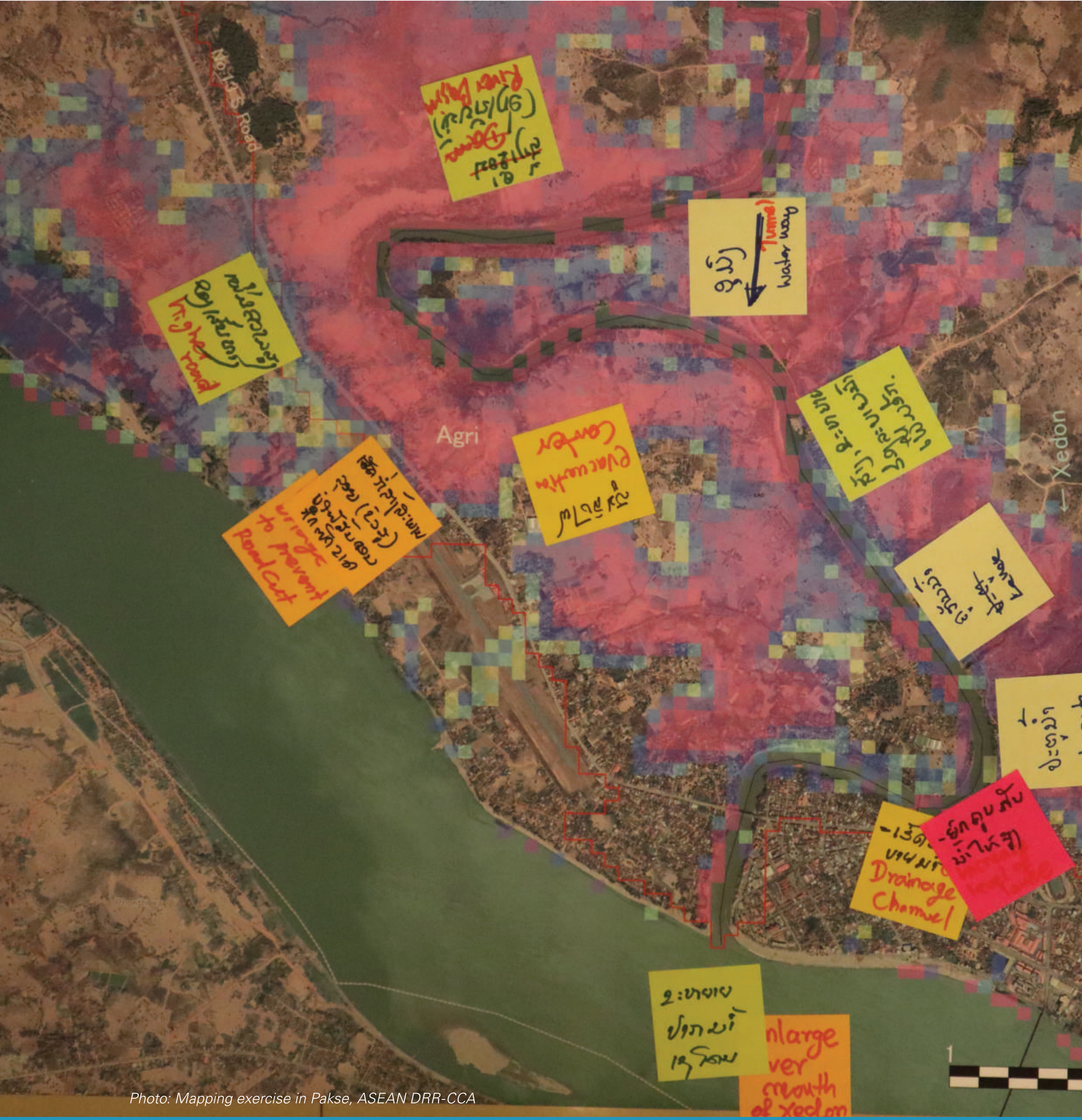


Photo: Mapping exercise in Pakse, ASEAN DRR-CCA

6

FLOOD RISK MAPPING

The degree of flood risk in a target river basin can be assessed with information on flood hazard conditions (area, duration, depth, velocity, etc.), exposure distribution, and exposure vulnerabilities as shown in the concept in Figures 2.1 and 6.1 (incorporating DRM). Integration of climate change impact into flood risk analysis is important. Flood risk is evaluated in two scenarios: with and without climate change impact conditions. Results are used to design and plan structural and non-structural flood countermeasures.

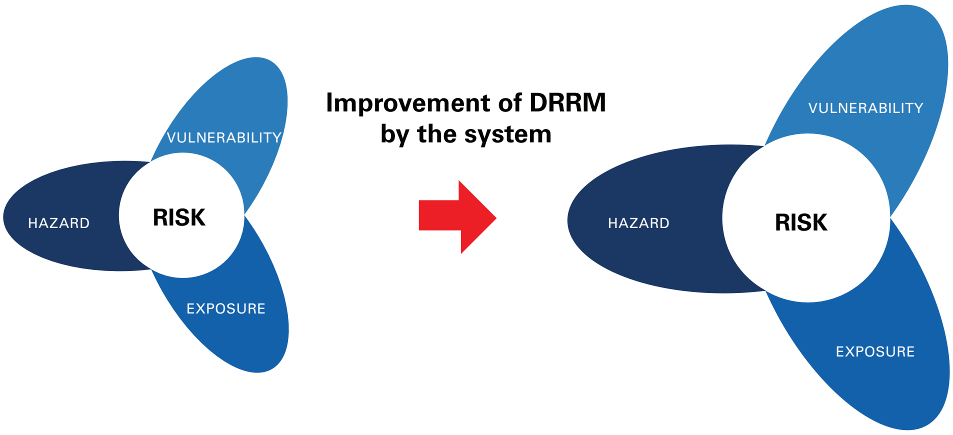
6.1 Flood risk assessment conditions

The degree of flood risk can be estimated by superimposing both the vulnerability and hazard condition distribution of those exposed in the target river basin (Shown in Figure 6.1).

6.1.1 Case simulation boundary conditions

Before the 1980's, a probabilistic-based approach (rainfall and discharge probability) and CCI scenarios to flood risk assessment was widely used. The IPCC recently concluded that climate change impacts (CCI) will affect future climate conditions, especially temperature and rainfall patterns and amounts. The IPCC climate change impact estimation also concludes that flood risk preparedness will lead to more effective responses to unexpected floods. Therefore, case-simulation stories for hydrological and

Figure 6.1. Flood risk degree concept with DRM improvement



Source: UNDP, Modified by Project Team

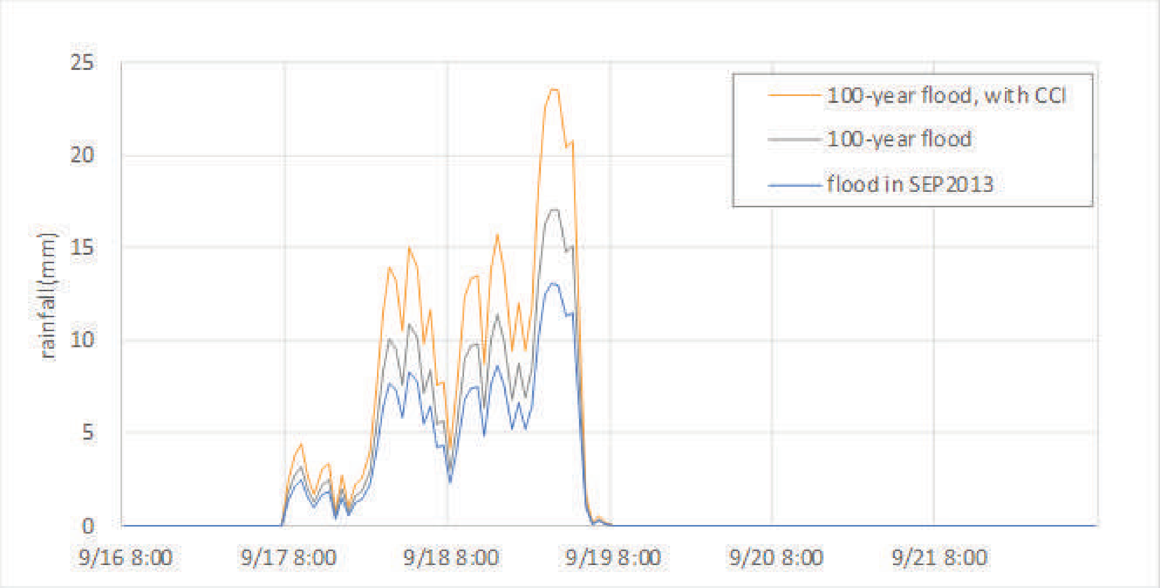
hydraulic analyses should employ both climate change impact scenarios and rainfall probability. As an example, Figure 6.2 from the ASEAN DRR-CCA Project shows 100-year flood damage with and without the CCI (Scenario: RCP 8.5, see Section 3).

Other conditions such as land use, river structures, ground elevation, road and railway networks, etc. that influence river channel and basin flood flow should be input into hydrological and hydraulic models based on national and local development plans.

6.1.2 Rainfall temporal pattern preparation probabilistic preparation

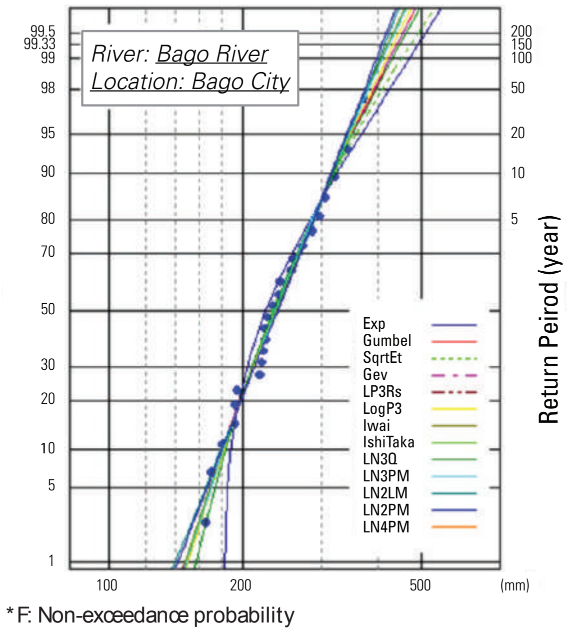
Rainfall hyetographs corresponding to requested flood scales can be constructed (Figures 6.3 and 6.4) if past major flood rainfall data is available. Past-observed rainfall data (hourly rainfall was measured for this project) in the hyetograph should be multiplied by the extension rate, estimated at 1.13 (425.3mm/376.1mm) if: (1) the total rainfall amount during the past flood was at least 376.1 mm, and (2) the estimated

Figure 6.2 Temporal Distribution of Rainfall in Lao PDR (with and without CCI)



Source: Project Team

Figure 6.3 Temporal distribution of rainfall



*F: Non-exceedance probability

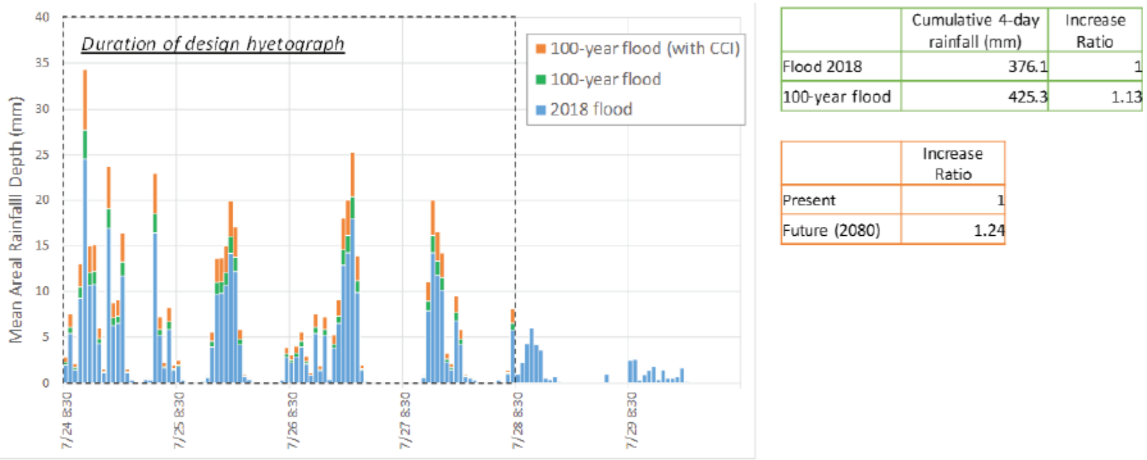
Table- Probable Rainfall by Gumbel

Return Period	Probable Rainfall (Gumbel)
2	234.3
3	258.5
5	285.5
10	319.3
20	351.8
30	370.5
50	393.8
80	415.2
100	425.3
150	443.7
200	456.7
400	488

Source: Project Team

flood scale is on the 100-year return period (see Figure 6.3). Construction of a 100-year scale rainfall hyetograph is illustrated in Figure 6.4. The graph shows hourly rainfall depth multiplied by the extension rate (blue to green bars).

Figure 6.4 Rainfall hyetograph extension for a 100-year return period with and without climate change impact



	Cumulative 4-day rainfall (mm)	Increase Ratio
Flood 2018	376.1	1
100-year flood	425.3	1.13

	Increase Ratio
Present	1
Future (2080)	1.24

Source: Project Team

Photo: Shutterstock / Dani Daniar

CCI-Scenario-Based Preparation

The extension ratio of past to future conditions can be assumed when comparing between past rainfall amounts with those predicted for the future, both of which are calculated by downscaling the GCM model. For example, to construct a rainfall hyetograph for 2080 using an RCP of 8.5, the 100-year scale hyetograph created in Figure 6.4 is multiplied with an extension ratio of 1.24, as shown (green to orange bars).

6.1.3 Flood hazard map creation (using HEC-FIA)

HEC-FIA (Flood Impact Assessment tools)

Global data, watershed data, hazard data and properties and assets data (see Figure 6.5) are necessary to carry out a Flood Impact Assessment (FIA). Watershed and hazard data, as explained in previous sub-sections of Chapter 4, can be used. An FIA should clarify flood event impacts and the benefits of flood mitigation measures.

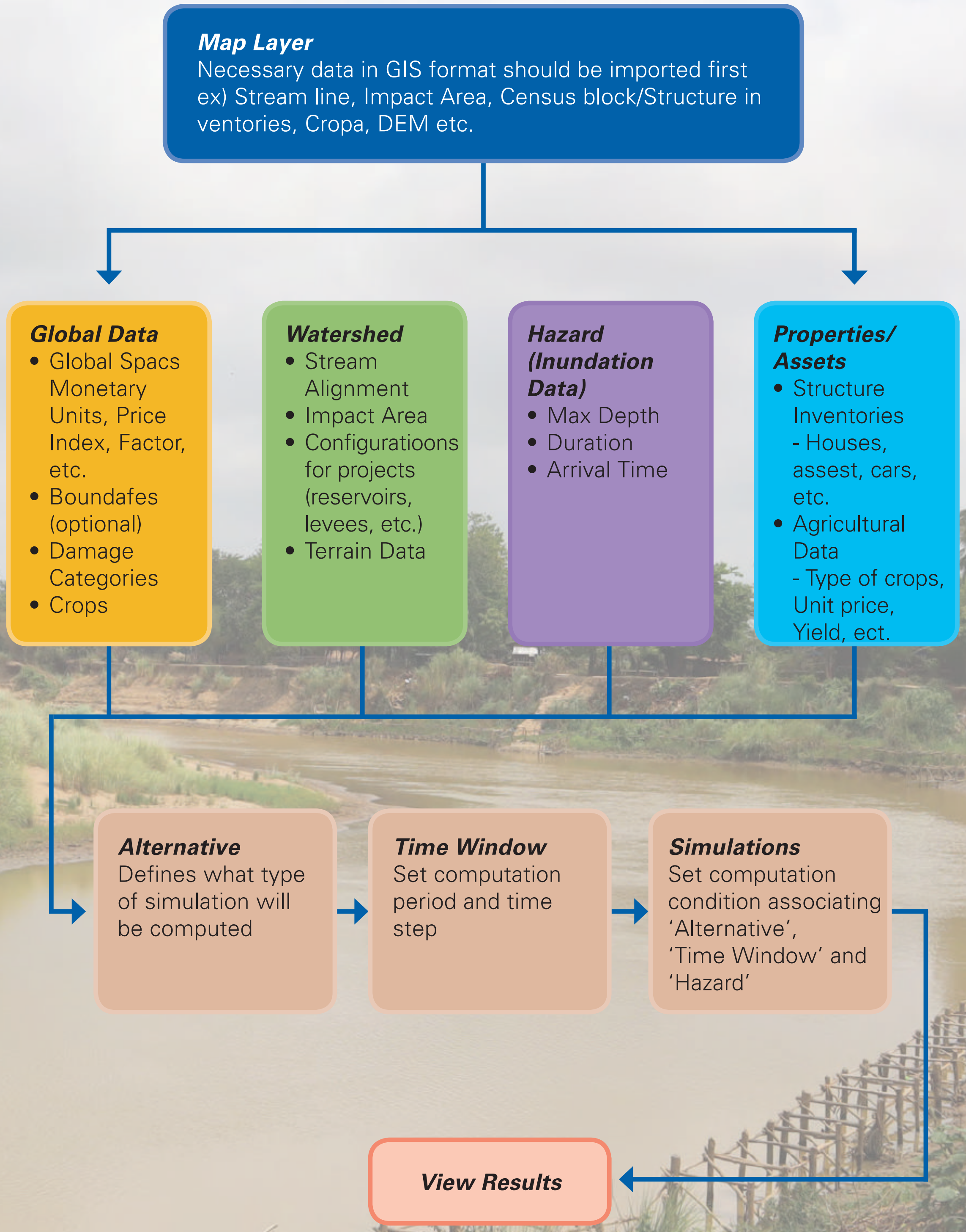
FIA Modeling

FIA modeling procedures are listed in Table 5.1 below.

Table 5.1 List of FIA modeling procedures

No.	Action	No.	Action
1	Create a new project	11	Create alternatives
2	Launch HEC-FIA	12	Set time window
3	Add map layers	13	Set simulation run
4	Watershed setup	14	Run simulation
5	Create terrain grid	15	View results
6	Import inundation data	16	Export results
7	Import agricultural data	17	Data preparation to import into QGIS
8	Import structure inventory	18	Create risk map
9	Change study display units	19	Draft risk map for structural damage
10	Set damage curve to structures		

Figure 6.5 Flood Impact Assessment workflow using HEC-FIA modeling



Map Layer
Necessary data in GIS format should be imported first ex) Stream line, Impact Area, Census block/Structure in ventories, Cropa, DEM etc.

Global Data
- Global Spacs Monetary Units, Price Index, Factor, etc.
- Boundafes (optional)
- Damage Categories
- Crops

Watershed
- Stream Alignment
- Impact Area
- Configuratioons for projects (reservoirs, levees, etc.)
- Terrain Data

Hazard (Inundation Data)
- Max Depth
- Duration
- Arrival Time

Properties/ Assets
- Structure Inventories
  - Houses, assest, cars, etc.
- Agricultural Data
  - Type of crops, Unit price, Yield, ect.

Alternative
Defines what type of simulation will be computed

Time Window
Set computation period and time step

Simulations
Set computation condition associating 'Alternative', 'Time Window' and 'Hazard'

View Results

Source: Project Team

6.1.4 Flood risk map creation

HEC-FIA flood damage calculation

The HEC-FIA estimates flood damages per mesh (Fig 4.13) using the basic equation below:

Flood damage = unit gate price of properties/assets×loss volume/number×damage rate

Where damage rate = *f* (depth and duration)

If the damage rate has not been determined yet, the vulnerability assessment should be used to create damage rate curves for each property and asset. The function should normally include variables for flood inundation depth and duration. Flood risks will be superimposed on topographic, land-cover and/or satellite maps to show risk areas. Basin-wide and local level maps will clarify the risk indicators. Risk areas will include flood degree indicators, such as water level, inundation area and duration, flow velocity, flood arrival time, flood damages, etc.

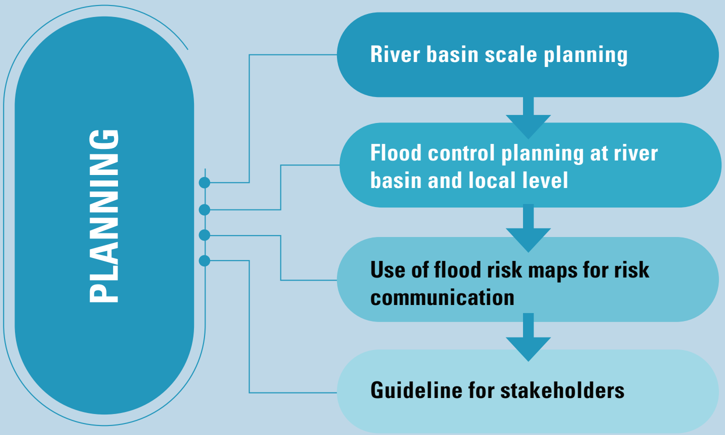
The risk maps will be prepared using two scenarios, with and without climate change impact. The climate change impact scenario will include flood season rainfall depth. The hydrological model will convert rainfall into runoff discharge in the river courses and inundation water flow to flood areas.

Exposure data distribution

Collected exposure data (people and houses or buildings, agricultural field location, etc.) will be overlaid on the basin map using a GIS base such as QGIS. The exposure data should be collected with association data such as ground positioning information (latitude and longitude or UTM coordination) and numbers should be distributed on as small an administrative level as possible.

Photo: Philippines Case Visit, ASEAN DRR-CCA

PART III: PLANNING



The developed flood risk maps are used for flood mitigation and prevention planning. The maps and completed hydrological analysis are very useful to plan flood mitigation and prevention in the target areas, both at the local level and basin-wide. The maps can also be used as a basis for Integrated Flood Management (IFM) that incorporates the concepts of ““effective use of land and water” and “best mix of countermeasures to prevent and mitigate flood damages”. The results of hydrological analysis will be used to determine the scale of planning and the design level of structural and non-structural measurements.

As there are different needs and capacities at different levels of governance, this section will cover planning at both the basin-wide and local level. The decision matrix below is a guide for relevant stakeholders and sectors for preparing short, medium and long-term plans to minimize the risk.

Setting the damage rate

Damage data is linked to exposure data. A damage rate is expressed by the relationship between exposure and disaster intensity. In a hazard analysis, disaster intensity is measured through inundation depth, duration, flow velocity, etc. A damage rate can be determined using the damage function developed as a part of a vulnerability assessment.

6.1.5 Simulation and output execution

Flood damage in an FIA is calculated by HEC-Flood Damage Reduction software, based on exposure data, hazard information, and the damage rate. Calculation results are shown in GIS through a CCI scenario and probability.

Photo: Countermeasure proposal/planning in Pakse, ASEAN DRR-CCA

7

INTEGRATED FLOOD RISK MANAGEMENT PLANNING

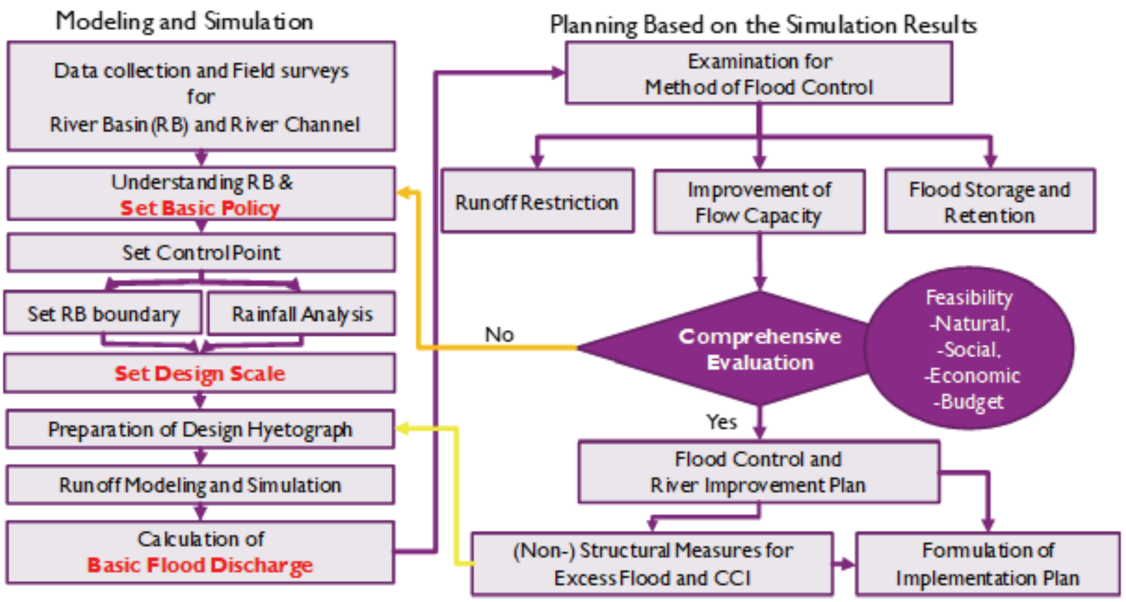
7.1 River basin scale planning

River basin scale planning involves interventions regarding flood storage and retention, runoff restriction, and channels/ network improvement through consideration of upstream and downstream linkages and associated vulnerabilities. To protect infrastructure, facilities, human habitats, cropping areas, etc., it should additionally entail identification of the best mix of structural and non-structural measures, use of nature-based solutions, resources allocation, and distribution of responsibility. The river planning flowchart shown in Figure 7.1 has been introduced in Japan and ASEAN countries such as Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Thailand and Viet Nam. The hydrological/hydraulic modeling and running simulation flow is shown on the left of the figure and the planning based on the simulation results is shown on the right. Malaysia and Japan in particular used the process in Figure 7.1 to develop guidelines for a flood control plan.

7.1.1 Data collection and field surveys

The data described in PART 1 should be collected for the flood risk analysis, as well as integrated flood management planning. In addition, information that will help to understand the causes of flooding and inundation should be collected in field household surveys (Appendix 4). This information will contribute to modeling and initial research designed to better understand flood mechanisms. Common causes of flooding and inundation are as

Figure 7.1 Flood control plan flowchart



Source: Technical Criteria for River Works by Japanese Ministry of Land, Infrastructure, Transport and Tourism

Box 3.1 Non-Structural Measures

Structural measures can never completely eliminate the risk of flooding. Nevertheless, because of their physical presence, they have the potential to create a false sense of security, leading to inappropriate land use in flood protected area by structural measures. Non-structural measures play an important role in reducing not only the catastrophic consequences of continuing risks, but also the adverse environmental impacts of those risks. For example, urbanization will lead a increment of river flow and change of climate condition may impact to amount of rainfall. Non-structural flood management measures such as land use regulations, flood forecasting and warning, flood proofing, and disaster prevention, preparedness and response mechanisms, have limited environmental consequences and should be actively considered as both as independent or complementary measures.

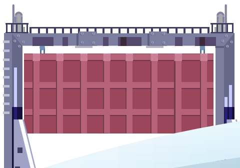
Source: Flood Manager E-Learning: http://daad.wb.tu-harburg.de/tutorial/integrated-flood-management-ifm-policy-and-planning-aspects/environmental-aspects/flood-management-interventions/non-structural-measures/)

follows: (1) heavy rainfall in areas where river and drainage channels lack water conveyance capacity, (2) high tides and backwater, (3) poor previous condition of river networks, flood control facilities, soil, etc., (4) Climate change impacts (affecting rainfall amounts and tidal levels), (5) flood control facility or operations failure during disasters, and (6) a combination of any of the above-mentioned causes.

7.1.2 Basic flood control policy and planning

Basic policy for a broad geographic area

A fundamental flood management policy for a broad geographic area at the country, provincial or regional level should be established for each target river system. This policy should contain (1) a long-term policy for flood control and (2) a conceptual plan for river improvement. The policy



should take into consideration the characteristics of individual rivers and their basins, and flood management balance across the region (Level of Uniformity and integrity between "upstream and downstream" or "main stream basin and tributary basins").

Target river basin flood control plan

A flood control plan that addresses the needs of the river basin inhabitants should prescribe specific improvements to be implemented over a 20 to 30-year period, in accordance with fundamental flood management policy as mentioned above.

7.1.3 Setting the flood control reference point

Reference points should be set for planning in order to confirm the efficiency and effectiveness of individual, or a combination of, proposed flood control interventions. The common conditions to consider for setting the points include:

- Availability of enough hydrological data
- Point contribution to hydrological and hydraulic analyses
- A close relationship to the full river basin flood control plan

In the example shown in Figure 7.2, the basin has a number of reference points: Point A for overall planning, Point B for a major tributary and Point C for confirmation of river structure effects.

7.1.4 Setting the river basin boundary and rainfall analysis

River basin boundary delineation

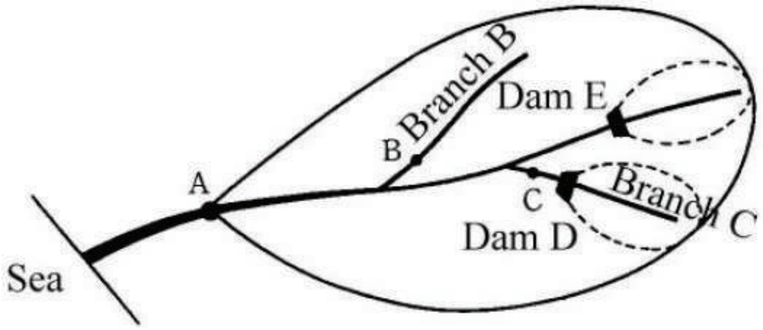
A river basin is defined as "an area of land characterized by the conveyance of all surface water through the same outlet, defined as a major river and its tributaries". The river basin boundary is commonly delineated, with the starting point located at the furthest downstream point of the primary stream. GIS software such as ARC-MAP, Q-GIS, etc. can be used for the delineation. However, errors are possible, and there might be no realistic conditions such as unexpected deep plunges for DTM and DEM, so it is better to confirm results using topographic paper maps with contour lines.

Rainfall analysis

Rainfall is set for each reference point as a boundary condition for the hydrological analysis. Normally, mean rainfall is prepared for the entire river and sub-river basins for hydrological model input. Rainfall is represented by the following three elements:


Photo: Shutterstock / Kahfi Irawan

Figure 7.2 Planning reference points



Source: Technical Criteria for River Works by Japanese Ministry of Land, Infrastructure, Transport and Tourism

- Rainfall amount during the peak flood inundation and discharge
- Rainfall temporal distribution
- Rainfall regional distribution

Use of satellite rainfall data (for example, from TRMM, GsMap or other radar rainfall products) is an alternative if ground-based rainfall data is not available, although confirmation is necessary if the satellite and ground-based data are from the same location or locations.

7.1.5 Determining design scale

In determining the design scale of the flood control plan, damage from past floods, expected economic effects, and other factors will help clarify the importance of the subject river. Several ASEAN countries have their own definition for deciding design scales. In Japan, all rivers are classified into one of five categories based on their importance, as shown in Table 6.1.

7.1.6 Hyetograph design and preparation

When the hydrological model is run with the inclusion of the design hyetograph, flood and inundation features will be expressed as a flood hazard area on topographic maps and hydrological graphs that depict river channel water level and discharge. As described in section 4, the hyetograph is based on observed rainfall and extension ratios for probabilities and climate change impact scenarios (see Figure 7.3). The hyetograph should be designed using the following guidelines.

- Temporal and spatial distributions of the subject rainfall make up the base of the hyetograph.
- Subject rainfall is arranged to have an equal amount of planning scale (probability).
- The hyetograph should be corrected if significant inconsistencies arise from extending the distributions.

7.1.7 Runoff Modeling and Simulation

Runoff modeling and hydrological/hydraulic simulation must be completed to determine the amount, direction and velocity of surface flood flow in river channels and on floodplains (Figure 7.4). To convert rainfall to flow discharge, a runoff calculation method that is best suited to river characteristics should be used. The rational method can be used for rivers in which flood storage does not have to be taken into consideration.

7.1.8 Basic and design flood discharge

Basic flood discharge

The model will show basic flood discharge if all runoff volume is confined to the river channel (left graph red line in Figure 7.5). The difference between river channel flow capacity (blue line, right graph in Figure 7.5) and runoff volume (red

Table 6.1 Design scale planning reference points for river classification in Japan

Importance of river	Planning scale (Return period in year of subject rainfall)*
Class A	Over 200
Class B	100-200
Class C	50-100
Class D	10-50
Class E	Below 10

* Inverse of the annual probility of excess

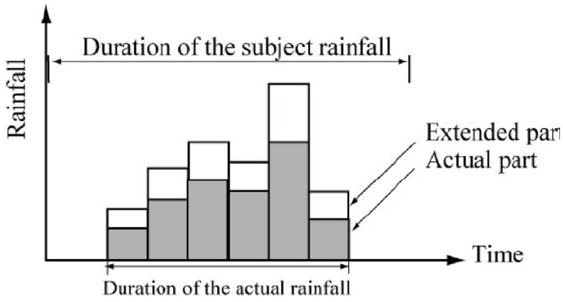
Source: Technical Criteria for River Works by Japanese Ministry of Land, Infrastructure, Transport and Tourism

line, right graph in Figure 7.5) can be considered overflow from the river to the floodplain.

Designed flood discharge

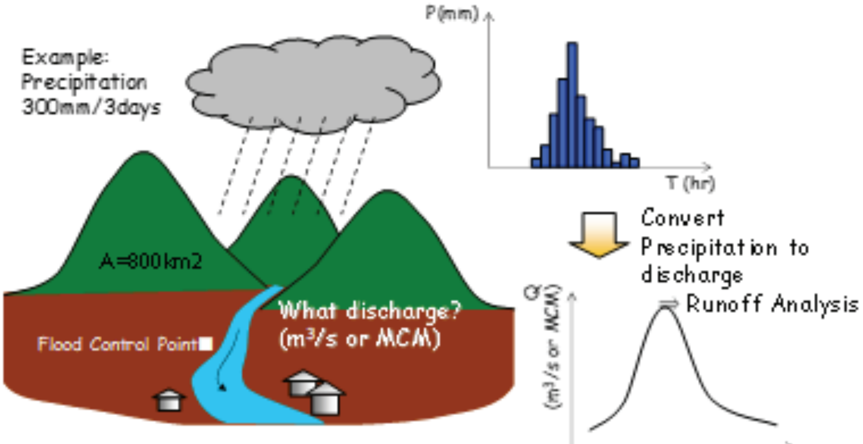
Proposed flood control countermeasures will reduce overflow water volume, resulting in flood damage mitigation and protection of people and assets on the floodplain (Figure 7.6). The reduced water volume in the river channel is referred to as "design flood discharge". The river will undergo improvements in order to confine the design flood discharge to its channels. Excess floodwater will be retained and stored (Figure 7.5) through other countermeasures.

Figure 7.3 Extension of a hyetograph to a requested degree



Source: Technical Criteria for River Works by Japanese Ministry of Land, Infrastructure, Transport and Tourism

Figure 7.4 Hyetograph extension for water amount, direction and surface flow velocity



Source: Project Team

7.2 Flood control planning

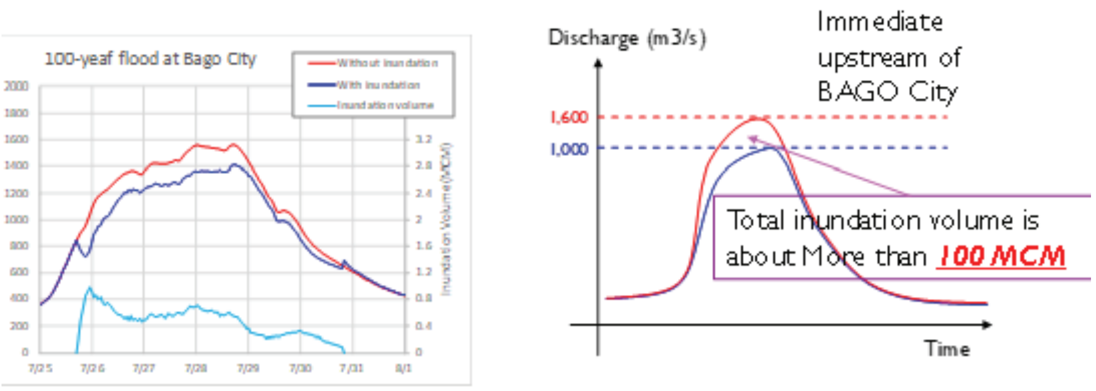
7.2.1 Creating a concept using flood management fundamentals

A basic concept should be created before establishment of a comprehensive flood management plan. The concept should be completed with the involvement of other water sector stakeholders. Proposed interventions should take into account technical, socio-economic, environmental and budgetary considerations.

7.2.2 River basin hydrological basis planning

Hydrological and hydraulic simulation results provide a mechanism to measure flood inundation and are key for mitigating and preventing flood damage. Simulation results can also help confirm the quantitative effects of proposed interventions. Climate change impacts require stakeholders to determine how to respond to floodwaters using the considerations described in sub-section 7.2.1 above. Stakeholders should also use Integrated Flood Management concepts, especially those pertaining to land and water, as well as the best mixture of structural and non-structural measurement.

Figure 7.5 Reference point flood discharge

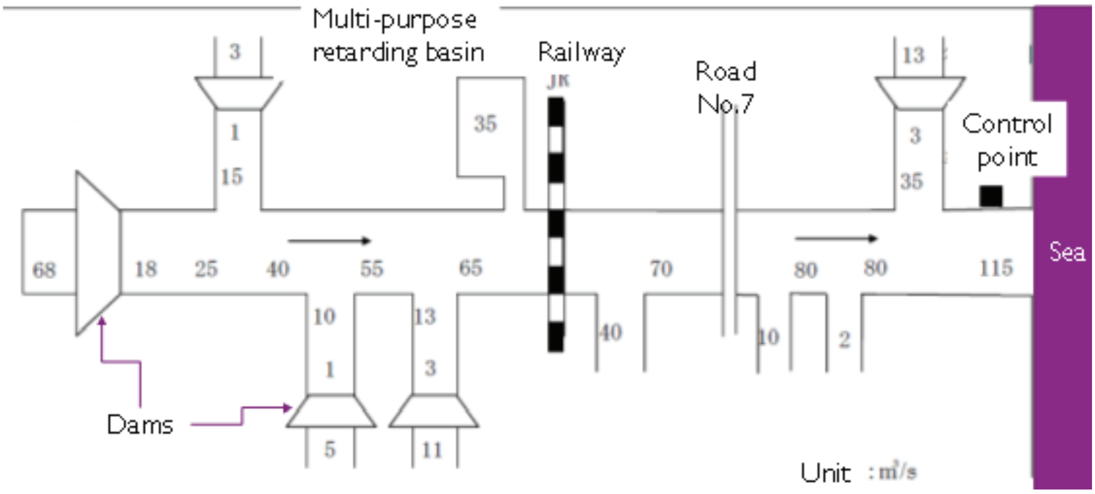


Basic Flood Discharge (Red)

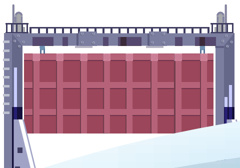
Rough Flow Capacity of Current (Blue) and Basic Flood Discharge (Red)

Source: Project Team

Figure 7.6 Example of Design flood discharge with countermeasures



Source: Japanese Ministry of Land, Infrastructure, Transport and Tourism



7.2.3 Local flood control plans

Local plans for flood management and control in cities and villages should be consistent with fundamental management policies and basin-wide flood control plans. Local communities at the village, city and provincial levels can, in particular, propose and work to improve drainage systems, establish early warning and evacuation systems, and institute flood resilient land-use. For example, by using flood hazard maps, the Project proposed the conceptual flood mitigation and prevention plans shown in Figure 7.10.

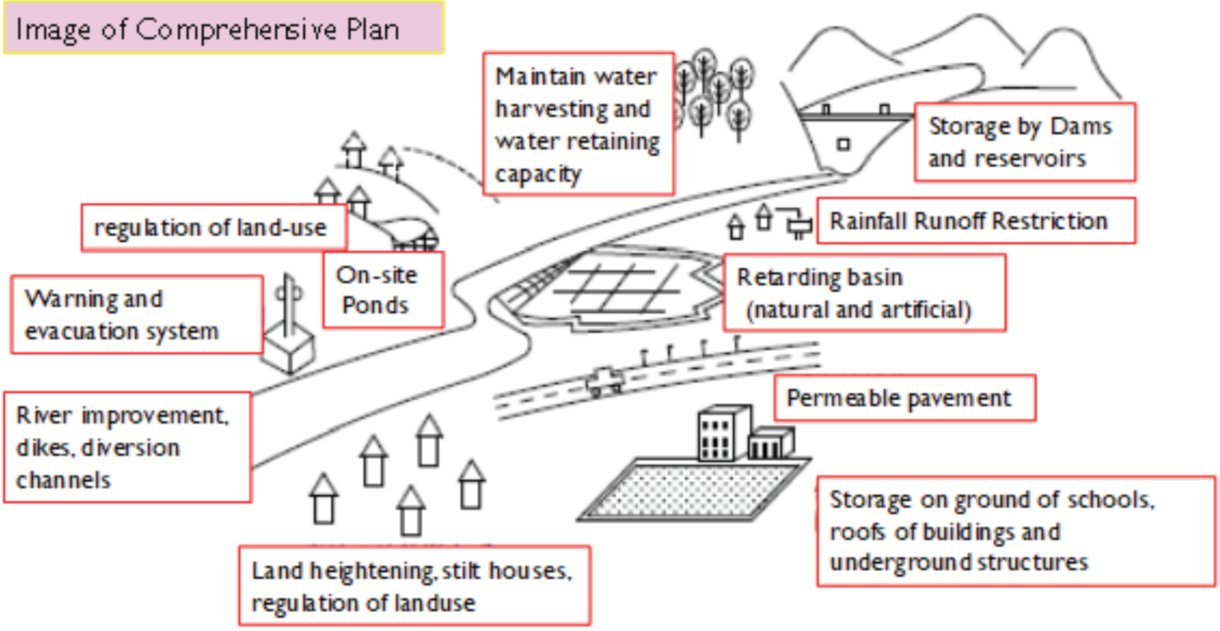
7.3 Use of flood risk maps for risk communication

7.3.1 Flood risk map examples

Flood risk maps show not only flood damages but also flood indicator degrees, such as inundation depth/duration, flood flow direction and velocity, flood arrival time, etc. A combination of indicators can also inform development of non-structural flood risk measures. Flood risk maps contribute to ASEAN country activities in many different sectors for socio-economic development and sustainable ecosystems. Figures 7.11 to 7.14 provide examples of Flood risk maps.

Photo: Risk and vulnerability survey in Bago, ASEAN DRR-CCA

Figure 7.7 Model of a comprehensive plan for river basin flood control and management



Source: Japanese Ministry of Land, Infrastructure, Transport and Tourism

Figure 7.8 100-Year Scale flood maps featuring inundation depth, with and without climate change impacts, prepared by the Bago RBP (ASEAN DRR-CCA Project)

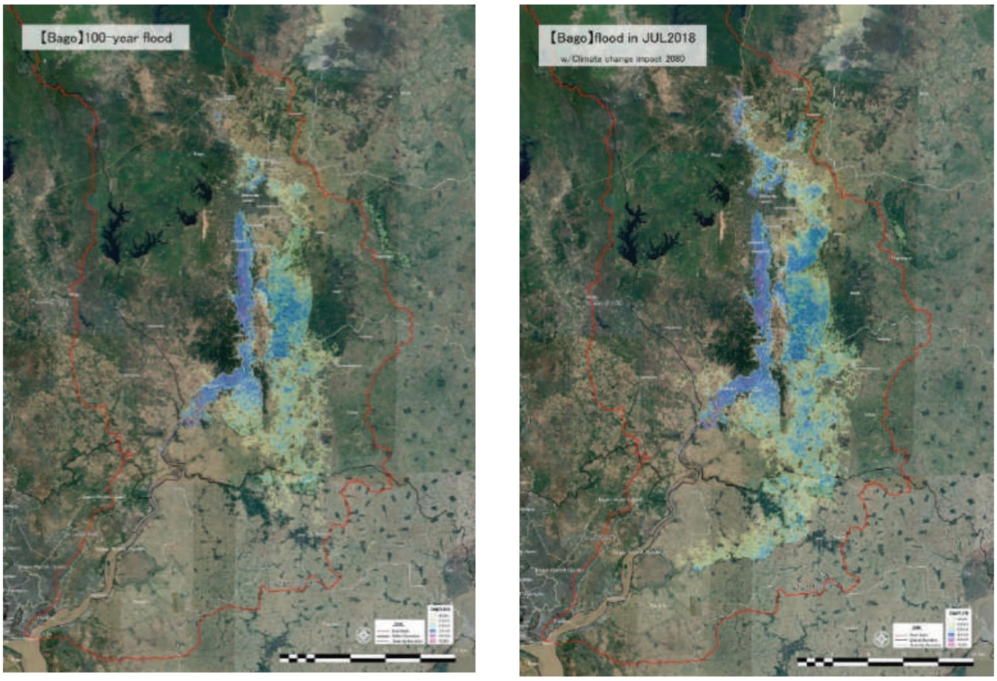
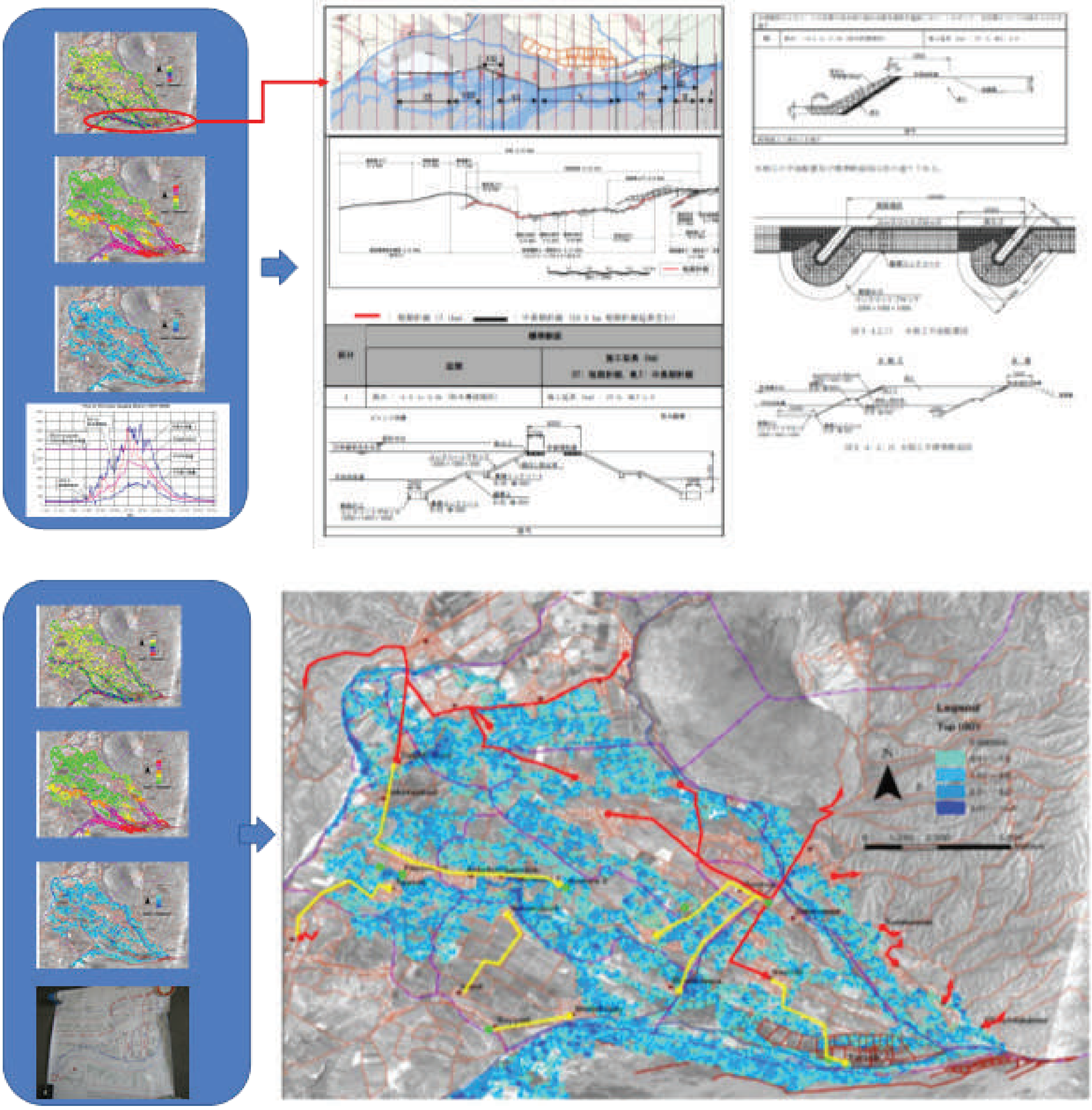


Figure 7.9 Conceptual plan for flood management example prepared by the Bago RBP (ASEAN DRR-CCA Project)

Figure 7.10 Example of a flood prevention (upper: structural measures) and mitigation plan (lower: evacuation map as a non-structural measure) for flood management



Source: JICA Study in Hamdani Area, Tajikistan

Figure 7.11 Flood risk map showing flood damages prepared by the Bago RBP (ASEAN DRR-CCA Project)

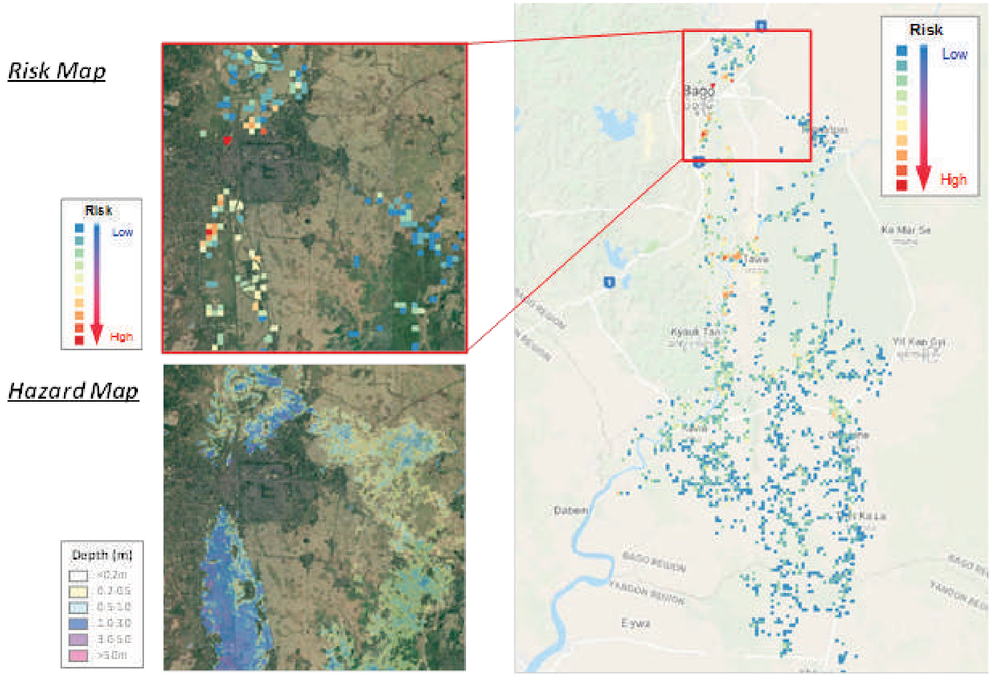
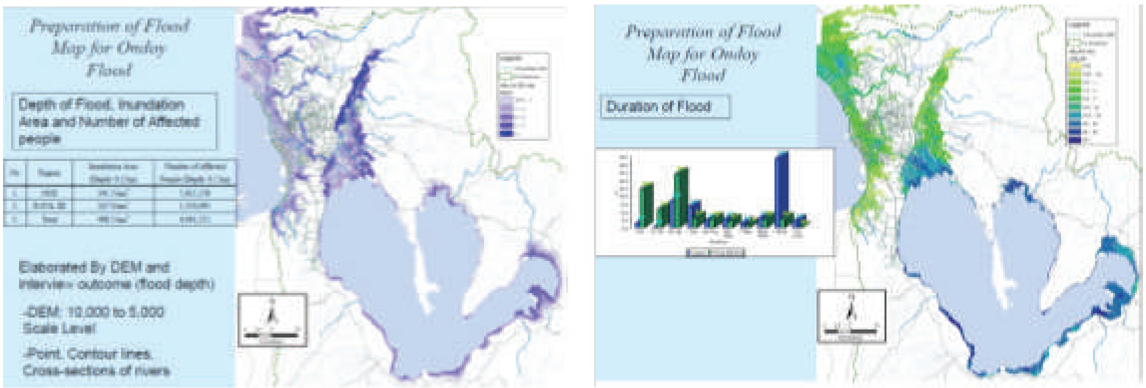
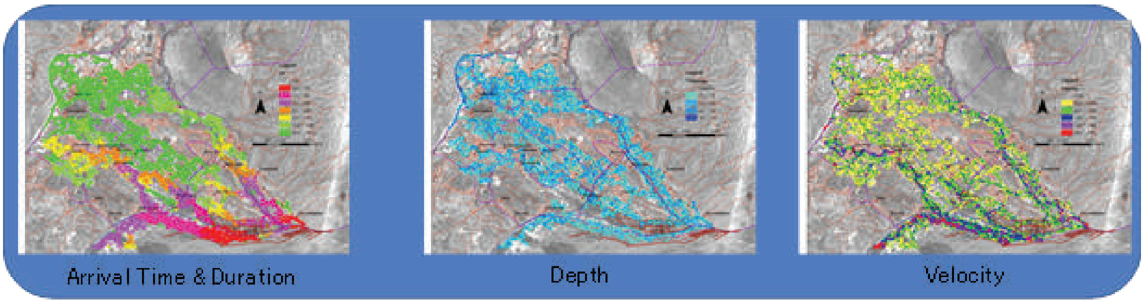


Figure 7.12 Individual indicators shown on a flood risk map



Source: WB Study



Source: JICA Study

Figure 7.13 Flood risk map showing a combination of flood indicators and local evacuation system usage

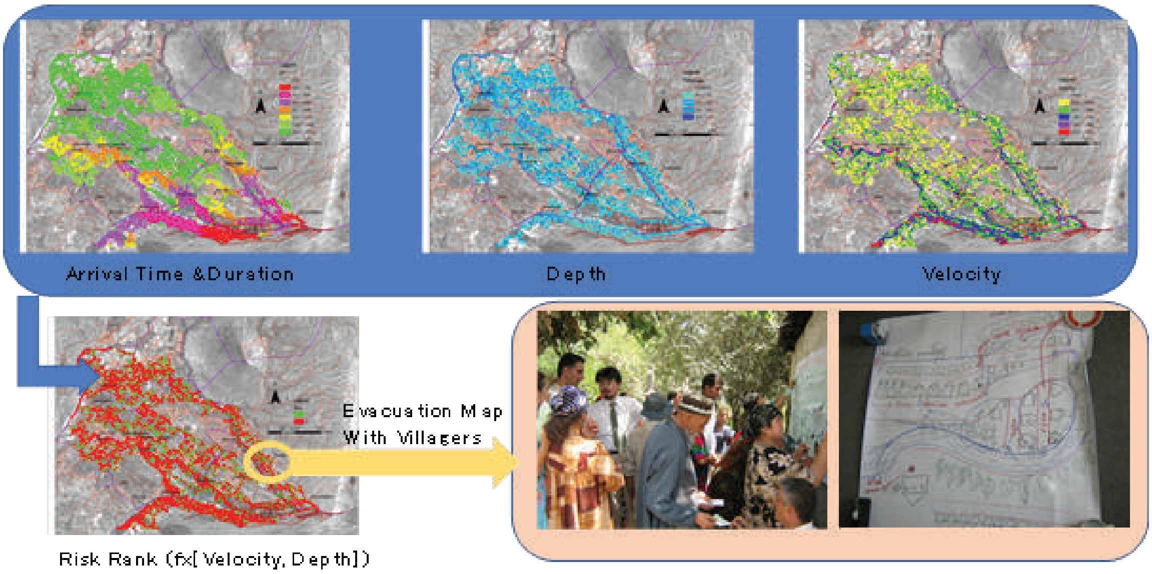
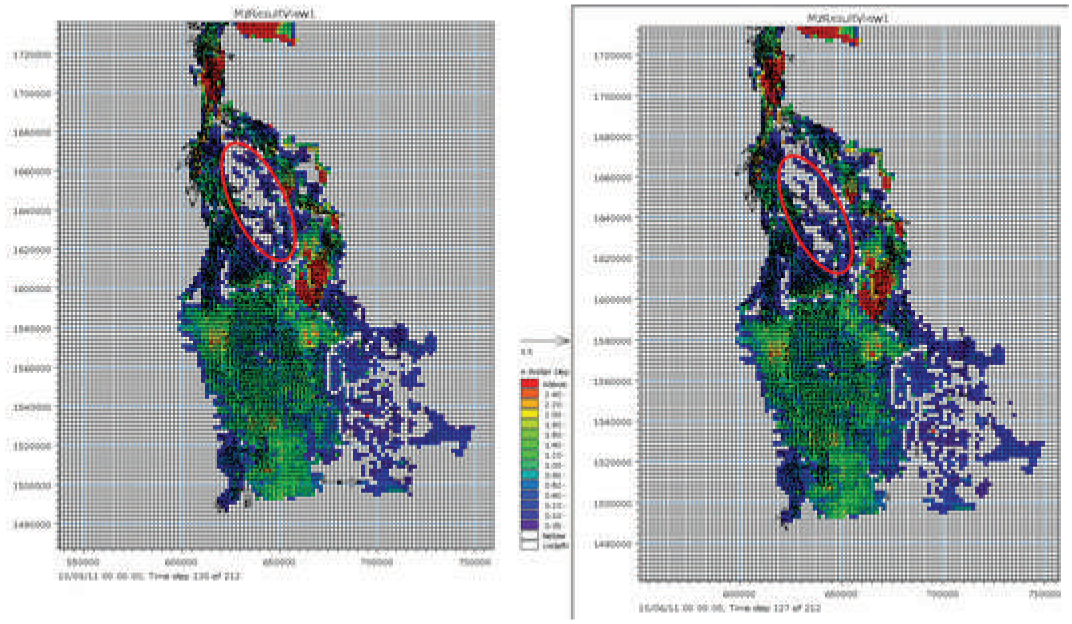


Figure 7.14 Flood risk map showing climate change impact

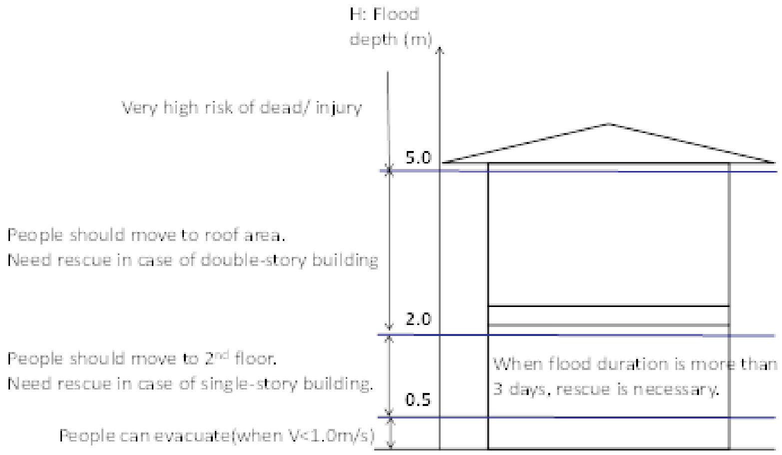


Source: *JICA Study in Thailand*

7.3.2 Example of Threshold Information to Rank Risk Level

Guidance previously developed in different countries can be used to evaluate risk degree. Risk can be ranked using this guidance. Examples are shown in Figure 7.15 below.

Figure 7.15 Example of threshold to express risk degree: upper for the movement of people in a floodplain, lower for decision-making when reacting to a flood



Source: Modified referring to Abt Associate Inc.: Estimating Loss of Life from Hurricane-Related Flooding in the Greater New Orleans Area, Final Report 2006.

7.4 Stakeholder guidelines

Application of the risk assessment methodology in these guidelines can contribute to long-term risk reduction only when risk assessment becomes the basis for decision-making at various levels. This sub-section visualizes the methods through which the risk assessment methodology presented in these guidelines can be used for planning and appropriate decision-making. It will present steps to establish this knowledge-based decision-making process at various levels, as well as the necessary capacities and protocols to ensure risk assessments are initiated at regular intervals. This sub-section will additionally provide a list of actions that sectoral agencies can take to use these risk assessment guidelines for planning structural and non-structural measures, as explained in Sections 7.1 and 7.2.

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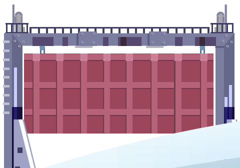

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