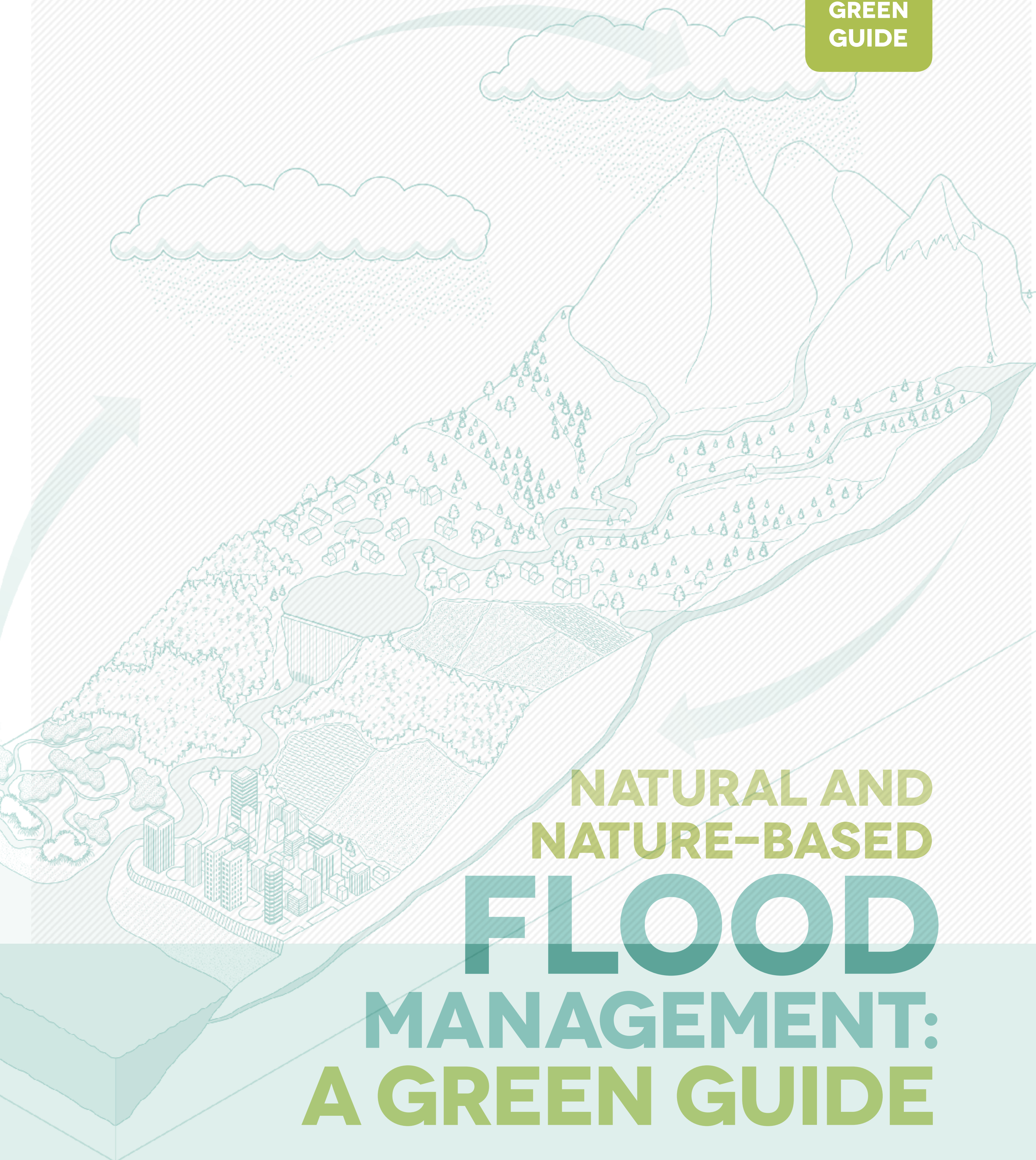
FLOOD GREEN GUIDE



NATURAL AND NATURE-BASED FLOOD MANAGEMENT: A GREEN GUIDE

The Flood Green Guide (FGG) is dedicated to the resilient spirit of people around the globe working to survive and thrive in a world at risk. We hope that this guide, and the services provided by nature, will inspire and support those efforts.

FLOOD GREEN GUIDE

NATURAL AND NATURE-BASED FLOOD MANAGEMENT: A GREEN GUIDE

CONTENTS

4

5

6

FIGURES AND TABLES

Figures

Tables

PREFACE

Multiple and varied factors contribute to the global increase in flooding. These include meteorological factors such as rainfall, storms and changing temperatures; hydrological factors such as soil moisture and groundwater levels; and societal factors such as changes in land use and occupation of floodplains. Floods in urban areas are an increasing concern as cities and towns expand rapidly, many along coastlines, where sea level rise and sinking land (or subsidence) compound risk.

Over the years, as flood risk has grown, the nature of that risk has changed. For example, although scientists cannot with certainty attribute a specific flood to climate change, they do know climate change contributes to extreme weather events. At the same time, policy-makers and practitioners have adopted a gradual but continual shift in policy and practice from flood control to flood risk management. The reason for this shift is that evidence confirms a narrow application of traditional engineering to control floods is not sufficient and is no longer appropriate as the sole approach to managing floods. Federal government policy requires all federal investments that affect floodplains to meet higher flood risk management standards and help conserve the natural values of floodplains. This policy establishes a new standard for flood risk reduction that reduces the risk and cost of future flood disasters, building on existing policy that "requires executive departments and agencies (agencies) to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative."[1]

Current better management practices for floods call for a holistic and integrated approach that engages multiple disciplines and experiences. Such an approach will build resilience and reduce vulnerability for both people and the environment. These improved practices also help planners understand and manage flood risk.

World Wildlife Fund (WWF), in partnership with the US Agency for International Development Office of Foreign Disaster Assistance (OFDA), has developed the *Natural and Nature-Based Flood Management: A Green Guide* (Flood Green Guide) to support communities at a local level in using natural and nature-based methods for flood risk management. An interdisciplinary global team developed the Flood Green Guide with a specific focus on advancing the development and application of natural and nature-based methods for managing flood risk.

The Flood Green Guide is based on collective experience, review and analysis of current and emerging flood management better practices, and on consultation with experts in engineering, water resource management, urban planning and policy, climate change, and community engagement and development. To develop the

1 Executive Order No. 13690, 80 FR 6425 (January 30, 2015), https://www.federalregister.gov/articles/2015/02/04/2015-02379/establishing-a-federal-flood-risk-management-standard-and-a-process-for-further-soliciting-and.

approach and content of the Flood Green Guide, the writing team also consulted with representatives from various communities in Asia and Latin America.

The Flood Green Guide draws from and complements existing resources and literature, and is based on the integrated flood management (IFM) approach, which recognizes that sometimes flooding is a natural and beneficial process. The Flood Green Guide is designed to maximize the benefits of floodwaters while offering guidance on managing and minimizing floods using natural and nature-based methods. We believe these methods are an important part of an integrated and strategic approach to flood risk management. As the Flood Green Guide is focused primarily on flood management methods, the guide is not designed to address every element of flood risk management. Additional resources are available to learn more about flood risk management.[2]

The guide is designed for those responsible for flood risk management, including municipal governments, community groups, and nongovernmental organizations (NGOs). The Flood Green Guide provides this audience with practical guidance and tools to understand the local context related to flood risk. At the same time, the Flood Green Guide describes a number of flood management methods that can be used in various combinations. Several case studies illustrate many of the issues and challenges related to flood risk management and how communities around the world are adapting and developing their own flood management methods. Every situation and community is different; the guide user will need to adapt the methods as appropriate for the local context and specific flood risk management objectives and acquire technical support as may be required.

The Flood Green Guide will be supported by a training program, and a website – www.envirodm.org – with a resource library containing additional information on innovative practices, case studies, and learning opportunities.

The Flood Green Guide builds upon WWF's global experience with disaster response and risk reduction. Since 2005, WWF has collaborated with humanitarian and development agencies, the United Nations (UN), and others to integrate environmental concerns into disaster recovery, reconstruction, and risk reduction policies and programs. We have provided training in environmentally responsible disaster management in Indonesia, Thailand, Sri Lanka, the Maldives, Nepal, Pakistan, Chile, Guatemala, Belize, and Haiti.

2 Paul Sayers et al., *Flood Risk Management: A Strategic Approach* (Paris: UNESCO, 2013), http://www.adb.org/sites/default/files/publication/30246/flood-risk-management.pdf.

ACKNOWLEDGMENTS

Project Manager

Anita van Breda, World Wildlife Fund

Creative Director / Graphic Designer

Melissa Carstensen, QueenBee Studio

Editors

Heather Benit

Martha Thomas

Illustrator

Greg Maxson

Research and Writing Team

Dr. Masood Arshad, WWF-Pakistan

Nadia Bood, World Wildlife Fund Belize

Oscar Guevara, WWF-Colombia

Dr. Missaka Hettiarachchi, WWF Fellow

Nausheen Iqbal, World Wildlife Fund

Charles Kelly, ProAct

Ibrahim Khan, WWF-Pakistan

Lauren Kovach, World Wildlife Fund

Linh Nguyen, World Wildlife Fund

Schuyler Olsson, World Wildlife Fund

Didier Pedreros, WWF-Colombia

Jennifer Pepson Elwood, World Wildlife Fund

Ed Tongson, WWF-Philippines

Anita van Breda, World Wildlife Fund

Dr. Bart Wickel, Stockholm Environment Institute

Advisory Group

Ada Benavides, U.S. Army Corps of Engineers

Dr. Wolfgang Eric Grabs, World Meteorological Organization

Karin M. Krchnak, World Wildlife Fund

Jonathan Randall, DAI

Steve Stockton, U.S. Army Corps of Engineers

Dr. Ayse Sezin Tokar, U.S. Agency for International Development

Consultations

Europe:

Associated Programme on Flood Management – World Meteorological Organization

Regina Junio, WWF-US Education for Nature Fellow

Dr. Bruce Lankford, University of East Anglia, UK

Homero Paltán, University of Oxford

Paul Sayers, Sayers and Partners and Associate Advisor WWF-UK

Colombia:

Luis Gerardo Camargo, DRR Officer – Usme Borough (Bogota)

Humberto Gonzáles Marentes, Consultant in Hydrology and Meteorology

Lina María Hernández, IDIGER – Bogota Office for DRR and Climate Change

Darío Londoño Gómez, Professor and Consultant

Diana A. Paredes, DRR Officer – Usme Borough (Bogota)

Belize:

John Augustine, Vice Chairman of Seine Bight Village

Sandy Beach, Sandy Beach Real Estate

Lily Bowman, Belize Red Cross Society

Jacinto Casimiro, Helpage Secretary

Wayne Casimiro, Hopkins Village Council

Victor Castillo Jr., National Emergency Management Organization

Climate Change Office of Belmopan, Belize

Rudolph Coleman, Helpage

Petrona Coy, Southern Environmental Association

Keith Emmanuel, National Emergency Management Organization

Shelton DeFour, National Emergency Management Organization

Walter Garbutt, Southern Environmental Association

Nicole Gomez, Southern Environmental Association

Dennis Gonguez, National Meteorological Service of Belize

Ann Gordon, Belize National Climate Change Office

Hopkins Village, Stann Creek District, Community Members

Frederick Hunter, Belize Red Cross Society

Charlie Leslie Jr., Former Village Council Leader, Placencia

Clyde Martinez, Teacher

Uwahnie Martinez, Palmento Grove

Ashford Miranda, Hopkins Village Council

Felix Miranda, Garifuna Fabrics

Arreini Palacio, Southern Environmental Association

Hilaria Ramos, Hopkins Village Council

Samir Rosado, Coastal Zone Management Authority

Seine Bight Village, Community Members

Florencio Shal, Driver

Wayne Usher, City Emergency Management Organization

Safira Vasquez, Belize National Climate Change Office

Monique Vernon, Southern Environmental Association

Tennielle Williams, Principal Hydrologist

Michalyn Young, Southern Environmental Association

Sri Lanka:

P. Hettiarachchi, Irrigation Department of Sri Lanka

Sunil Jayaweera, Disaster Management Centre of Sri Lanka

Chandana Kalupahana, Urban Development Authority of Sri Lanka

Badra Kamaladasa, Sri Lanka Water Partnership

Ranjith Rathnayake, Sri Lanka Water Partnership

S. Soysa, Sri Lanka Land Reclamation and Development Corporation

Dr. Kithisiri Weligepola, Irrigation Department of Sri Lanka

Dr. Nimal Wijerathne, Wetlands Management Unit, Sri Lanka Land Reclamation and Development Corporation

Pakistan:

Dr. Masood Arshad, WWF-Pakistan

United States:

Angela Andrade, Conservation International

Curtis Barrett, USAID Office of Foreign Disaster Assistance

Charles Conley, iMMAP

Pascal Debons, Action Against Hunger

Manishka de Mel, Columbia University Center for Climate Systems Research

Adam Dixon, World Wildlife Fund

Robyn Fischer, WaterAid America

Mark Gruin, International Orthodox Christian Charities

Julia Hanby, InterAction

Youngjae Kim, George Washington University

Achala Navaratne, American Red Cross

Dana Perzynski, Ayers Saint Gross Architects

Dr. Malini Ranganathan, American University

Tonya Rawe, CARE USA

Cynthia Rosenzweig, Columbia University Center for Climate Systems Research

Rose Schneider, Health Systems Management

Charles Setchell, U.S. Agency for International Development

Doug Sheredos, Site Resources Inc.

Kevin Taylor, World Wildlife Fund

Alice Thomas, Refugees International

Vietnam:

Dr. Ian F. Wilderspin, *Disaster Risk Reduction & Climate Change Adviser*

World Wildlife Fund. 2016. Natural and Nature-based Flood Management: A Green Guide. Washington, DC: World Wildlife Fund. http://envirodm.org/flood-management

ACRONYMS

ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
APFM	Associated Programme on Flood Management
CCA	Climate change adaptation
CDA	Capital Development Authority (Pakistan)
CDRN	Corporate Disaster Response Network (Philippines)
DRA	Disaster Risk Assessment
DRR	Disaster risk reduction
DSS	Decision support system
EIA	Environmental Impact Assessment
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FEMA	Federal Emergency Management Agency
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information Systems
GLOF	Glacial Lake Outburst Flood
GRASS	Geographic Resources Analysis Support System
GRB	Gender Responsive Budgeting
HDDS	Hazards Data Distribution System
IAHR	International Association for Hydro-Environment Engineering and Research
ICIMOD	International Centre for Integrated Mountain Development
IEE	Initial Environmental Examination
IFM	Integrated flood management
IFNet	International Flood Network
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated water resources management
LIMCOM	Limpopo Watercourse Commission
LWD	Large woody debris
MOU	Memoranda of Understanding

NGO	Nongovernmental organization
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Administration
NRM	Natural resource management
OFDA	USAID Office of US Foreign Disaster Assistance
PPP	Public-private partnership
PSNDM	Private Sector Network for Disaster Management (Philippines)
SAGA	System for Automated Geoscientific Analyses
SME	Small and medium enterprises
SUDS	Sustainable urban drainage systems
UAV	Unmanned aerial vehicle
UHI	Urban heat island effect
UN	United Nations
UNDP	United Nations Development Programme
UNIFEM	United Nations Development Fund for Women
UNISDR	United Nations Office for Disaster Risk Reduction
UNITAR	United Nations Institute for Training and Research
UNOOSA	United Nations Office of Outer Space Affairs
UNOSAT	UNITAR Operational Satellite Applications Programme
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development
USGS	United States Geological Survey
VA	Vulnerability assessment
VCA	Vulnerability and capacity assessments
VIA	Vulnerability impact assessment
WMO	World Meteorological Organization
WWF	World Wildlife Fund

CHAPTER 1

1. INTRODUCTION

Since their earliest settlements, humans have experimented with and adopted ways to manage flood risk. Some approaches are designed to prevent, some to manage, and others to handle the impact of floods. Anyone exploring flood risk management options should understand how different methods are intended to work – and under which circumstances. The financial, social and environmental costs and benefits of various flood management interventions also should be examined.

When communities live, work and play in areas prone to flooding, they expose themselves to flood-related damage.[1] Human activity (such as landfill, damming and urbanization) can introduce new risks to areas previously not subjected to flooding. In both cases, flood risk can be managed by altering either the natural or physical features (such as landscape, hydraulics, vegetation) or human activities (such as land use plans and settlement locations).

The *Natural and Nature-Based Flood Management: A Green Guide* (Flood Green Guide) supports the concept that flood risk management measures should be comprehensive, locally specific, integrated and balanced across all concerned sectors.[2] Therefore, the guide is based to the extent possible and practical on the **integrated flood management**[3] (IFM) approach as defined by the Associated Programme on Flood Management (APFM):

> "IFM integrates land and water resources development in a river basin, within the context of integrated water resources management, with a view to maximizing the efficient use of floodplains and to minimizing loss of life and property. Integrated flood management, like integrated water resources management, should encourage the participation of users, planners and policymakers at all levels. The approach should be open, transparent, inclusive and communicative; should require the decentralization of decision-making; and should include public consultation and the involvement of stakeholders in planning and implementation."[4]

For the purpose of the Flood Green Guide, we use the definitions adopted by the US Army Corps of Engineers (USACE) to describe natural features as those created through the action of physical, biological, geologic, and

---

1 The Flood Green Guide recognizes the definition of a community can vary and is context specific.

2 Abhas K. Jha, Robin Bloch and Jessica Lamond, *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* (Washington, DC: World Bank Publications, 2012), 167, https://www.gfdrr.org/sites/gfdrr/files/urban-floods/urbanfloods.html.

3 Terms in bold can be found in the glossary.

4 Associated Programme for Flood Management (APFM) and World Meteorological Organization (WMO), *Integrated Flood Management: Concept Paper*, Integrated Flood Management Tools, no. 1047 (Geneva, Switzerland: WMO, 2009), http://www.apfm.info/publications/concept_paper_e.pdf.

chemical processes operating in nature, whereas nature-based features are created by human design, engineering and construction.[5]

Throughout the guide, we use the terms "natural" and "nature-based" interchangeably. We also recognize that in some cases, practitioners may use other terms, such as "green" or "**green infrastructure**," interchangeably with the terms natural and nature-based.

The Flood Green Guide organizes flood management methods into two categories: structural and non-structural. **Structural methods** involve physical changes to natural features or human infrastructure, including engineered (**hard**) methods (sometimes referred to as **gray** methods), such as dams or floodways, and **natural and nature-based** (**soft**) methods (sometimes referred to as **green** methods), such as wetland protection, upper watershed restoration or rain gardens.

Non-structural measures are defined as those that seek to change social conventions like laws, regulations, social institutions, organizations or individual behavior. Most flood risk management projects will comprise both *structural* (hard and soft methods) and *non-structural* components. In the Flood Green Guide, we recommend the use of a combination of multiple methods of hard and soft, structural and non-structural approaches that complement one another and enhance the efficacy of any existing flood risk management methods. In most cases, a combination of methods will be required and, therefore, the use of a single approach in isolation is not advised. Chapter 5 of the guide discusses in detail a comprehensive list of structural and non-structural flood risk management methods.

The "How to Use the Flood Green Guide" chapter leads those responsible for flood management (referred to as managers or guide users) through information gathering, analysis, and decision-making at multiple stages of a typical flood risk management project cycle.[6]

The Flood Green Guide is organized into the following chapters:

Chapter 1. Introduction

This chapter explains the objective and organization of the Flood Green Guide.

Chapter 2. How to Use the Flood Green Guide

This chapter explains how to follow a project management cycle to conduct preliminary analysis and set goals and objectives based on an understanding of context and risk; identify a range of suitable flood management methods; select specific methods; determine operation and monitoring plans; and conduct evaluation of the strategies implemented. The entire process is meant to be continual and circular; thus, the system should be regularly updated as described in this chapter.

GUIDANCE: The Flood Green Guide recommends managers first apply IFM non-structural methods and then if needed include structural (hard and/or soft) methods as part of an integrated approach.

Chapter 3. Foundational Concepts and Key Crosscutting Issues

This chapter explains the key elements to understanding the context in which flood risk management takes place. Topics covered include flood definitions, causes, benefits and hazards; watershed systems and characteristics; the water cycle and managing water; and climate, climate variability and weather. This chapter also discusses

5 US Army Corps of Engineers (USACE), *Coastal Risk Reduction and Resilience* (Washington, DC: Directorate of Civil Works, 2013), http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf.

6 Although the Flood Green Guide was written to address most types of floods, glacial lake outburst floods (GLOFs) are not discussed in this document.

key crosscutting issues relevant to flood risk management, including institutions, regulations, cross-sector coordination and cooperation, community engagement, gender, private sector, finances and funding.

Chapter 4. Assessing Flood Risk: Data, Methods, and Analysis

This chapter covers elements involved in assessing flood risk. Understanding flood risk is critical to planning and selecting the appropriate risk management options presented in chapter 5. This chapter reviews flood risk management needs and sources, followed by a simple way to understand the nature of watersheds. Since a wide range of risk assessment techniques and tools are currently available to the Flood Green Guide user, this chapter focuses on the results that a risk assessment should produce, and how these results can be used to select flood management methods. The chapter closes with a method to assess institutional capacities to manage flood risk, a key consideration in deciding on the most appropriate combination of management methods.

Chapter 5. Structural and Non-structural Methods

This chapter discusses the structural and non-structural methods for flood management based on an integrated flood management (IFM) approach. Flooding has consequences at multiple levels, including national/regional, watershed, floodplain, community and household. Therefore, this chapter discusses management methods that should be selected based on the specific requirements at different scales. This guide does not advise the use of a single flood risk management method in isolation. A combination of integrated structural – both hard and soft – and non-structural methods is recommended as the optimum approach, one that will enhance the efficacy of existing flood risk management methods. The remainder of this chapter introduces different flood risk management methods, offering essential design and selection criteria, and comparative costs and benefits.

Chapter 6. Urban Issues

This chapter describes issues unique to urban areas, including the nature of flooding, the impacts of climate, urban flood governance, and considerations for urban coastal areas. Urbanization amplifies flood risk and increases the frequency of localized floods, and urban coastal areas face the additional threat of rising seas. The differences between urban and rural floods are not often distinguished; there is no common definition for what constitutes an urban area. Given the severity and expense of urban flood impacts, however, we highlight some key issues related to flooding in urban areas that the Flood Green Guide user should consider when using the guide in urban areas.

CHAPTER 2

GUIDE SYMBOLS

The symbols below are found throughout the Flood Green Guide to help users refer to relevant worksheets and to point out important guidance/warnings, information, and examples of interest. Throughout the text, important terms are bolded to indicate that they can be found in the glossary.

- Foundational Concepts and Key Crosscutting Issues
- Urban Issues
- Flood Risk Assessment Data Summary
- Institutional Flood Management Capacity Assessment
- Watershed Characterization Table and Report
- Project Evaluation
- Methods Selection Review
- Operational Requirements
- Monitoring Plan

- Related Information
- Example
- Guidance or Warning

2. HOW TO USE THE FLOOD GREEN GUIDE

This chapter describes a Flood Green Guide Framework (the framework) that corresponds with the structure of the Flood Green Guide chapters and is organized similar to a basic project cycle consisting of five stages:

FIGURE 2.1 STAGES OF THE FLOOD GREEN GUIDE FRAMEWORK

GUIDANCE: These stages do not imply a linear sequence. In practice, the stages are continually revisited, and information is reevaluated. For example, managers may have to return to the preliminary analysis stage during methods identification if they find additional data is needed or if new data becomes available.

Each chapter provides supporting tools (tables and worksheets) to help the user gather and organize information to move through the cycle and make informed decisions about the selection and use of flood management methods. Each stage within the framework involves multiple steps, including what the guide refers to as ***PROCESS STEPS***.

Please be aware, however, that the Flood Green Guide and the framework are not designed as a decision tree or decision support system (DSS) with specific quantifiable outcomes. Instead, the framework details key steps and information requirements managers should study and consider when selecting natural and nature-based methods for a given flood management project. The framework instructs users to do the following:

- Identify the types of information and analyses required to characterize the flood management context and risk.

- Identify and select a potential combination of flood management methods (hard, soft and non-structural) applicable within the given context and watershed.
- Develop maintenance and monitoring plans for the project.
- Evaluate chosen methods and the project as a whole.

As described in the introduction, the Flood Green Guide provides basic information about a range of flood management methods categorized into three types: natural and nature-based (soft or sometimes called "green" methods), **hard engineering** (sometimes called "gray" or hard methods), and non-structural methods. The guide describes the comparative advantages and disadvantages of various methods and discusses how combinations of these methods can complement each other and maximize social and environmental co-benefits.

2.1 STAGES OF THE FLOOD GREEN GUIDE FRAMEWORK (THE FRAMEWORK)

Five distinct stages of the Flood Green Guide Framework are identified in figure 2.1. Figure 2.2 illustrates the key steps and tools involved in each stage. The rest of this chapter explains how to use the information and tools in the guide according to the stages of the framework.

STAGE 1 PRELIMINARY ANALYSIS AND ASSESSMENT (CHAPTERS 2, 3, 4 AND 6)

At this stage, the guide users will analyze information to understand the key features of their local context and potential flood risk, and set preliminary objectives for flood risk management.

STEP 1: Understand the watershed and social context

Users should conduct a contextual analysis to understand key foundational issues in the geographic area of interest. A contextual analysis should enable the manager to understand key issues, including the primary types of flooding the area experiences; the physical characteristics of the watershed; local weather and climate trends; the social characteristics of the area, including gender-related issues; the potential for community engagement; and the relevant actors. In addition, the manager should develop an understanding of key institutional, governance, financial and political issues that are relevant to flood management.

See chapter 3 for contextual analysis considerations; Flood Green Guide Framework Worksheet will help the user document and organize information relevant to analyzing key contextual issues. For projects located in urban areas, see chapter 6; Flood Green Guide Framework Worksheet will help the user document and organize information relevant to key urban issues.

STEP 2: Understand risk and climate uncertainties

The guide user should develop an understanding of the area's flood risk. The Flood Green Guide suggests ways to interpret critical parameters related to hazard mapping and analysis, vulnerability and capacity analysis, institutional capacity analysis and managing climate uncertainty. The guide does not provide instructions on conducting full risk assessments, as multiple resources exist to support conducting or commissioning risk and vulnerability assessments. Instead, the Flood Green Guide provides discussion on understanding risk assessments to assist with choosing appropriate methods to manage flood risk. The guide does not include discussion regarding the costs of risk assessments.

See chapter 4 for a basic outline of a risk assessment, mapping procedures, and links to additional resources on risk and vulnerability assessment procedures. Flood Green Guide Framework Worksheets

, and will help users organize pertinent information on risk, institutional capacity and watershed characteristics. In addition, information needs and sources described in chapter 4 will assist with options to visually present and monitor the geographical distribution of potential flood risk and impacts.

PROCESS STEP: Set preliminary flood risk management objectives

Before identifying the potential methods for a flood risk management project, managers should decide on preliminary objectives. Objectives refer to the specific and measurable goals of the project—for example, "reducing inundation of area A in a 50-year flood from river B."

Guide users should set flood risk management objectives collaboratively and with the participation of multiple stakeholders. Usually flood management objectives fall into three categories based on the type of the intervention:

1. Reducing and managing the flow (also known as flood flow) entering a floodplain
2. Improving flood drainage and increasing flood protection in a floodplain
3. Improving adaptation and preparedness to flooding in a given area

The scale of intervention will depend to some extent on the objectives and may include activities at one or more scales including

- national or transnational
- watershed
- floodplain
- community
- household levels

Flood types (and extents), watershed characteristics, and vulnerabilities and capacities (social/institutional) identified in the risk and context analyses should help determine the project objectives. In practice, however, objectives are often influenced by ongoing discussions and negotiations among stakeholders based on broad economic and political factors and institutional norms. **It is beyond the scope of the Flood Green Guide to provide specific guidance for setting preliminary objectives, as that would potentially oversimplify a complex process. The Flood Green Guide also assumes that the users will follow established principles of public participation, social inclusion and democratic governance.**[1]

STAGE 2 METHOD IDENTIFICATION (CHAPTER 5)

Once the preliminary objectives have been set, flood managers should identify possible methods for flood risk management. At this stage, it is important for flood managers to understand that a number of different combinations of methods can be used to achieve the same objectives. Identifying appropriate methods for a given set of objectives relies on the findings from stage 1, which is often revisited as issues about context and risk arise. Once potential methods are identified, they should be analyzed for social, political, environmental, economic and financial suitability in the local context.

1 Asian Development Bank (ADB), *Strengthening Participation for Development Results: An Asian Development Bank Guide to Participation* (Mandaluyong City, Philippines: ADB, 2012), http://www.adb.org/sites/default/files/institutional-document/33349/files/strengthening-participation-development-results.pdf; UN Women, *Guidance Note: Gender Mainstreaming in Development Programming* (New York: UN Women, 2014), http://www.unwomen.org/~/media/headquarters/attachments/sections/how%20we%20work/unsystemcoordination/gendermainstreaming-issuesbrief-en%20pdf.pdf; UN Economic and Social Commission for Asia and the Pacific, "What is Good Governance?" Last accessed April 14, 2016, http://www.unescap.org/sites/default/files/good-governance.pdf.

Chapter 5 provides basic technical descriptions for a wide range of flood risk management methods summarized in the table below. Chapter 5 also includes information and guidance on the applicability of a number of tools, design considerations, operational and maintenance issues, safety, cost components, and environmental and social impacts of these methods.

INTEGRATED FLOOD RISK MANAGEMENT METHODS

STRUCTURAL

HARD

- AX1 Dams and reservoirs
- AX2 Diversions
- AX3 Constructed wetlands
- AX4 Levees
- AX5 Canal widening and deepening
- AX6 Floodways
- AX7 Pumping
- AX8 Engineered drainage systems
- AX9 Groynes and revetments
- AX10 Multipurpose infrastructure
- AX11 Warning/evacuation infrastructure

SOFT

- AY1 Upper watershed restoration
- AY2 Soil conservation measures
- AY3 Wetlands restoration
- AY4 Swales and infiltration devices
- AY5 Rainwater harvesting
- AY6 Detention basins and retention ponds
- AY7 Natural drainage path restoration
- AY8 Riparian vegetation restoration
- AY9 Removal of barriers
- AY10 Green roofs/walls and blue roofs
- AY11 Coastal and reef restoration

NON-STRUCTURAL

- B1 Soil and watershed protection legislation
- B2 Land use planning (regional/community)
- B3 Flood- and waterproofing (building regulations)
- B4 Regular maintenance of headworks
- B5 Flood monitoring and warning framework
- B6 Crop change and alternative land use
- B7 Community flood awareness and preparedness

Structural and Non-structural Flood Risk Management Methods

The main steps in this stage are the following:

STEP 1: Identify suitable methods

Identify flood risk management methods that broadly fit the preliminary objectives and the context. Figure 5.1 gives the hard, soft and non-structural methods included in the guide. The methods selected should meet three basic criteria:

1. Appropriate for the types of interventions considered in the preliminary objectives. Table 5.1 categorizes methods according to the type of intervention.

2. Applicable to the scales of interventions considered in the preliminary objectives. Figure 5.2 categorizes methods according to the scale of intervention.

GUIDANCE: The Flood Green Guide recommends managers first apply IFM non-structural methods and then if needed include structural (hard and/or soft) methods as part of an integrated approach.

3. Suitable for the flood types identified in the risk analysis and appropriate for the intended location of the watershed. Table 5.2 categorizes the methods based on applicable flood types and suitability for different locations in a watershed.

STEP 2: Compare the methods

After appropriate methods have been selected based on the three criteria, the manager can begin comparing the methods, based on economic, operational, social and environmental advantages and disadvantages and structural method issues. Tables 5.3 and 5.4 provide some information and guidance for such comparisons. Whenever possible, guide users are encouraged to acquire more in-depth information about these issues. Comparisons will help managers refine their list of methods and eliminate those with more disadvantages than advantages. (For example, a method that may have significant economic and operational advantages may have unacceptable environmental disadvantages.) Therefore, the Flood Green Guide recommends the manager comprehensively consider any tradeoffs during the comparison and incorporate a participatory decision-making process with a multidisciplinary team.

PROCESS STEP: Review and revise the flood risk management objectives

The manager should revisit stage 1 after completing the method comparisons and creating a short list of appropriate flood risk management methods. At this point, the Flood Green Guide Framework calls for revisiting preliminary objectives to either adjust them so they are consistent with the methods, or to adjust methods so they are consistent with the flood risk management objectives. Preliminary objectives are set according to risk and local context; however, factors such as cost, operational maintenance requirements, government regulations and social norms can limit the practicality of meeting the set objectives. The method identification stage may also identify a need for further data from the risk and contextual analysis, which in turn will affect the determination of specific objectives. Therefore, reviewing and, if necessary, revising the objectives after methods identification are important steps in the overall process. The main steps in the next stage (methods selection and design) include cost estimation and feasibility studies, which require expert input and may incur significant costs. Therefore, carefully revisiting the objectives in order to limit the number of short-listed methods is an important cost optimization measure.

STAGE 3 METHODS SELECTION AND DESIGN (CHAPTER 5)

After the project objectives are finalized and the potential methods are short-listed, managers can select a final combination of flood management methods, and conduct feasibility studies and detailed project designs.

The main steps of this stage are:

STEP 1: Consider preliminary specifications, management issues and cost estimates

Managers should prepare basic specifications (e.g., components, land requirements, sizing, resource inputs) and approximate cost estimates for each short-listed method. "Basic specifications" does not mean detailed designs or precise estimates. Method descriptions in chapter 5 (sections 5.2 and 5.3) and appendix D provide some guidance on specifications, resource inputs and cost breakdowns to get the user started. It is important that managers clearly understand the relevant issues related to each short-listed method (design, implementation, maintenance and closure). Table 5.4 gives basic guidance on these issues for each method. To comprehensively understand the design, cost and management implications and eliminate methods that may pose problems within the given context, the guide user should seek advice from professionals with expertise in specific methods.

STEP 2: Combine the methods

The importance of selecting a diverse combination of flood risk management methods is emphasized throughout the guide. Methods combined in ways that complement each other will be most successful in achieving flood risk management objectives along with social and environmental co-benefits. Table 5.5 gives basic guidance regarding the advantages of combining hard engineering and natural and nature-based methods. The Flood Green Guide recommends the user seek advice from experts in these methods in order to combine and locate them strategically within the watershed to meet project objectives.

STEP 3: Review the selected methods

Once a final set of methods has been selected, managers should review them to ensure they meet the technical, environmental and social criteria emphasized in the Flood Green Guide. Flood Green Guide Framework Worksheet is designed to help managers review the selection.

PROCESS STEP: Conduct feasibility studies, environmental assessments and review designs

A feasibility study is an important step in any project and is essential to establishing the technical and financial feasibility of the selected flood management methods.[2] As appropriate, managers should select a qualified team of professionals to conduct feasibility studies on the project. Ideally, the team's expertise should cover the full range of selected methods under consideration (hard, soft and non-structural). Method descriptions given in chapter 5, especially sections 5.7 and 5.8, provide guidance on the recommended expertise needed for feasibility studies and design. Typically, an Environmental Impact Assessment (EIA) or Initial Environmental Examination (IEE) is also required in any flood risk management project.[3] In most countries, the law requires an EIA or IEE before undertaking a large- or medium-scale project, and procedures are well established by statutory guidelines and professional standards. Regardless of statutory requirements, the guide recommends conducting an environmental impact study for both development and disaster management situations.[4] As with feasibility studies, qualified professionals should conduct an EIA or an IEE based on the methods selected. Feasibility studies and environmental impact studies should be carried out with maximum stakeholder participation.

Most flood risk management methods should be carefully designed and planned by a qualified professional, regardless of the type: conventional, natural and nature-based or non-structural. Managers should carefully select professionals for the technical design. Design of most methods will require multidisciplinary professional input (e.g., engineer, ecologist, social scientist, community organizer). Method descriptions given in chapter 5, section 5.2, describe basic design issues for structural methods. Design principles for each method, however, are very specific to the established science of that method and to the local context. Therefore, managers should obtain detailed technical designs for each method selected, including operational and monitoring plans, by appropriate professionals.

STAGE 4 OPERATION AND MONITORING (CHAPTER 5)

Project implementation includes construction and the physical establishment of structural methods (such as dams, and wetland or watershed restoration) and mobilization of non-structural methods (such as land use planning

---

2 Public and Private Infrastructure Investment Management Center (PIMAC), *General Guidelines for Preliminary Feasibility Studies*, 5th ed. (Seoul: Korea Development Institute, 2008), http://pimac.kdi.re.kr/eng/mission/pdf/General_Guidelines_for_PFS.pdf.

3 Bindu N. Lohani et al., *Environmental Impact Assessment for Developing Countries in Asia: Volume 1 – Overview* (Asian Development Bank, 1997), http://adb.org/sites/default/files/pub/1997/eia-developing-countries-asia.pdf.

4 The Flood Green Guide does not provide details on feasibility and environmental impact studies methodology, as this information is readily available in established scientific processes beyond the Flood Green Guide's scope.

and community flood committees). Managers must ensure that when a project is implemented, it is properly operated (controlled and maintained). It is also important to regularly monitor the project against operational, safety, social, environmental and financial indicators.[5] Data collected by monitoring should be examined to detect any issues (especially safety and environmental issues) that need immediate remedial action before it is recorded and archived for periodic evaluation.

Each method has specific tasks related to implementation, operation, maintenance and monitoring. Generally, these tasks are completed or supervised by qualified professionals or trained staff and volunteers. Therefore, the Flood Green Guide does not go into details of implementation, operation or monitoring for any method. The Flood Green Guide does, however, provide instruction for developing basic monitoring and operational plans for the overall project.

STEP 1: Develop detailed operation and monitoring plans

The Flood Green Guide recommends that managers develop operation and monitoring plans during the design stage. These plans are essential for effective operation and maintenance of the project and are helpful in the evaluation stage.

Table 5.4 highlights the most important operational and maintenance-related issues for each method. Flood Green Guide Framework Worksheet helps managers plan for the key operational requirements of the selected methods. It is important to identify, document, and allocate resources and finances required to operate each method. These needs encompass materials, equipment, human resources, documentation, and other logistical needs. Having this information up front will help the manager plan operational procedures, maintenance protocols and regulatory standing orders (e.g., spilling of dams, when to issue flood warnings).

Table E1 outlines important monitoring needs for each method. Flood Green Guide Framework Worksheet helps managers draft a monitoring strategy by selecting monitoring methods, parameters and frequencies. Framework Worksheets and should be completed based on review plans developed during the design stage, with assistance from the experts employed for design and employees trained for operational activities.

PROCESS STEP: Prepare evaluations

The user should regularly review operation and monitoring plan reports and make required adjustments. The user also should prepare a plan, including terms of reference, for periodic evaluations by an independent evaluation team.[6]

STAGE 5 PROJECT EVALUATION (CHAPTER 5)

Evaluating the success and failures of individual flood risk management methods, and the project as a whole, is an important step in identifying the necessary changes (revisions) required to continue the project successfully.

---

5 Asian Development Bank (ADB), *Guidelines for Preparing a Design and Monitoring Framework*, 2nd ed. (Bangkok: ADB, 2007), http://www.adb.org/sites/default/files/institutional-document/32509/files/guidelines-preparing-dmf.pdf; International Tropical Timber Organization (ITTO), *Manual for Project Monitoring, Review, Reporting and Evaluation*, 3rd ed., General Series 14 (ITTO, 2007), http://www.itto.int/news_releases/id=3624.

6 European Agency for Reconstruction (EAR), *Evaluation Guidelines* (Brussels: EAR, 2005), http://ec.europa.eu/enlargement/archives/ear/publications/main/documents/RevisedEvaluationGuidelines.pdf; Japan International Corporation Agency (JICA), *JICA Guideline for Project Evaluation* (JICA, 2004), http://www.jica.go.jp/english/our_work/evaluation/tech_and_grant/guides/pdf/guideline01-01.pdf.

STEP 1: Periodically evaluate the methods and the project as a whole

A periodic evaluation schedule should be decided during the design stage. Evaluation is not the same as monitoring; monitoring is done more frequently to consistently record the key project indicators. Evaluation involves longer intervals and is used to interpret monitoring data and understand the patterns of project outcomes.

Typically, evaluations are designed to help managers

- assess the effectiveness, efficiency, safety and social-environmental acceptability of the project as a whole and each method separately
- highlight new issues (such as social, environmental, and climatic issues), threats and opportunities as the project evolves
- provide the necessary inputs for project revision and planning the next cycle

Evaluations can be conducted in fixed time periods (e.g., five-year reviews) or when external factors (e.g., change in population, new planning regimens, climate changes) necessitate changes to the project operations or objectives. Flood Green Guide Framework Worksheet provides basic guidelines for a project evaluation that can be conducted as an initial step by the managers. Evaluation is a participatory process that should be completed with input from all staff, stakeholders and communities connected to the project. If the evaluation indicates that the objectives are met and the condition/operation of individual methods is appropriate, and there are no major shifts in watershed characteristics or climate patterns, the manager may decide to continue with the project as it is for the next period. In most projects, however, the evaluation will indicate that changes or updates are required for the project to continue.

PROCESS STEP: Evaluate with experts and proceed to closure or project revision

If some notable issues are identified regarding outcomes, conditions or context of a flood risk management project, the managers should consult a team of experts to get initial advice on what kinds of changes are needed. Based on this review process, managers can decide which methods should be upgraded or expanded and which can be downsized, decommissioned or discontinued. Sometimes, based on the evaluation outcomes, the manager may decide to close the entire project. The Flood Green Guide does not discuss how these decisions should be made, as they are context specific and subject to political and economic factors. However, if a project is discontinued, the manager should go back to the beginning of the Flood Green Guide Framework (fig. 2.2) and start the planning process over from the analysis stage.

THE FLOOD GREEN GUIDE FRAMEWORK STAGES AND STEPS

FLOOD GREEN GUIDE FRAMEWORK STAGES AND STEPS

STAGE 1

PRELIMINARY ANALYSIS AND ASSESSMENT

STEP 1: *Understand the watershed and social context*

- Foundational Concepts and Key Crosscutting Issues
- Urban Issues

STEP 2: *Understand the risk and climate uncertainties*

- Flood Risk Assessment Data Summary
- Institutional Flood Management Capacity Assessment
- Watershed Characterization Table and Report

PROCESS STEP: *Set preliminary flood risk management objectives*

STAGE 2

METHOD IDENTIFICATION

STEP 1: *Identify suitable methods*

- Table 5.1 Flood Risk Management Methods and Scales of Application
- Figure 5.2 Scale of Application of Structural and Non-structural Methods
- Table 5.2 Applicability of Structural Methods to Different Flood Types and Locations in the Watershed

STEP 2: *Compare the methods*

- Table 5.3 Factors Critical to Successful Implementation of Structural Methods
- Table 5.4 Structural Method Design, Implementation, Maintenance and Closure Considerations

PROCESS STEP: *Review and revise the flood risk management objectives*

STAGE 3

METHODS SELECTION AND DESIGN

STEP 1: *Consider preliminary specifications, management issues and cost estimates*

- Sections 5.2–5.5, Structural and Non-structural Methods; Application of Methods According to Type of Intervention, Location (in the watershed) and Scale; Factors Affecting Successful Implementation of Structural Methods
- Table 5.4 Structural Method Design, Implementation, Maintenance and Closure Considerations
- Appendix D: Resource and Cost-Planning Guidance for Methods

STEP 2: *Combine the methods*

- Table 5.5 Combinations of Hard and Soft Structural Methods to Ensure Optimum Functionality, Cost, Social and Environmental Benefits

STEP 3: *Review the selected methods*

- Methods Selection Review

PROCESS STEP: *Conduct feasibility studies, environmental assessments and review designs*

STAGE 4

OPERATION AND MONITORING

STEP 1: *Develop detailed operation plans*

- Operational Requirements

STEP 2: *Develop detailed monitoring plans*

- Monitoring Plan

PROCESS STEP: *Prepare evaluations*

STAGE 5

PROJECT EVALUATION

STEP 1: *Periodically evaluate the methods and the project as a whole*

- Appendix E: Monitoring and Evaluation Requirements for Different Methods
- Project Evaluation

PROCESS STEP: *Evaluate with experts and proceed to closure or project revision*

FIGURE 2.2 FLOOD GREEN GUIDE FRAMEWORK STAGES AND STEPS

FLOOD GREEN GUIDE FRAMEWORK STAGES AND STEPS

World Wildlife Fund. 2016. Natural and Nature-based Flood Management: A Green Guide. Washington, DC: World Wildlife Fund. http://envirodm.org/flood-management

FLOOD GREEN GUIDE FRAMEWORK WORKSHEETS

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: FOUNDATIONAL CONCEPTS AND KEY CROSSCUTTING ISSUES				
	Topic	**Indicative Sample Answer**	**Description /Remarks**	**Relevant Chapter Section**
1	List the flood types and impacts that your community experiences	*Flash floods and seasonal riverine floods*		Floods: Definitions, Natural Process and Benefits, Hazards *Section 3.2*
2	Do floods in your community contribute to beneficial processes that support agriculture or flush nutrients? If so, briefly describe	*Support rice production in delta*		Natural Process and Benefits *Section 3.2.2*
3	Briefly describe the drainage patterns, precipitation regimes and land use in your community	*Radial drainage pattern; variable precipitation; primarily agriculture*		The Watershed System *Section 3.3*
4	Is your community monitoring local weather? If so, briefly describe and include information regarding monitoring maximum and minimum levels of precipitation along with averages	*Local community group has monitoring station at school*		Climate and Weather *Section 3.5*
5	Are you aware of areas in your watershed that currently lack weather stations or monitoring information?	*Yes, mountain area above town*		Weather Observation and Monitoring *Section 3.5.3*
6	Are you familiar with all of the organizations, institutions, and their processes related to flood risk management? Complete the Institutional Flood Management Capacity Assessment	*Yes, will complete the institutional analysis*		Institutions *Section 3.7.1*
7	Have you considered how your community and other sectors can be engaged in flood risk management activities? If so, briefly describe	*Yes, have included youth and women's groups*		Community Engagement *Section 3.7.4*
8	Briefly describe how your agency/ community integrates gender into all phases of flood risk assessment and planning, including gender-responsive budgeting	*Completing gender analysis with community and business partners*		Gender *Section 3.7.6*
9	Are there existing public-private partnerships or networks that could be included in flood risk management activities? If so, briefly describe	*Yes, have contacted the local business association disaster management network*		Private Sector Participation *Section 3.7.7*
10	Have you considered funding sources for natural and nature-based flood risk management from multiple sectors? If so, briefly describe	*Yes, considering financing from local government budget, community fund and NGO partners*		Finance *Section 3.7.8*

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: URBAN ISSUES

	Topic	Indicative Sample Answer	Description /Remarks	Relevant Chapter Sections
1	How is your area affected by land use change and impervious surfaces?	*More land has been converted from open space to covered areas*		Physical Factors *Section 6.4.1*
2	What are visible impacts of urbanization on the hydrology and microclimate of the area?	*The area has experienced increased temperature, and there is more runoff*		Physical Factors *Section 6.4.1* Governance and Management *Section 6.4.3* Climate and Weather Factors *Section 6.4.2*
3	Describe how the frequency of local flooding has changed in the past 10 years	*More frequent flash floods*		Physical Factors *Section 6.4.1* Governance and Management *Section 6.4.3* Climate and Weather Factors *Section 6.4.2*
4	What is the condition of the natural and engineered drainage systems (canals, drains, gullies, small streams) in the area?	*Some erosion of canals*		Physical Factors *Section 6.4.1* Governance and Management *Section 6.4.3* Climate and Weather Factors *Section 6.4.2*
5	Are conditions (lack of maintenance, encroachment of water bodies) contributing to flood risk?	*Rubbish accumulates in drainage canals*		Physical Factors *Section 6.4.1* Governance and Management *Section 6.4.3*
6	Is the urban flood risk management process in your area supported by governance practices such as adequate urban planning, cross-sector integration and community engagement?	*Not much integration with waste management or community groups*		Urban Flood Governance *Section 6.6*
7	How can flood risk management be better supported by local government?	*Improved rubbish collection and management regulations*		Urban Flood Governance *Section 6.6*
8	Are climate issues a key consideration in urban flood risk management in your area?	*Not sure but will review*		Climate and Weather Factors *Section 6.4.2*
9	If not, how can climate be incorporated into urban flood risk management and urban planning?	*Considering climate issues in method selection*		Climate and Weather Factors *Section 6.4.2*
10	Have you considered the specific flood risks in low-lying coastal areas and unique drivers such as sea level rise, storm surges and tsunamis?	*No, will study sea level rise issues with local government and NGOs*		Urban Coastal Areas and Special Considerations *Section 6.7*

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: FLOOD RISK ASSESSMENT DATA SUMMARY

Column 1	Column 2		Column 3	Column 4	Column 5
Flood hazard event/spatial and temporal extent	**Factors contributing to the event**		**Event frequency**	**Expected or historical losses**	**Number of people affected or at risk** (indicate specific groups where possible)
	Anthropological factors	**Natural factors**			

Column 6	Column 7	Column 8	Column 9
Groups identified with higher-than-normal vulnerability (indicate type and number)	**Adaptive capacities** (identify specific groups when appropriate)	**Notes**	**Priority**

Instructions for completing the Flood Risk Assessment Data Summary table:

Column 1 – List the type of flooding (see chapter 3, appendix A for flood types) and describe the spatial and temporal extent (flood frequency or recurrence interval).

Column 2 – List the factors contributing to the flooding under the appropriate heading.

Column 3 – Indicate how frequently past events have occurred, preferably using yearly, 1:5 (once in five years), 1:10 (once in 10 years), 1:20 (once in 20 years), 1:50 (once in 50 years), or other event frequencies.

Column 4 – Losses, in monetary terms, for the flood hazard event based on historical data or model projections.

Column 5 – Total population that could be affected by the flood event. The gender and age breakdown of the affected population can also be provided for future use.

Column 6 – List short descriptions and number of groups considered more vulnerable to the flooding event than the overall affected population.

Column 7 – List, for specific groups where appropriate, specific adaptive capacities that have been identified.

Column 8 – Add any notes to clarify or expand on the information provided.

Column 9 – List the priority (1 to X) based on (1) the original risk assessment report, (2) per capita damage per year or (3) adjustments in per capita damage ranking based on specific issues of vulnerability and **adaptive capacity**.

**FLOOD GREEN GUIDE FRAMEWORK WORKSHEET:
INSTITUTIONAL FLOOD MANAGEMENT CAPACITY ASSESSMENT**

This table describes flood management capacities for use in the Flood Green Guide Framework.

I. Which organizations are involved in flood management?

Name of organization	**Contact information, including location**	**Type of work done**	**Area of operations** (mark area on map)	**Specific projects or activities in watershed and duration** (mark locations on map)	**Note whether project/activity documents and/or details have been collected**

II. Existing flood management policy and activities

Question	**Circle response**	**Action to be taken**
Do you have information on national or watershed-specific flood management plans?	Yes or no	If yes, provide summary below, and collect copies if possible. If no, provide an explanation.
Do you have information on how flood management methods are being implemented upstream from the community?	Yes or no	If yes, provide a summary, and collect copies of plans and activity reports if possible. If no, provide an explanation and plan to acquire information.

Do you have information on how flood management methods are being implemented downstream from the community?	Yes or no	If yes, provide a summary, and collect copies of plans and activity reports if possible. If no, provide an explanation and plan for acquiring information.
Do you have information on local flood management plans or projects?	Yes or no	If yes, provide a summary, and collect copies of plans and activity reports if possible. If local flood management plans exist but no information is available, provide a plan for acquiring additional information.

III. Capacity of implementing agency or agencies	
Topic	**Input to be provided**
Level of authority for flood management	Provide the name of the authority/authorities involved and a summary of the actions they can take to manage floods.
Level of planning for flood management	Provide the name of the authority/authorities involved and a summary of their flood management planning.
Financial resources available for flood management	Provide the level of annual funding available for flood management. Indicate what level of funding is available for specific types of flood management.
Organizational capacity to carry out infrastructure projects	Provide a summary of how effectively agencies accomplish flood management activities. For example, consider the number of staff, area and level of staff expertise, location of staff, authority and financial resources of the agency, etc.
Organizational capacity to maintain infrastructure	Provide a summary of how the agency maintains the flood management activities it has implemented.
Community outreach	Provide a summary of how the flood management agency engages with communities on flood management.

IV. Capacity of communities involved in flood management					
Community organizations involved in flood management, disaster management or environment-based work or advocacy					
A. Name of community organization	**B. Contact information and location**	**C. Type of work done**	**D. Area of operations** (describe area and mark on map)	**E. Projects in watershed and duration** (describe locations and mark on map)	**F. Note whether project documents and details have been collected**

Topic	Action to be taken
G. Short-term mobilization capacity	Provide a short summary of the capacity of the above listed community-based organizations to mobilize human and other resources for flood management activities.
H. Literacy and technical skills	Provide a short assessment of the literacy and technical skills available in the community or communities involved in flood management activities.
I. Environmental and disaster awareness	Provide a short assessment of the local (community) awareness of environmental conditions, climate and disaster management, noting any specific projects or organizations active in these areas.

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: WATERSHED CHARACTERIZATION TABLE AND REPORT		
Date	**Name of watershed** (usually the name of the major stream or river draining the watershed)	**Location of watershed** (either a short description of the location or map coordinates)
Person(s) completing the form (If more than one person, add additional names at end of table)		
What is the type of the watershed or sub-watershed? (See chapter 3)		
Response Circle or fill in	**Source** Indicate source document or contact name where possible	**Implications**
Question 1: What is the current precipitation regime for the watershed?		
1. Infrequent precipitation confined to specific months and in very small amounts on average, though, with rare extreme events 2. Frequent precipitation throughout the year with months of higher totals 3. Variable precipitation throughout the year, with some of the precipitation as snow 4. Variable precipitation concentrated during specific periods of the year, as with rain in the fall, snow in the winter and rain and snow in the spring 5. Distinct dry* and wet periods	For instance: • Records from national meteorological office • Local weather monitoring station	1. Floods are uncommon and occur infrequently, with heavy precipitation. 2. Flooding occurs when rainfall totals exceed averages, either in single events (a cyclone) or through a combination of events (several cyclones in a short period). 3. Flooding can occur from a single severe storm, the melting of snow and periods of extended intense precipitation, such as cyclones or stalled weather systems. 4. Flooding occurs with intense storms in the fall or spring and the combined effect of rainfall and snowmelt in the spring. 5. Flooding is associated with violent storms at the beginning of the rainy season or as the result of weather systems that stall over an area and result in unusually heavy precipitation.
Question 2: What types and conditions of soils are present in the watershed?		
1. More permeable, sandy, pebbles and small rocks, more organic matter 2. Less permeable, silty, clay, peaty, saline, less organic matter 3. Soil layer, thick or thin 4. Soil moisture, wet or dry	For instance: • Soil map obtained from local NRM office • Soil reports from government agencies	The soil type influences the infiltration rate and retention capacity. Less permeable soils increase the likelihood of water runoff, which can contribute to flooding.

* "Dry" is used here as the absence of regular precipitation. These areas may remain humid in the absence of rainfall.

Question 3: What type of geologic substrate is present in the watershed?		
1. More permeable (fractured rock, weathered limestone, volcanic rocks) 2. Less permeable (fresh/unfractured granite, sandstone, limestone)	For instance: • Geological map obtained from local land use planning office	Less permeable geologic substrate increases the likelihood soils will become saturated, leading to runoff, which can contribute to flooding.
Question 4: What type of vegetation is dominant in the watershed?		
1. Largely undisturbed habitat such as forest, grasslands, marshes 2. A combination of undisturbed habitat and introduced species (including crops and pasture) 3. Largely managed areas in the form of fields, plantations and pasture lands 4. Little or no vegetation	For instance: • Land use map or report obtained from local land use planning or NRM office	The type, quantity and management of vegetation and how it interacts with the soil can be contributing factors in flood risk.
Question 5: What is the size of the watershed?		
1. Large relative to other watersheds in the region 2. Neither large nor small when compared to other watersheds in the region 3. Small when compared to other watersheds in the region	For instance: • Land use map or report obtained from local land use planning or NRM office	Larger watersheds receive and can discharge more water than smaller watersheds receiving the same level of precipitation. (However, smaller watersheds with less retention capacity may flood more quickly than larger watersheds with greater retention capacity.)
Question 6: What is the general slope of the watershed?		
1. More than 5% 2. Between 5% and 1% 3. Less than 1%	For instance: • Land use map or report obtained from local land use planning or NRM office	The steeper a watershed, the more likely it will experience rapid flooding when there is a large volume of precipitation or rapid snowmelt. The shallower a slope, the less likely it will experience rapid flooding. However, a shallow slope is more likely to sustain flooding from water that drains slowly.
Question 7: What is the nature of land use in the watershed?		
1. Land is largely in an undisturbed state 2. Half of the watershed has been converted to fields, pasture or orchards, or cut for wood 3. All the watershed has been converted to fields, pasture, or orchards, or cut for wood	For instance: • Land use map or report obtained from local land use planning or NRM office	In some instances, a watershed with undisturbed areas is less likely to flood than a watershed with fields, pasture, orchards or wood harvesting. The less an area is disturbed, or the lower impact its use, the better for flood risk management.

Question 8: What types of channels are present in the watershed? (Several types may exist in one watershed. Mark types on the map.)		
1. Narrow and steep 2. Meandering "S" curves, not large streambed 3. Meandering "S" curves, large streambed	For instance: • River authorities • Geologic or hydrologic maps • Local land use or geologic service offices	1. Rapid movement of water is likely, but bank erosion is not extreme. 2. Bank erosion is possible, but flow levels are modest. 3. Bank erosion is possible, and flow levels can be significant.
Question 9: Are there any wetlands, lakes or marshes in the watershed?		
If yes, describe and mark on the map	For instance: • Land use maps • Parks and protected area maps • River authorities • Geologic or hydrologic maps • Local land use or geologic service offices	Wetlands, lakes or marshes can provide natural buffers for flooding and can be used to reduce flood hazards.
Question 10: How have infrastructure elements (roads, bridges, buildings, irrigation systems) contributed to previous flooding in the watershed?		
Describe and mark on the map	For instance: • Local public works or road authorities • Local disaster management authorities • Local media reports • Local flood control, water, river, irrigation or watershed authorities	Moving or replacing infrastructure that contributes to flooding can be expensive; alternative risk management options may be needed.
Question 11: How does the infrastructure (dams, dikes, levees, weirs, cutoffs, roads, bridges, buildings, irrigation systems) contribute to a reduction in floods or flood damage in the watershed?		
Describe and mark on the map	For instance: • Local flood control, water, river, irrigation or watershed authorities • Local public works or road authorities • Local disaster management authorities • Local media reports	While infrastructure is an essential way to reduce flood risk, structures must be well maintained and designed to anticipate floods in order to avoid being taken by surprise.

Question 12: What is the nature of the assets in the watershed?		
1. Limited number or no assets in the watershed 2. Significant number of assets in the watershed, but they are generally located outside previously flooded areas 3. Most assets are located in areas that have flooded in the past.	For instance: • Local water, river, irrigation or watershed authorities • Local government (e.g., tax or land use offices) • Land use map or report obtained from local land use planning or NRM office	Having fewer assets in areas threatened by flood means reduction in potential damage.
Question 13: How urbanized is the watershed?		
1. The watershed is not at all urbanized. 2. Only a small part of the watershed is urbanized. 3. The watershed has one or more urbanized areas containing more than 50% of the watershed's population. 4. The watershed is heavily urbanized.	For instance: • Local sanitation authorities • Local government • Local disaster management authority • Land use maps and reports from land use offices or NRM projects	The more urbanized the area, the greater the risk of flooding, particularly flash flooding. The flood impact risk level can be reduced if adequate warning, drainage and water management plans and operations are in place.

Watershed Characterization Report

Once the Watershed Characterization table is complete, a narrative report should be prepared for future use in selecting flood management methods. (The report can also be used as public information on the watershed.) The report takes the 13 questions in the Watershed Characterization table and turns them into statements that incorporate the information collected.

For instance, question 10 becomes "Wetlands are located at [indicate the locations], lakes are located at [indicate locations], and marshes are located at [add locations]."

The Watershed Characterization Report includes space for additional comments. These can include information sources used to develop the characterization, observations by those involved in developing the characterization, and any additional information useful to understanding the watershed and the flooding hazard.

An initial format for the report is provided here. The format should be modified to describe different parts of a single large watershed or to note whether only one or several sub-watersheds are covered.

Information presented in the report should be noted on a map, where appropriate. This can be done by transferring data from the working map developed for the Watershed Characterization table and adding further notes from the narrative report. Photos and drawings can be added to the report to help explain the information provided and the impact of past flooding.

SUGGESTED TEMPLATE FOR THE WATERSHED CHARACTERIZATION REPORT

Watershed Characterization Report for [add name of watershed]

Date report completed:

Person(s) completing the report:

Location of Watershed:

1. The [add name of watershed] is a [add type] of watershed.
2. The precipitation regime for the watershed is [add regime].
3. The following types of soils can be found in the watershed:
4. The following geologic substrate can be found in the watershed:
5. The following types of vegetation can be found in the watershed:
6. The watershed is [add size] relative to other watersheds in the same area.
7. The slope of the watershed is [add slope].
8. The land use in the watershed is [add land uses].
9. The following types of stream or river channels are present in the watershed:
10. The following wetlands, lakes or marshes are present in the watershed (indicate name and location):
    - Wetlands -
    - Lakes -
    - Marshes -
11. The following infrastructure has been affected by flooding in the past (indicate name and location):
    - Roads -
    - Bridges -
    - Buildings -
    - Irrigation systems -
    - Other (list) -
12. The following infrastructure has contributed to reducing flooding (provide names, locations and details):
    - Dams -
    - Dikes -
    - Levees -
    - Weirs -
    - Cutoffs -
    - Roads -
    - Bridges -
    - Buildings -
    - Irrigation systems -
    - Other (list) -
13. The physical assets in the watershed range from [add description] to [add description].
14. Urbanization in the watershed is [add description].

Additional Comments:

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: METHODS SELECTION REVIEW

	Question	Assessment	Indicative Sample Answer	Description/Remarks
1	Have you considered all types of floods?	Yes/No/ Not sure	*Riverine floods, flash floods*	
2	Have you considered all flood-related risks?	Yes/No/ Not sure	*Inundation of 50-70 households (1-2 m); village road was inundated and completely cut off from the city; contamination of 30 wells*	
3	Have you accounted for the uncertainty of risks due to future climate change/variability?	Yes/No/ Not sure	*Precipitation is likely to increase and storms are increasing in severity.*	
4	Have you accounted for the uncertainty of risk related to future land use in the watershed?	Yes/No/ Not sure	*Potential conversion of 20,000-40,000 ha of forest gardens in area A into oil-palm cultivations; may significantly increase runoff and riverine floods in city B*	
5	Have you accounted for the uncertainty of risk due to future population/demographic changes in the watershed?	Yes/No/ Not sure	*City B is rapidly urbanizing; may increase impermeability and reduce wetlands, increasing flash floods*	
6	What are your proposed non-structural methods in the affected area?	N/A	1. *Create a no-build zone 100 m from stream center.* 2. *Introduce mandatory flood-proofing measures to buildings constructed between 100-250 m from the river.*	
7	What is/are the proposed structural flood risk management method(s) in the affected area?	N/A	1. *Restore 3,000 ha of wetlands in city B.* 2. *Introduce rain gardens to 20,000 households.*	
8	What is/are the proposed non-structural and structural flood risk management method(s) upstream?	N/A	1. *Establish protected area for existing forest.* 2. *Conduct reforestation of 15,000 ha of abandoned tea plantation in area C in the upper watershed.*	
9	What is/are the proposed non-structural and structural flood risk management method(s) downstream?	N/A	1. *Enforce existing land use plans.* 2. *Construct a flood barrage in estuary to control tidal floods entering the river.*	

10	Have you considered an appropriate balance of conventional and natural/ nature-based (hard and soft) methods to reduce cost and increase social and environmental co-benefits?	Yes/No/ Not sure	*Yes, the only hard method used is the tidal flood barrage; excess runoff could be significantly reduced by reforestation and rain gardens. Wetland restoration will improve flood management.*	
11	What are your non-structural methods?	N/A	1. *Create a no-build zone 100 m from stream center.* 2. *Introduce mandatory flood-proofing measures to buildings constructed between 100-250 m from the river.*	
12	Have you considered all possible environmental implications of the proposed methods?	Yes/No/ Not sure	*Frequent closing of the tidal flood barrage may decrease the salinity level of the estuary and disrupt animal migration.*	
13	Have you consulted the community in the selection of the methods?	Yes/No/ Not sure	1. *Initial community consultations* 2. *Establishment of flood committees*	
14	Have you considered all of the regulatory requirements for the proposed methods?	Yes/No/ Not sure	1. *Construction of the tidal flood barrage needs an EIA and approval from the Coastal Conservation Department.* 2. *Reforestation project has to be approved by the Forest Department.*	

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: OPERATIONAL REQUIREMENTS					
Topic		**Indicative Sample Answer**	**Method 1**	**Method 2**	**Method 3**
1	Main operational activities	*e.g., pump operation, flood committee meetings, painting and repair of flood warning signs*			
2	Staff required for operation and mode of engagement	*e.g., pump operators – regular; community mobilizes flood awareness – one day per week*			
3	Material and logistical requirements for operation per annum	*e.g., fuel, vehicles*			
4	List of documented operational procedures and standing orders*	*e.g., pump operation schedule, flood evacuation drill schedule, flood gate operation standing orders*			
5	Expected annual operational cost				
6	Main maintenance activities and frequency	*e.g., pruning of vegetated swales twice a year*			
7	Staff required for maintenance and mode of engagement	*e.g., canal dredging – two dredger operators, one week per year*			
8	Material and logistical requirements for operation per annum	*e.g., fuel, vehicles, equipment*			
9	Expected annual maintenance cost				
10	List of documented operational procedures and standing orders	*e.g., drain cleaning schedule, green roof maintenance guide*			

* "Standing orders" are operational procedures mandated by government directives. For example, a standing order may state: When the water level of a river exceeds a certain limit, lock gates in the levees should be closed, flood warnings should be issued, and flood evacuation committees should be mobilized.

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: MONITORING PLAN					
Topic		Indicative Sample Answer	Method 1	Method 2	Method 3
1	Description of the method	*Small watershed dam to control overland flooding in Village A*			
2	Monitoring parameters (based on table E1)	*Performance/condition; social*			
3	Monitoring responsibility and frequency (community, officials, experts)	*Performance/condition:* 1. *Regular (monthly or after heavy rains)* 2. *Community monitoring, intermediate (6 months)* 3. *Local government official monitoring, long term (3-5 years or as needed)* *Social:* 1. *Local government officials, intermediate (1-2 years or as needed)*			
4	What are the key elements of the monitoring parameters selected?	*Performance/condition:* *Visible damages or malfunctions in the structures of devices* *Social:* *Community embraces the project with a sense of ownership*			
5	Resources required for monitoring	*Cost of training CBOs for monitoring;* *Travel cost for officials for 6 months of monitoring*			
6	Funding source(s)	*Local government, Irrigation Department*			
7	Organizations and responsibilities (personnel, resources, funding)	*Local government: manages community monitoring, conducts official monitoring*			
8	How do you plan to evaluate the monitoring data?	*Five-year evaluation meeting, organized by local government with Irrigation Department and selected CBOs*			
9	Communications plan for organizations	*Brief annual status report of the dam sent to senior government officials and the Irrigation Department*			
10	Communications plan for community	*Annual meeting held with the community stakeholders of the dam*			

FLOOD GREEN GUIDE FRAMEWORK WORKSHEET: PROJECT EVALUATION				
Overall Project				
Topic		**Assessment**	**Indicative Sample Answer**	**Description/Remarks**
1	Has the project fulfilled the planning objectives?	Yes/No/ Partially	*No inundation or flood-related damage was recorded in the target area in the past 5 years.*	
2	Are there any major failures?	Yes/No	*Main road was flooded in 2 years (within 5 years) during the storm season.*	
3	Has the project exceeded the planned objectives/targets?	Yes/No	*Average peak water level (5 years) of the river has reduced by 10%, exceeding the planned 5%.*	
4	Has the project been generally accepted by the community (including disadvantaged groups)?	Yes/No/ Partially	*Community is actively engaged in monitoring, and women are using the restored wetland for fodder gathering.*	
5	Has the project been accepted and supported by the stakeholder agencies (state, nongovernmental and local government)?	Yes/No/ Partially	*Active participation from Irrigation Department officials but lacks support from the Agrarian Services Department.*	
6	Have the geophysical conditions of the watershed/surroundings changed substantially since project initiation?	Yes/No/ Not sure	*No.*	
7	Have the ecological conditions of the watershed/surroundings changed substantially since project initiation?	Yes/No/ Not sure	*Upper watershed terraced paddies are being converted to cash-crop plantations.*	
8	Has the population or demographic characteristics of the watershed/surroundings changed substantially since project initiation?	Yes/No/ Not sure	*Rapid urbanization has occurred in lower watershed, especially around city B.*	
9	Have the planning regimes, laws and regulations pertaining to the project changed substantially since initiation?	Yes/No/ Not sure	*Wetland Management Board was merged with Urban Development Authority.*	
10	Is there substantial change in climate trends?	Yes/No/ Not sure	*Rainfall intensity has increased but with no significant change in annual average rainfall.*	

Individual Methods					
	Topic	Indicative Sample Answer	Method 1	Method 2	Method 3
1	Is the method still operational?	*Yes*			
2	Has the method fulfilled the planned objectives?	*No overland flooding of the village in past 5 years*			
3	Are there physical defects or faults in the method (structural methods only)?	*Sluice gate needs repair, minor erosion in the northern end of the dam, silting is higher than expected*			
4	Are there maintenance difficulties in the method (structural methods only)?	*Desilting is very expensive, requires minor desilting every 3 years*			
5	Have there been any operational or implementation issues in the method?	*Operation of the sluice gate is not done properly and regularly by the assigned volunteer farmer*			
6	What are the social impacts of the method (positive or negative)?	*Farmers use the dam for watering their livestock (mainly goats)*			
7	What are the environmental impacts (positive or negative) of the method?	*No significant impacts observed*			
8	Are there any operational or maintenance cost overruns?	*Maintenance allocation exceeded due to desilting costs*			
9	What are the additional remarks of the project staff?	*Project staff are satisfied with the dam apart from the silting issue; they propose an upstream revegetation program to control the silt load*			

CHAPTER 3

3. FOUNDATIONAL CONCEPTS AND KEY CROSSCUTTING ISSUES

3.1 SECTION CONTENT

This chapter discusses key overarching foundational concepts and crosscutting issues that will help the guide user understand the fundamental contextual issues related to flood management. The foundational concepts explain biophysical parameters and will help the reader understand how flood-related terms are defined and used. The crosscutting issues are key social and economic factors related to successful flood risk management. Key foundational issues include

- flood definitions and causes, benefits, hazards
- watershed systems and characteristics
- the water cycle and managing water
- climate, climate variability and weather
- resilience

Key crosscutting issues include

- institutions
- regulations
- cross-sector coordination and cooperation
- community engagement
- gender
- private sector
- finances and funding

3.2 FLOODS: DEFINITIONS, NATURAL PROCESS AND BENEFITS, HAZARDS

3.2.1 DEFINITIONS

Floods come in many shapes and forms and have the potential to cause tragic loss of life and enormous economic damage. In some situations, however, floods are also an important natural process, and serve a broad range of functions for people and **ecosystems**, as discussed in section 3.2.2.

© WWF-Canon/Yifei Zhang

Lake Flooding in East Dongting Lake, Yuyang City, Hunan Province, China.

There are as many different definitions of floods as there are types of floods. Most government and academic agencies define floods according to their own missions and/or responsibilities related to physical or social priorities. For example, the US Geological Survey (USGS) defines flood as "an overflow or inundation that comes from a river or other body of water and causes or threatens damage. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream."[1] The Asian Disaster Preparedness Center (ADPC), on the other hand, defines flood **disaster** as a damaging flood hazard that adversely affects human populations and the **environment**.[2]

Floods can be grouped into several different types and sub-types. For the purpose of the Flood Green Guide we have developed a flood hazard typology as described in appendix A. The typology provides a list of flood hazard types, definitions, and associated causes and processes (The Flood Green Guide does not include glacial lake outburst floods [GLOFs]).

Flood types:

- **Riverine (fluvial) flooding** is the most familiar type of flooding. It results from water in a river or drainage channel that cannot be constrained within its stream channel or by constructed structures (e.g., levees) and inundates the floodplain. Riverine flooding can develop from heavy or extended periods of rainfall and rapid snowmelt, and it is often seasonal (i.e., occurs in the rainy season). Overtopping/

1 US Geological Survey (USGS), "Flood Definitions," Kansas Water Science Center, accessed January 6, 2016, http://ks.water.usgs.gov/flood-definitions.

2 Asian Disaster Preparedness Center (ADPC) and United Nations Development Programme (UNDP), *A Primer Integrated Flood Risk Management in Asia* (Bangkok, Thailand: ADPC, 2005), http://www.preventionweb.net/files/2776_adpcprimerapr05.pdf.

bank flooding is caused by an increase in water volume within a river channel, which overflows natural or constructed banks, flooding adjacent areas. This type of flood is often associated with riverine flooding.

- **Flash flooding** normally results from heavy or intense rainfall over a period ranging from minutes to hours, inundating creeks, streams and otherwise dry valleys.[3] Because they are not always caused by meteorological phenomena, flash floods present different forecast and detection challenges. Flash floods result when favorable meteorological and hydrological conditions exist together; while heavy rainfall is always present, the hydrologic characteristics of the watershed where it is raining can affect whether the amount and duration of rainfall result in a flash flood.[4]

- **Lake level flooding** can be caused by excessive inflow from the lake's tributaries; although extremely uncommon, lake tsunamis can be triggered by landslides and changes in regional groundwater conditions, particularly in constructed reservoirs.

- **Coastal flooding** can be caused by hurricanes, cyclones and other large storm systems, tsunamis and rising sea levels. It often results from a combination of rising coastal waters and riverine flooding. During periods of high tides or strong winds onshore, coastal water can act as a dam that blocks surface runoff from dissipating, with the buildup of standing water resulting in flooding. Where areas inland from the sea are very flat, this type of flooding can develop some distance from the coast as natural and constructed drainage systems back up.[5]

- **Storm surge** is a type of coastal flooding, an abnormal rise of water generated by a storm, over and above predicted astronomical tides. The water level rise from the combination of storm surge and an astronomical tide is called a storm tide and can result in extreme flooding in coastal areas – reaching up to 6 m or more in some cases – particularly when storm surge coincides with normal high tide.[6]

- **Tsunami flooding** is often coastal, and while similar to a storm surge, has different causes (e.g., an earthquake or subsea landslide) and can occur with very short warning compared to surges.

- **Urban flooding** is often due to a combination of factors that accompany urbanization. These factors include an increase in impervious surfaces, such as rooftops, roads and parking lots, that prevent water from being absorbed; inadequate stormwater storage or drainage capacity; and poorly planned infrastructure – particularly in rapidly urbanizing areas.[7]

- **Areal flooding** develops gradually, usually from prolonged and persistent moderate to heavy rainfall. Gradual ponding or buildup of water in low-lying, flood-prone areas, as well as in small creeks and streams, can occur more than six hours after rainfall begins, and may cover a large area.[8]

---

3 NOAA National Weather Service (NWS) Weather Forecast Office, "NWS Flood Products: What Do They Mean? Flash Flood Warning, Areal Flood Warning, River Flood Warning or Urban and Small Stream Flood Advisory," accessed January 6, 2016, http://www.srh.noaa.gov/bmx/?n=outreach_flw.

4 NOAA National Severe Storms Laboratory, "Flood Forecasting," accessed January 6, 2016, http://www.nssl.noaa.gov/education/svrwx101/floods/forecasting/.

5 Sam Ricketts and Jennifer L. Jurado, "How Can the Federal Government Help Prepare Local Communities for Natural Disasters?" (briefing, Environmental and Energy Study Institute (EESI), Washington, DC, April 1, 2015) http://www.eesi.org/briefings/view/040115resilience.

6 National Oceanographic and Atmospheric Administration (NOAA) National Hurricane Center, "Storm Surge Overview," accessed January 6, 2016, http://www.nhc.noaa.gov/surge/.

7 James Wright, "Chapter 2 Types of Floods and Floodplains," FEMA Emergency Management Institute, 2008, https://www.training.fema.gov/hiedu/aemrc/courses/coursetreat/fm.aspx.

8 NWS, "NWS Flood Products."

© Pablo Sanchez/WWF

Typhoon Haiyan in the Philippines caused storm surge that devastated local communities.

- **High groundwater** can affect buildings or other infrastructure and sources of livelihoods (e.g., fields that become very muddy). High groundwater is not universally considered flooding, but it is included here because managing the impact is often related to managing other types of flooding.
- **Mudflood** occurs when floodwater carries a heavy sediment load (such as mud, rocks, trees), and it is often triggered by flash flooding or heavy rainfall flowing over nonporous geology with a soluble surface layer. Examples of these conditions include barren soil or land after a wildfire. Mudfloods are also known as mudflows, debris flows, or landslides triggered by rain.
- **Rain on ice flooding** is a type of sheet flooding, where rainfall on ice leads to flows across the ice, flooding low areas.

3.2.2 NATURAL PROCESS AND BENEFITS

While floods result in incalculable loss of life each year and cost the global economy billions in damages, flooding is also a natural process that supports important biogeochemical and ecological processes such as supplying water and recharging aquifers for humans, animals and crops. Floods provide sediment and nutrients required for fertile soil, which support human well-being. For example, many fish species require an inundated floodplain to reproduce, thereby supporting both **livelihoods** and **biodiversity**. In Niger, farmers grow onions in riverbeds where wet season floodwaters soak in to create high groundwater levels and optimal growing conditions. The produce, exported to other parts of West Africa, is an important agricultural livelihood system that would not be possible without the seasonal flooding.

Freshwater floods can also help to flush out **floodplains**, helping to prevent silt buildup, encouraging greater biodiversity and productivity by encouraging floodplain habitat. While floods can cause damage, in some cases, they provide ecological and/or social co-benefits. An **integrated water resource management** (IWRM) approach, which **integrated flood management** (IFM) supports, is designed to acknowledge these co-benefits, environmental flows and/or ecosystem services while minimizing the damage caused by floods.

Environmental flows are defined as the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems, as well as the human livelihoods that depend on them.[9]

Ecosystem services are defined as the benefits that people and communities obtain from ecosystems. These benefits include regulating services such as regulation of floods, drought, land degradation, and disease; provisioning services such as food and water; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits.[10]

Examples of ecosystem services supported by floods include the following:

9 Rafik Hirji and Richard Davis, *Environmental Flows in Water Resources Policies, Plans, and Projects: Findings and Recommendations* (Washington, DC: World Bank, 2009), http://elibrary.worldbank.org/doi/book/10.1596/978-0-8213-7940-0.

10 UN International Strategy for Disaster Reduction (UNISDR), "Terminology on DRR," August 30, 2007, http://www.unisdr.org/we/inform/terminology#letter-e.

Regulating:

- sediment, nutrient and water delivery (e.g., rice farms in Madagascar, floodplain agriculture in Bangladesh)
- episodic inundation of dry valleys and recharge of **groundwater** (e.g., seasonal rivers in Central Niger)
- flushing of sediment to maintain (natural and engineered) flow channels (e.g., Mississippi)
- flushing of nutrients and organic materials to prevent eutrophication (e.g., Amur wetlands)

Provisioning:

- large-scale nutrient and sediment cycling to support mangroves and marine fisheries (e.g., coastal wetlands of Marismas Nacionales in Mexico, fisheries reproduction in the Sea of Japan)
- inundation of floodplain lakes and wetlands to trigger fish spawning (e.g., subsistence fisheries in the Amazon and Mekong [Tonle Sap])
- transportation mechanism for inland and coastal water systems

Cultural:

- transportation of human remains in religious rituals (e.g., Ganges, India)

Recreational:

- kayaking and rafting during high flow events (e.g., Western United States, tourism related to rafting and recreation in Sri Lanka)

In other words, ecosystem services can directly and indirectly support community survival and quality of life.

Efforts to mitigate flood damage should consider the benefits of flooding. For example, in Bangladesh, dikes were constructed to prevent flooding of fields. When communities learned that floods actually provide nutrients, water and sediment for rice production, they shifted flood management strategies to focus on limiting damage of detrimental flooding rather than trying to prevent all floods.

EXAMPLE: No other aspect of Bangladeshi life is more sensitive to the flood problem of the country than its time-honored agricultural practices. This is because the cropping patterns in the floodplains have been so intricately adjusted to the annual flood regime that any major deviations from the normal regime, with regard to timing, duration, or magnitude, may cause a serious setback in crop production. In normal years, flooding is considered an asset because it supplies the moisture and fertility (silt) to the soil that are vital to crop production. It is the abnormal flood, the extreme event, that is considered a hazard, as it can cause widespread damage to standing crops and property and sometimes to livestock and human lives. The agriculture in Bangladesh is, thus, both flood dependent and flood vulnerable.[11, 12]

11 Text adapted from Bimal Kanti Paul, "Perception of and Agricultural Adjustment to Floods in Jamuna Floodplain, Bangladesh," *Human Ecology* 12, no. 1 (1984), http://www.jstor.org/stable/4602721

12 Example from Harun Rasid and Bimal Kanti Paul. "Flood Problems in Bangladesh: Is There an Indigenous Solution?" *Environmental Management* 11, no. 2 (1987): 155-173.

3.2.3 HAZARDS

Although there are many types of floods, not all floods are hazards. A **hazard** is defined as a "potentially damaging physical event, phenomenon or human activity that may cause the loss of life, or injury, property damage, social and economic disruption, or environmental degradation."[13]

Factors in understanding the threat posed by a flood hazard include the following:

- **Magnitude:** For flood-related hazards, the magnitude is often expressed as the volume of water per time period (e.g., cubic meters per second) or as total volume (e.g., cubic meters of water flooding an area).[14]
- **Frequency:** How often a hazard of a certain magnitude occurs, often expressed in the number of times an event occurs during a specific period of years.
- **Exposure:** What might be affected or damaged by a hazard of a specific magnitude recurring within a specific frequency. Exposure is often assessed by identifying the extent to which lives and physical assets would be affected by a flood of a specific magnitude.

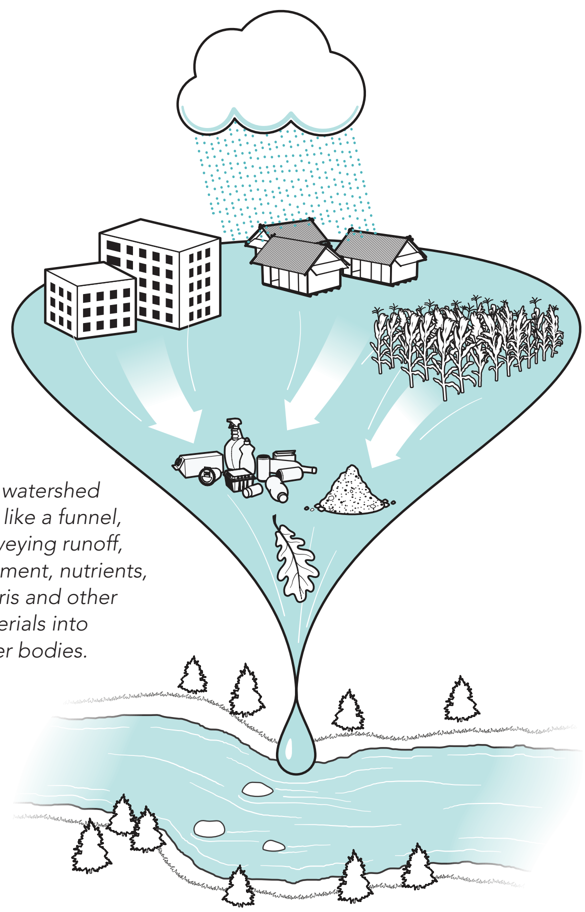
The nature of hazards and risks is further described in chapter 4.

3.3 THE WATERSHED SYSTEM

To better assess a region's flood-related risk and options available to manage that risk, it is important to know the area of interest's location within the watershed. Multiple and varied factors within a watershed affect the potential for **flood risk** and the options for putting together a flood management strategy.

A **watershed** is commonly defined as the area of land that drains downslope to the lowest point and conveys water to a common outlet.[15] For the purposes of the Flood Green Guide, we are using the term watershed interchangeably with the terms **river basin**, sub-basin, **catchment**, catchment area, drainage basin and drainage area.

Watersheds have been shaped by thousands, if not millions, of years of interaction between climate, vegetation and geology. Large watersheds contain thousands of smaller watersheds, "sub-watersheds" or "sub-catchments." Similar to the rim of a funnel, the boundary of a watershed is often defined by the highest points in an area – hills, mountains and ridges – that capture the precipitation (rain, hail, snow) that falls within the watershed.



The watershed acts like a funnel, conveying runoff, sediment, nutrients, debris and other materials into water bodies.

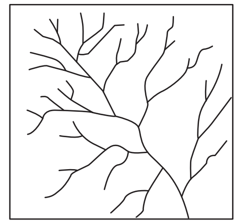
13 World Meteorological Organization (WMO), "DRR Definitions," Disaster Risk Reduction (DRR) Programme, accessed January 6, 2016, https://www.wmo.int/pages/prog/drr/resourceDrrDefinitions_en.html.

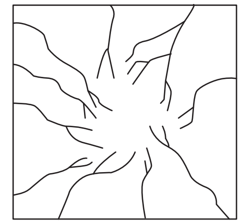
14 High groundwater is measured in water depth below the level of the ground.

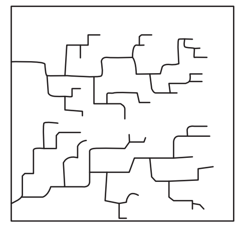
15 USGS, "What is a watershed?," accessed February 10, 2017, https://water.usgs.gov/edu/watershed.html.

3.3.1 DRAINAGE SYSTEM

Moving downslope, away from the watershed divide, stream channels develop and then merge with other, smaller tributaries, gradually combining flows into larger and larger streams. The linked channels become what is known as a drainage network.[16] Drainage networks can evolve over time by natural processes such as erosion, changing the shape of streams, for example.


Dendritic Drainage


Radial Drainage


© Stephen Nelson

Rectangular Drainage

Common drainage patterns.

3.3.2 DRAINAGE PATTERN

Drainage channels tend to develop along areas where rock types and structures are most easily eroded.[17] The types of drainage patterns that develop in a region thus often reflect the structure of the rock and the faulting or fracturing. Here are some common **drainage patterns**, as defined by Stephen A. Nelson, of Tulane University:[18]

- **Dendritic drainage patterns** are the most common. They develop on a land surface where the underlying rock uniformly resists erosion.
- **Radial drainage patterns** develop surrounding elevated land areas where elevation drops from a central high area to surrounding low areas.
- **Rectangular drainage patterns** develop where linear zones of weakness, such as joints or faults, cause the streams to cut down along the weak areas in the rock.

ADDITIONAL INFORMATION:

A watershed is the most logical unit to use for flood risk management planning, as it defines a more or less "closed" system for measuring and predicting **water balance** (broadly defined as the input, output and storage of water).

3.3.3 SIZE OF THE WATERSHED

The size of a watershed determines how much water can be expected to accumulate in streams and rivers following precipitation (rainfall or snowmelt). Within larger watersheds, smaller sub-watersheds may respond differently to the same volumes and intensities of precipitation. Therefore, it is important to assess flood risk at the appropriate scale for each watershed.

3.3.4 SLOPE OF THE WATERSHED

In general, the slope of a watershed can have a bearing on floods. Steeper slopes are generally more prone to flash floods, while flatter areas are more likely to experience areal or riverine flooding due to poor drainage.

3.3.5 PRECIPITATION REGIME

Precipitation (e.g., rain, snow, hail) in a watershed can be a major factor in eventual flooding. Defining a precipitation regime for the watershed helps users understand how and when flooding can be expected.

---

16 Stephen A. Nelson, "Streams and Drainage Systems," Tulane University, EENS 111 Physical Geology, accessed January 6, 2016, http://www.tulane.edu/~sanelson/eens1110/streams.htm.

17 Ibid.

18 Four drainage pattern definitions from Nelson, "Streams and Drainage Systems."

The following are five generalized precipitation regimes:[19]

1. **Infrequent precipitation** is confined to specific months and on average comes in very small amounts. This regime can experience infrequent (sometimes once a decade) rainfall, which can be heavy and result in widespread flooding.[20] Examples are the deserts of northern Chile and southern coastal Peru, where precipitation is rare but, when it does occur, can lead to extensive flooding.

2. **Frequent precipitation** occurs throughout the year but with months of higher totals. Flooding in this regime occurs when rainfall exceeds averages, either in single events (a cyclone) or in a combination of events (several cyclones in a short period). The Solomon Islands, which experienced severe flooding due to a cyclone in 2014, is an example of this regime.

3. **Variable precipitation through the year**, with some of the precipitation as snow, can lead to flooding from single severe storms, from melting snow, and from periods of extended intense precipitation, such as cyclones or stalled weather systems. Much of continental Europe fits this regime.

4. **Variable precipitation concentrated in specific periods of the year**, such as rain in the fall, snow in the winter, and rain and snow in the spring, can lead to floods from intense storms in the fall or spring and the combined effects of rainfall and snowmelt in the spring. Central Asia fits this regime.

5. **Distinct dry and wet periods** can lead to precipitation from low pressure systems bringing in moisture from the oceans, even from a significant distance.[21] Flooding can be associated with the violent storms at the beginning of the rainy season or as the result of weather systems that stall over an area and lead to unusually heavy precipitation. The coastal and interior zones of West Africa and South Asia fit this regime.

These regimes are generalized, and variations can occur over relatively small distances (e.g., from the windward to the leeward side of a mountain) and with elevation. Near sea level the precipitation regime may have distinct wet and dry periods, whereas nearby mountains may experience relatively low levels of average precipitation.

Extreme precipitation can occur at almost any time under each of these regimes. For instance, the Himalayas normally experience most precipitation – and flooding – during the summer monsoon. Occasionally, however, low pressure systems can bring heavy snowfall and rains during the normally dry fall and winter seasons. To predict future flooding events, it is important to know when these extreme precipitation events have occurred in the past, based on local histories and weather data, and whether these events led to flooding.

3.3.6 VEGETATION AND SOIL

Under some conditions, the abundance and type of vegetation in a watershed can affect the likelihood of flooding. Vegetation can influence flood hazard by

- reducing the intensity of precipitation, as when rainfall hits multiple layers of leaves and results in smaller drops hitting the ground, thereby protecting the soil;

- creating a layer of organic material above and in the soil, which can protect the soil from the direct impact of rain;

---

19 Drawn from Michael Pidwirny and Scott Jones, "Introduction to the Atmosphere," in *Fundamentals of Physical Geography*, 2nd ed. (E-book, 2010), http://www.physicalgeography.net/fundamentals/7v.html.

20 This regime can be applied to polar areas where there are relatively low levels of precipitation. In these areas, flooding can occur when rapidly increasing temperatures melt snow but not the underlying frozen ground.

21 "Dry" is used here as the absence of regular precipitation. These areas may remain humid in the absence of rainfall.

- holding soil together with roots; and
- absorbing water from the soil, thus increasing soil water storage capacity.

However, human-modified areas, such as agricultural fields, orchards, pastures, mining areas, roads and developed areas, often have degraded soils and/or less vegetation coverage than unmodified areas. This can affect infiltration capacity and contribute to higher levels of runoff and increased localized flooding.

It is often assumed that the presence of more natural vegetation in a watershed lowers the risk of flooding. The critical factor in flood reduction, however, is the condition of the soil. Intact natural vegetation is usually an indication of stable soil conditions. Altered landscapes (from logging or agriculture, for example) often result in soil compaction and, therefore, reduction in infiltration capacity. **Deforestation** is often accompanied by logging roads and skid tracks, which create pathways for floodwaters to accumulate and shortcuts to streams and rivers.[22]

Managing vegetation at a watershed scale to address flood risk can be complicated and is not always possible (e.g., on very steep slopes with thin soils or where not politically or economically possible). Conserving natural landscapes and their infiltration capacity can be far more cost effective than restoration after the fact. Assessing the type of vegetation and the conditions of the soil in a watershed can help predict whether and what kind of vegetation and soil management might contribute to managing flood risk.

When a manager plans restoration as an element of flood management, a few general guidelines should be considered:

- Native plant species are usually better adapted to the climate conditions present.
- Non-native or invasive species have the potential to alter hydrological processes. For example, fast-growing trees such as Eucalyptus (*Eucalyptus* species) or Poplar (*Populus* species) transpire water much faster and in greater volumes. These qualities might make them a useful choice for certain drainage solutions, but they tend to shade out lower layers of vegetation, resulting in soil erosion under tree plantations and soil compaction.
- Layered vegetation – typical in a natural forest, with layers close to the ground, at midlevel and taller – is more effective than a single layer. The understory (vegetation close to the ground and at midlevel) can reduce the impact of rainfall, slow the melting of snow, and promote the development of the organic materials at ground level.[24]

GUIDANCE: While some of the natural functionality of the soils in the landscape can be restored, doing so is typically very complex, taking decades to centuries and is usually prohibitively expensive.[23] Therefore, it is better to avoid altering the landscape whenever possible.

3.3.7 SOIL AND GEOLOGY

A watershed's soils and underlying geologic conditions determine its basic hydrologic nature and how water flows through it. This information helps to explain the watershed's risk for flooding. More porous geologic features,

22 L. A. Bruijnzeel, "Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review," (UNESCO/Vrije Universiteit, 1990), http://www.hydrology-amsterdam.nl/personalpages/Sampurno/Bruijnzeel_1990_UNESCO.pdf; Chandra Prasad Ghimire et al., "Reforesting Severely Degraded Grassland in the Lesser Himalaya of Nepal: Effects on Soil Hydraulic Conductivity and Overland Flow Production," *Journal of Geophysical Research: Earth Surface* 118, no. 4 (December 2013): 2528–45, doi: 10.1002/2013JF002888; M. Bonell and L. A. Bruijnzeel, eds., *Forests, Water, and People in the Humid Tropics: Past, Present, and Future Hydrological Research for Integrated Land and Water Management* (Cambridge, UK; Cambridge University Press, 2004), http://public.eblib.com/choice/publicfullrecord.aspx?p=228293; L. A. Bruijnzeel, "Hydrological Functions of Tropical Forests: Not Seeing the Soil for the Trees?" *Agriculture, Ecosystems & Environment* 104, no. 1 (September 2004): 185–228, doi:10.1016/j.agee.2004.01.015.

23 For more information, visit FAO at http://www.fao.org/docrep/008/ae929e/ae929e04.htm.

24 Ibid.

such as certain types of limestone or volcanic rocks, will absorb water better than less porous features, such as granite. Porous soils – generally those with more sand or organic content – absorb water better than less porous soils, such as those with higher clay content. Soil characteristics such as thickness, permeability, infiltration rate and degree of moisture have an effect on how, when and where water moves through an area.[25] More permeable soils and geologic features (e.g., karst, certain volcanic formations) can reduce the volume and/or speed of water moving downslope, so collection routes like streams, creeks and rivers are less likely to be overloaded.

Further, when precipitation saturates the soil, the likelihood of flash flooding – and other downslope movement of soil, mud and rock – increases. Once the soil has become saturated, any additional water will flow across the surface, and if the volume of precipitation or snowmelt is high, this can lead to flooding – often rapidly. Consequently, monitoring soil water levels and precipitation is important for flood risk management.

3.3.8 WETLANDS, LAKES AND MARSHES

Wetlands, lakes and marshes can collect floodwater and release it more slowly, limiting or preventing downstream flooding. In general, a watershed with more wetlands, lakes and marshes is better able to absorb floodwater, although extreme weather events have the potential to overload any system. From an ecosystem perspective, such watershed features should be managed and restored as natural ways to manage flooding; in many cases, wetland restoration is a low-cost method for managing potential flooding.

© Mauri Rautkari/WWF

Wetlands in Amboseli National Park, Kenya.

3.3.9 GEOMORPHOLOGY AND CHANNELS

Stream and river channels often affect the impact of flooding. Generally, if the watershed is steep and water runs over or close to the bedrock, channels are relatively straight, and water flows rapidly. These conditions are often found in the upper part of large watersheds.

25 Liu Zhiyu et al., *Guidelines on Urban Flood Risk Management (UFRM)*, Technical Report of TC Cross-Cutting Project on Urban Flood Risk Management in the Typhoon Committee Area (Macao, China: ESCAP/WMO Typhoon Committee (TC), 2013), http://www.typhooncommittee.org/46th/Docs/item%2010%20Publications/UFRM_FINAL.pdf.

Lower in a watershed, a river or stream has a natural tendency to meander, moving in an "S-" shaped pattern, particularly if erodible geology and soils exist. Over time the "S" can change, with downstream curves eroding banks and leading to local flooding as banks wash away.

Since downstream channels carry more flow than channels higher in a watershed, and flow may vary over the course of the year, these channels may naturally accommodate significant volumes of water. However, large volumes of water can increase erosion, with riverbank loss and associated flooding creating significant problems.

In particularly large channels, the meander process can create large river loops that are cut off from the main channel through bank erosion. The resulting lakes and wetlands can become natural retention areas for floodwaters.[26]

3.3.10 LAND COVER, LAND USE AND INFRASTRUCTURE

Infrastructure in a watershed can influence both the likelihood of flooding and the severity of potential flood damage. Infrastructure – such as dams, dikes, embankments and diversions – can reduce the impact of small and frequent floods if they are appropriately designed, constructed and maintained. At the same time, poorly designed bridges that prevent sufficient water from passing during floods, or structures built in places that experience frequent flooding, can heighten damage from floods – not only to the structures themselves but also to neighboring areas.

Because floodplains are flat, easy to build on, and accessible, they are often the sites of towns and industry. When not adequately protected, these areas can suffer considerable losses from flooding. While it is sometimes impossible to avoid building on a floodplain, planners should consider potential flooding and build in a way that protects the area without shifting flood problems elsewhere (e.g., upstream, downstream or to neighboring low-lying areas).

Changes in land use upstream (especially increased urbanization) will have serious implications for floodplains located **downstream**.

> "Of all the land-use changes that can impact a watershed and its **hydrology**, urbanization is by far the most significant. Such development increases impervious surfaces, such as asphalt and cement, producing greater volumes of runoff from storms, which 'run off' the land quicker than if a natural watershed was absorbing rainfall. Urbanization tends to increase the volume and peak of stream flows. The delivery of runoff to streams after the beginning of rainfall becomes flashier, reducing the lag time between the rainfall and the peak of a stream's flood stage… While urbanized watersheds can be expected to create long-term increases in runoff and stream flows, they cause more complex cycles in contributing sediment to their streams and valleys."[27]

In other words, because **urban** areas typically have a lot of pavement that prevents water from infiltrating, cities and towns are at particular risk for experiencing rapid onset (flash) floods. Urban areas can also change the type and amount of sediment that ends up in local waterways, reducing water quality and increasing water and physical pollution in local waterways.[28]

Upstream land use, such as farming, commercial agriculture and roads, can affect flood risk in the downstream community, mainly due to changes in how water infiltrates soils. Land use planning, management and enforcement are thus key elements of flood risk management.[29]

---

26 Text in Geomorphology and Channels adapted from Stephen A. Nelson, "River Systems and Causes of Flooding," Tulane University, EENS 3050 *Natural Disasters*, July 13, 2012, http://www.tulane.edu/~sanelson/Natural_Disasters/riversystems.htm.

27 Ann L. Riley, Restoring Streams in Cities: A Guide for Planners, Policy Makers and Citizens (Washington, DC: Island Press, 1998), 132.

28 For more discussion on the unique features of urban areas, see chapter 6.

29 UNISDR, Progress and Challenges in Disaster Risk Reduction: A Contribution towards the Development of Policy Indicators for the Post-2015 Framework on Disaster Risk Reduction (Geneva: UNISDR, 2014), https://files.zotero.net/818470294/40967_40967progressandchallengesindisaste.pdf.

3.4 THE WATER CYCLE AND MANAGING WATER

The way water naturally changes and moves around the Earth is known as the hydrologic cycle. The hydrologic cycle begins when water evaporates from oceans. After temporary storage in the atmosphere, moisture precipitates in the form of rain, hail or snow (**precipitation**). Some of the water reenters the atmosphere after direct evaporation from the surface or from inland water bodies (lakes, rivers), while some is transpired by vegetation (**evaporation/transpiration**). The remainder infiltrates to the groundwater or "runs off" through rivers and streams, until it eventually returns to the ocean (**streamflow and groundwater recharge/discharge**).

After precipitation falls, water undergoes a complex interaction with vegetation and soil. If the soil surface has sufficient capacity, the water will infiltrate the soil and penetrate downward through the soil profile. If soils are compacted, possibly due to agricultural intensification or the application of an impervious (impermeable) layer, such as concrete or asphalt, water will run over the surface in the form of **overland flow** or **surface runoff**. The water flows across the surface as either confined or unconfined flow.[30] Unconfined flow moves in broad sheets or as a temporary layer of water, often causing sheet erosion, removing thin layers of soil uniformly.[31] This often occurs on recently plowed fields or where soil is loose and there is little vegetation. On the other hand, confined flow occurs in gullies, ditches and other natural or artificial flow channels, rapidly increasing in volume as water accumulates downslope.

Surface runoff may become trapped in, and slowed by, depressions. Here water may either evaporate back into the air, infiltrate the ground, or spill out as the depression fills.[32] If local drainage conditions cannot accommodate rainfall through a combination of evaporation, infiltration of the ground, and surface runoff, accumulation of water may cause localized flooding problems.[33] Water that infiltrates the ground can take hours to months to arrive in a stream, while water flowing freely usually takes minutes to hours to end up in streams.

ADDITIONAL INFORMATION:

Professional hydrologists can measure and model the water that moves through a catchment, and that understanding can help with planning for flood risk management. A professional hydrologist can help the manager understand local water balance and how that information can affect the selection of flood management methods.

Understanding short and long-term water balances can help to determine where and how much water to expect during flood conditions. While it is often hard to exactly predict a flood event, it is possible to identify and map the parts of the landscape prone to flooding, and what the prevailing pathways of flow might be. Where, when, how and how much water flows in a watershed depends on a series of complex interactions between weather, land cover, river channel **geomorphology** (the physical features and shape of the river and land surface) and geology (the physical properties of the rocks underlying the land surface). It is important to recognize the limits to our knowledge and our ability to predict extreme events such as floods.

---

30 James Wright, "Chapter 2: Types of Floods and Floodplains," FEMA Emergency Management Institute, 2008, https://www.training.fema.gov/hiedu/aemrc/courses/coursetreat/fm.aspx.

31 Ibid.

32 Ibid.

33 Wright, "Chapter 2: Types of Floods."

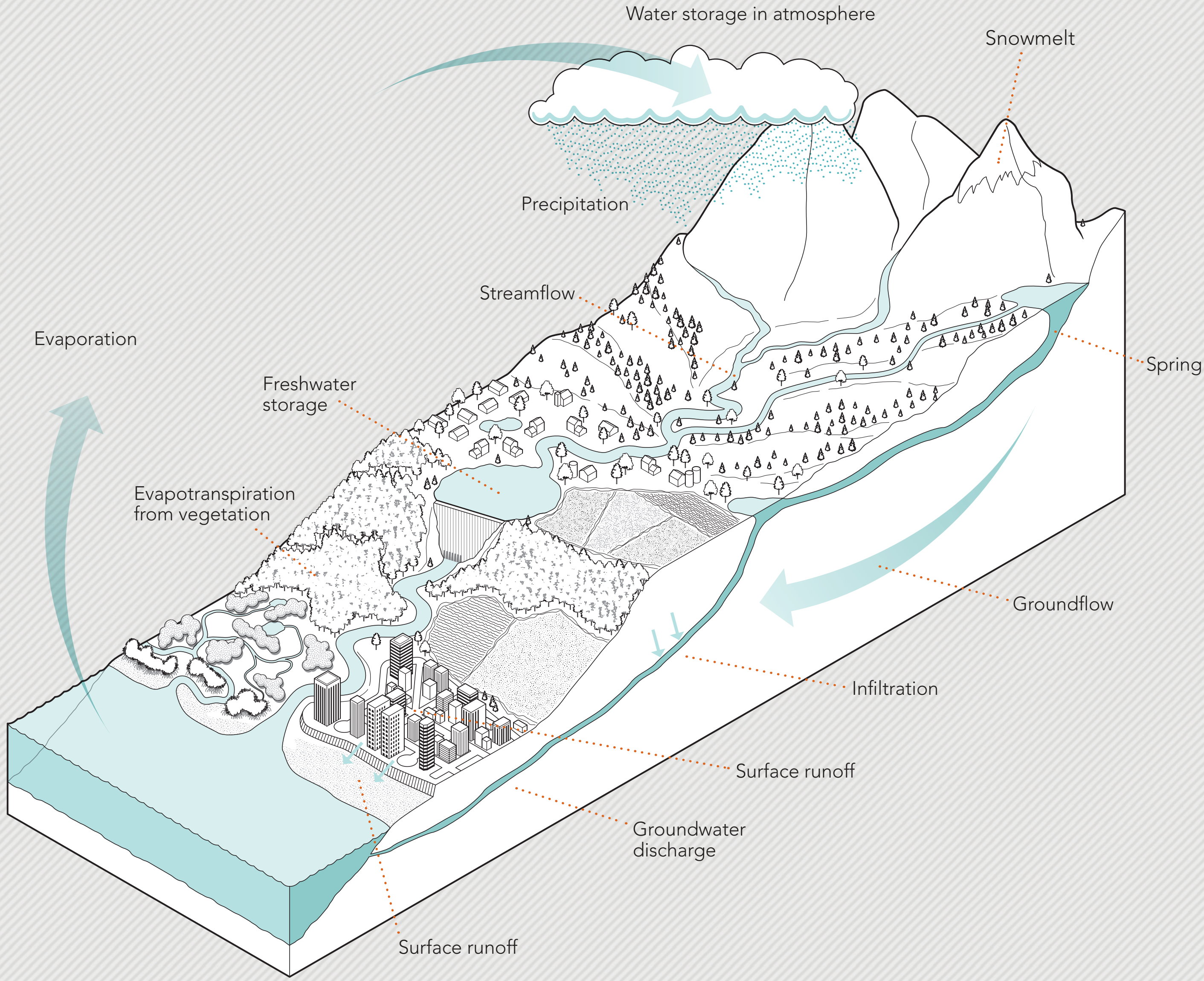


FIGURE 3.1 THE WATERSHED AND WATER CYCLE

3.5 CLIMATE AND WEATHER

3.5.1 WHAT IS CLIMATE?

The World Meteorological Organization (WMO) defines **climate** as the average **weather** (e.g., temperature, precipitation and wind) over a 30-year period.[34]

The climate variables of a watershed – precipitation, temperature and wind – can change with the following:

- **Elevation:** Precipitation can increase, while temperature can decrease, with elevation.
- **Peaks:** Peaks, high hills or mountains can contribute to severe local weather like thunderstorms, which can trigger flooding or flash flooding, and heavy snowfall, which can lead to localized flooding during melting.
- **Passes:** Low areas (known as passes or saddles) in the hills or mountains around a watershed can channel winds into and through it, at times causing more severe damage to some parts of the watershed. Watersheds themselves can channel wind and contribute to local damage during storms.
- **Orientation:** Watersheds facing away from prevailing weather systems may receive less precipitation than watersheds facing prevailing weather systems. This is often referred to as a rain shadow effect. For example, moist air pushed by winds to the base of a mountain will create rain on one side of the mountain as the air rises and cools. The air is dry as it flows over the top of the mountain, contributing to dry conditions on the other side of the mountain range.

Climate conditions in one part of a watershed can impact other parts of the watershed, thereby influencing flood risk. For instance, the bottom of a watershed may be an arid zone with almost no rainfall. The upper areas of the watershed, however, may experience high levels of snow and/or rainfall throughout the seasons. Melting snow and rain, therefore, could be essential for irrigation in the arid lower sections of the watershed.

Snow and rain can also contribute to flooding. Knowing whether the upper sections of a watershed will accumulate precipitation, how much may accumulate, the intensity of precipitation, and how fast snow may melt as a result of temperature change is critical for flood risk management.

Although climate is defined by wind, temperature and precipitation averages over a 30-year period, these averages are not the only information needed for flood risk management. For instance, average precipitation data for two different years can obscure the fact that in one year most of the precipitation fell in a short period and contributed to flooding, while in another year, precipitation was spread out over many months, and no flooding occurred. Historical analysis of precipitation can identify baseline conditions, as monthly, seasonal or average means. Further analysis can be carried out, based on the availability of daily weather station data, to identify precipitation extremes, precipitation intensity, the number of wet days per month or season, and the trends in this data. In the absence of weather station data, gridded data sets and satellite data can be used for analysis. Projections of precipitation based on climate model outputs can be analyzed and compared to historical climate data to identify how precipitation is expected to change in the area of interest.

Local climate monitoring within a watershed should identify minimum and maximum levels of precipitation and temperature. The data can be used to predict the likelihood of extremely high precipitation or temperature levels that can lead to either flooding or very dry conditions. The use of climate data to better understand flood risk is

34 Intergovernmental Panel on Climate Change, *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (New York: Cambridge University Press, 2012), 557.

most reliable when managers also consider past flood events' precipitation and temperature data and look at other local and regional factors (such as vegetation cover, **permeability** of soils, development), which can also contribute to flood risk.

3.5.2 CLIMATE VARIABILITY AND CLIMATE CHANGE

The Flood Green Guide definitions of climate change and variability are based on the Intergovernmental Panel on Climate Change (IPCC) definitions, as follows:

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.[35]

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.[36]

For flood risk management, it is important to consider both climate variability and climate change. Past records of weather data (from as far back as possible) can help illustrate how precipitation patterns (and extremes) have changed over time. A climate-informed approach to flood risk management calls for considering historical climate trends in the region in conjunction with existing knowledge based on projections and scenarios of extreme weather events and any information available on predicted future climate change.

For example, an analysis of daily precipitation and flood records may indicate that when a certain level of precipitation falls in an hour, flash flooding can be expected. As a result, weather conditions can be monitored to identify when storms may lead to precipitation that can cause flash flooding, prompting warning systems and evacuation. Analysis of historical climate and **climate projections** could identify future possibilities in terms of increased precipitation (at the monthly or seasonal scale) and changes in intensity.

Considering future changes to climate provides a perspective on what adaptations may be required to withstand climate extremes and minimize harm.

Global climate models are widely used to project future climate conditions – for instance, the climate in 30 or 100 years. The models show changes in the *average* precipitation and temperature and, in some cases, can identify extreme events. In addition to the range of climate outcomes in the future, non-climate factors can be expected to change as well.

The goal is to take a holistic approach, as many factors will influence future climate and future flood risk, as well as options for flood risk management.

ADDITIONAL INFORMATION:

In the United States, federal government policy requires agencies to systematically consider climate resilience in the US government's international development work and to promote a similar approach with multilateral entities.[37]

35 International Panel on Climate Change (IPCC). "Annex III: Glossary." In *Climate Change 2013: The Physical Science Basics*. (New York: Cambridge University Press, 2013).

36 Ibid.

37 Executive Order No. 13677, 79 FR 58229 (September 23, 2014), https://www.federalregister.gov/articles/2014/09/26/2014-23228/climate-resilient-international-development.

3.5.3 WEATHER OBSERVATION AND MONITORING

Precipitation, temperature and wind data is necessary to understand the local and regional climate. The data can be collected from national meteorological and hydrological services (NMHSs), agricultural stations or river basin authorities, among other sources. Flood risk management depends on, first and foremost, reliable weather observations – ideally taken throughout a **catchment** area, especially at higher elevations since precipitation is often driven by changes in elevation. Managers should determine whether national weather service information is available and historical climate data for the area can be obtained. Where local weather station data is not available, other climate products and satellite information can be used. In order to use this information effectively, however, guidance from meteorologists and climate scientists is recommended.

Ideally, managers should collect data about weather and water levels from several locations within the area of interest and, if possible, upstream from the area. If a nearby weather station is not available, a simple station to collect precipitation, temperature and wind data can be constructed at minimal cost and operated with basic knowledge. Community-based monitoring of weather and water-level conditions can encourage community participation in, and ownership of, flood risk management actions. At least 30 years of good-quality data are required in order to conduct a historical analysis of the climate. Data from historical records and more recently established weather station data can be useful to identify recent extreme events and flooding. Setting up new weather stations is useful, especially in areas where observed climate measurements are sparse or absent. For more information on weather and water-level gauge construction, see chapter 4.

© Filmaciones y Contenidos/WWF

This weather station monitors precipitation, temperature and wind to relay weather information to farmers.

3.6 RESILIENCE

USAID defines resilience as the ability of people, households, communities, countries and systems to mitigate, adapt to and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth. As this suggests, the concept of resilience and its measurement are complex.[38]

38 United States Agency for International Development (USAID). "Resilience at USAID." (Washington, DC: USAID, June, 2015).

WWF defines **resilience** as the ability of a social-ecological system to absorb and recover from shocks and disturbances, maintain functionality and services by adapting to chronic stressors, and transform when necessary.

The Zurich Flood Resilience Alliance[39] includes Four Rs in its characterization of community flood resilience:

- robustness (ability to withstand a shock)
- redundancy (functional diversity)
- resourcefulness (ability to mobilize when threatened)
- rapidity (ability to contain losses and recover in a timely manner)

There are therefore multiple ways to define and employ the concept of resilience in both natural and social systems. Thus in relation to flood risk management, the term "flood resilience" is also associated with multiple uses; for example, reference may be made to flood-resilient buildings, construction, or communities.

The Flood Green Guide recommends using four guiding questions for flood management issues (adapted from Carpenter et al., 2001[40]) in order to operationalize the concept of resilience:

1. **Resilience *of* what?** Which community, livelihood, institution, infrastructure, ecosystem, protected area?
2. **Resilience *to* what?** Are you addressing a shock, disturbance or stressor?
    - **Shocks and disturbances:** floods, cyclones?
    - **Stressors:** increased frequency and intensity of tropical storms, sea level rise, glacial melt, unpredictable rainfall?
    - **Impacts:** loss of life, damage to infrastructure, failing infrastructure?
3. **Resilience *for* what? (Why? Who benefits?)** An objective related to community, household, institution, infrastructure, ecosystem, protected area?
4. **Resilience *through* what? (How?)** Activities in flood management methods, land use planning, conservation, sustainable development, **disaster risk reduction**? These may be potentially new pathways to resilience through new and different sets of activities.

3.7 CROSSCUTTING ISSUES

3.7.1 INSTITUTIONS

Integrated flood management (IFM) takes place at various scales, including community, local/municipal, watershed, national and sometimes the region as a whole (for example, the Himalayas, the Greater Mekong region).[41] Because the source and/or causes of flooding may be some distance from the primary area of interest, managers must consider issues of scale.

Often, the best option may be to address flooding before it reaches the area of interest, and it is critical to ensure flood management methods in one area do not shift flood risk to other communities.

Managers should understand the institutions that are, or could be, involved with flood management, as well as those relevant to the use of natural and nature-based management methods. Relevant

39 A collaboration between the International Federation of Red Cross and Red Crescent Societies (IFRC), Practical Action, International Institute for Applied Systems Analysis (IIASA), and the Wharton Risk Management and Decision Processes Center.

40 Steve Carpenter et.al., "From Metaphor to Measurement: Resilience of What to What?" *Ecosystems* no. 4 (2001): 765-781, doi: 10.1007/s10021-001-0045-9.

41 Zhiyu et al., "Guidelines on Urban Flood Risk Management (UFRM)."

institutions may include those involved with water management, land management, planning, infrastructure, agriculture, the environment and meteorological services, to name a few.

Institutional mapping can be used to identify the level of awareness and perceptions of key institutions, both formal and informal, as well as of key individuals, inside and outside a community, city, province or country.[42] Institutional mapping also will help the manager identify how the different actors relate to one another.[43]

See chapter 4 for additional information on assessing institutional capacity.

3.7.2 REGULATION

Regulations play a vital role in implementing and enforcing flood risk management strategies. In most cases, three types of regulations can be put into place:

1. **Command and control:** Restrictive regulations prohibit specific types of development (such as residential structures in a floodway); limit density (the number of structures built); and exclude hazardous or critical facilities (such as medical or industrial complexes). Prescriptive regulations can mandate such norms as building safety standards and minimum ratios of unpaved areas. Command and control regulations are generally introduced as laws, municipal bylaws, statutory norms or mandatory agency procedures. Command and control regulations are effective but often require significant financial and human resources for monitoring and enforcement.

2. **Self-regulation:** Self-regulation means that certain policies and practices are adopted by industries, communities or businesses. The regulations are encouraged by the government but are without means of enforcement. Self-regulation can be cost-effective, but it requires genuine commitment from businesses and communities.

3. **Incentive-based regulations:** As an alternative to costly command and control regulations, governments can provide economic incentives to induce businesses and communities to follow desirable practices. Economic incentives include taxing offending development while subsidizing preferred types of development. Incentives are formally instituted by governments through regulatory agencies and require a certain degree of monitoring and legal enforcement.

The use of natural and nature-based methods may require adoption of new, or modification of existing, regulations. When selecting methods, managers should consider the role regulation plays in the success of those methods.

3.7.3 CROSS-SECTOR COORDINATION AND COOPERATION

Integrated flood management (IFM) includes coordination between national and city governments and public-sector companies, including utilities, along with civil society, nongovernmental organizations (NGOs), educational institutions and the private sector.[44] Cooperation and coordination among various sectors in both planning and implementing flood risk management methods are important in the IFM approach because the contributing factors of flood risk may reach across organizational and governmental boundaries.[45] Coordination and collaboration among various agencies will help bring about improved flood risk management. For example, municipalities, which often handle community-level development and building approvals, should coordinate with the urban development agencies that handle city-level planning.

---

42 Ibid.

43 Ibid.

44 Ibid.

45 Gasparini et al., *Resilience and Sustainability in Relation to Natural Disasters*, highlights cross-sector coordination as essential for building resilience and sustainability in relation to natural/manmade disasters in cities.

Managers can approach cross-sector coordination in a number of ways. One is to create a platform, such as a flood task force, to facilitate discussion and decision-making among various agencies and actors. For example, some governments will create a task force consisting of elected or appointed officials and business representatives to review past flooding events and develop recommendations to minimize or eliminate future flooding in the region. Another approach is to delegate one agency as a coordinating body. National or state-level disaster management agencies can often take on this role. The Flood Green Guide recommends, however, that when multiple institutions and actors are involved, care and consideration are given to understanding and managing institutional boundaries, so staff in agencies are motivated and willing to cooperate. In addition, organizational policies and procedures can be set up to compel agencies to communicate with each other when making decisions that have an impact on flood risk.

3.7.4 COMMUNITY ENGAGEMENT

Engaging the community at all stages of flood management – from assessment to selection and implementation of management methods – will help ensure that the methods enacted are fair, equitable and effective, and meet the needs and priorities of the entire affected population.[46] Community engagement also helps generate extra knowledge and resources; however, it can easily be absent due to lack of training, cohesion and community organization.[47] According to the National Research Council (USA), "communities most likely to survive disaster are those committed to building a sense of community, those that are actively committed to social equity and inclusion, those that are economically and environmentally sustainable, and those that create a vision to which its residents and institutions can relate."[48] Flood risk management interventions planned or implemented without proper community engagement have a high risk of failure.

Engaging the community can occur at many levels: through community consultation, participatory planning, community involvement in implementation and construction, and community-based monitoring and evaluation. Community engagement leads to community empowerment and a greater chance of success in flood management. Generating the necessary changes in attitude and behavior, however, calls for time and investment in widespread communication and participatory consultation with multiple stakeholders.[49] Flood management project design and implementation can be substantially strengthened when the community works with the experts on assessment, planning and decision-making.

The issue of time constraints must be considered by decision-makers in relation to the involvement of communities and other stakeholders. The time that most people have to participate in flood risk management measures, including public consultations and other activities, is often limited. Mobilizing the community to participate in voluntary service is also a challenge.[50] Managers and decision-makers should also note that various marginalized groups – including the poor, indigenous people, ethnic and religious minorities, marginalized castes, migrants, and people with special needs – are often underrepresented in community planning. Gender issues should also be considered in participatory activities (see gender section).

Young people can contribute much to flood management approaches. Examples from around the world confirm the opportunities and benefits of engaging a community's young people.

To the extent possible and appropriate, flood risk management activities should aim to empower communities through building awareness of, and resilience to, floods, while building technical skills and generating **co-benefits** such as local employment.

---

46 Zhiyu et al., *Guidelines on Urban Flood Risk Management* (UFRM).

47 See Jha et al., *Cities and Flooding*, Section 6.3.

48 See National Research Council (US), *Private-Public Sector Collaboration to Enhance Community Disaster Resilience*, 3.

49 Zhiyu et al., *Guidelines on Urban Flood Risk Management* (UFRM).

50 Ibid.

3.7.5 GAMES

Games can be tools to foster community engagement and cooperation, and help with complex decisions related to flood risk management. Games and visuals can help participants understand the existing and future risks while assisting with decisions about management approaches.

Dr. Bruce Lankford, a professor at the University of East Anglia, UK, developed a water resource management game as a teaching tool for facilitating cooperation over water resources. His research shows simple activities like games can facilitate discussion and expand people's perspectives on water issues.[51]

People's ideas relating to water, for example, are often biased toward their own experiences. Whether the water user is a farmer, engineer or policy-maker, solutions for water-related problems are influenced by how they use and benefit from the water. Their solutions are usually based on their experiences and needs. When games are employed, participants are more likely to work together to generate interdisciplinary proposals that will benefit all involved.[52]

Lankford's games approach was adapted by LIMCOM (Limpopo Watercourse Commission) in September 2011. LIMCOM conducted water allocation training for officials and commissioners and included the River Basin Water Allocation game. "The River Basin game was found to be very important in the sense that participants could understand aspects of water resources management, taking into account the basin as a unit."[53]

Although games can be a useful approach, underlying the use of such tools must be a fundamental understanding – so often lacking – of the physical impact of flooding and the expected outcomes of the flood management techniques in place.

3.7.6 GENDER

With increased research and analysis, our understanding of how gender plays a role in disaster management, including flood risk management, is growing. For the purpose of the guide, we use the following definition of gender:

> **Gender** is a social construct that refers to relations between and among the sexes based on their relative roles. It encompasses the economic, political, and sociocultural attributes, constraints, and opportunities associated with being male or female. As a social construct, gender varies across cultures, is dynamic, and is open to change over time. Because of the variation in gender across cultures and over time, gender roles should not be assumed but investigated. Note that "gender" is not interchangeable with "women" or "sex."[54]

3.7.6.1 Why Is Gender Important?

It has been well established that climate change and disasters, as well as disaster risk reduction activities, have gender components in terms of impacts and interventions. For example, women are affected by disasters differently – and often more severely – than men; this is largely because men and women are bound by distinct social and economic roles and responsibilities.[55]

---

51 Dr. Bruce Lankford, a professor at the University of East Anglia, UK, developed a water resource management game as a teaching tool for facilitating cooperation over water resources.

52 Bruce Lankford, *Resource Efficiency Complexity and the Commons: The Paracommons and Paradoxes of Natural Resource Losses, Wastes and Wastages* (Abingdon, UK: Earthscan Publications, 2013), 190.

53 Email from Sérgio Bento Sitoe, Limpopo Watercourse Commission (LIMCOM) secretariat, to Dr. Bruce Lankford, of University of East Anglia, UK, sent February 19, 2016.

54 USAID, *Guide to Gender Integration and Analysis: Additional Help for ADS Chapters 201 and 203*, March 31, 2010, https://www.usaid.gov/sites/default/files/documents/1865/201sab.pdf.

55 UNDP, *Gender and Climate Change: Impact and Adaptation Workshop Highlights*, UNDP Asia-Pacific Gender Community of Practice Annual Learning Workshop (Negombo, Sri Lanka, 2009), http://www.snap-undp.org/elibrary/Publications/GenderAndClimateChange.pdf.

Following its adoption at the Third UN World Conference on Disaster Risk Reduction, the UN General Assembly endorsed the Sendai Framework for Disaster Risk Reduction (DRR), which recognizes the importance of gender dimensions in DRR and calls for inclusiveness and engagement of all of society. The Sendai Framework calls for

> "a gender, age, disability and cultural perspective in all policies and practices; and the promotion of women and youth leadership; in this context, special attention should be paid to the improvement of organized voluntary work of citizens."[56]

Furthermore, the Sendai Framework emphasizes that

> "women and their participation are critical to effectively managing disaster risk and designing, resourcing and implementing gender-sensitive disaster risk reduction policies, plans and programmes; and adequate capacity building measures need to be taken to empower women for preparedness as well as build their capacity for alternate livelihood means in post-disaster situations."[57]

The Flood Green Guide promotes gender integration in all aspects of flood risk assessment and management, including planning, design, implementation, monitoring and evaluation. A number of resources and tools can assist the user with gender integration (see the additional resource section in this chapter).

3.7.6.2 Gender Analysis

As a key component of contextual analysis (see chapter 2), guide users should conduct or commission a gender analysis. A **gender analysis** will provide guide users with greater understanding and appreciation for the existing and future role that gender can play in local flood risk management. Gender analysis should always be a part of assessments, project planning, design and implementation.

Six domains of gender are typically included in gender analysis:[58]

- access
- knowledge, beliefs and perceptions
- practices and participation
- time and space
- legal rights and status
- power and decision-making

Appendix B provides details related to the six domains and suggests questions that might be included in gender analysis as part of designing a flood risk management project.

3.7.6.3 How to Integrate Gender and Flood Risk Management

Based on work conducted by the International Centre for Integrated Mountain Development (ICIMOD) in 2014, the United Nations Development Programme (UNDP) in 2010, and others, we suggest the following guidance be applied to flood risk management methods to better integrate gender:

- Analyze how flood risk affects both males and females.

- Develop and apply gender-sensitive monitoring criteria and indicators.

---

56 UNISDR, "Gender," last accessed February 2016, http://www.unisdr.org/we/advocate/gender.

57 Ibid.

58 USAID, "Tips for Conducting a Gender Analysis at the Activity or Project Level," March 2011, https://www.usaid.gov/sites/default/files/documents/1865/201sae.pdf.

- Include statistics on women as well as on men when collecting and presenting data.
- Capitalize on the talents and contributions of both women and men.
- Develop local infrastructure with the active involvement of local men and women.
- View flood risk management as a social and development activity rather than an exclusive domain of engineers and technicians.
- Consider gender from the very beginning of the project cycle, to avoid interventions that can have unintended gender implications.
- Ensure that facilitators are sensitive to equitable community participation in discussions and decision-making.
- Utilize new techniques and technologies as entry points for overcoming traditional gender barriers.
- Work to establish gender-balanced participation in all aspects of project planning and implementation.
- Undertake a gender analysis of all budget lines and financial instruments.

3.7.6.4 Gender-Responsive Budgeting

Applying a gender integration approach to flood risk management also includes gender-responsive budgeting (GRB). GRB is a tool that can be used to ensure that budgets recognize that while the needs of women and men are sometimes the same, they can also be different, and allocations should reflect these differences.[59] GRB is one way of ensuring that observed gender differences are reflected in project budgeting, making it more likely that the project will equally assist men and women.[60]

3.7.7 PRIVATE SECTOR PARTICIPATION

According to the Asian Disaster Preparedness Center (ADPC) and the UN Office for Disaster Risk Reduction (UNISDR), private sector involvement is a key part of building disaster-resilient cities.[61] Big businesses as well as small and medium enterprises (SMEs) suffer substantial losses in disasters. SMEs can be hit the hardest, as their losses are often not fully covered by insurance.

Private sector involvement in flood risk management is advantageous in two ways. First, it can reduce the market-based barriers to plans for flood risk management activities, including natural and nature-based methods. Second, it can channel private sector resources to flood risk management.[62]

The private sector can participate in flood risk management in a number of ways. Managers should include representatives from the business community in discussions and meetings. Start by consulting local business associations like the chamber of commerce. A more advanced step is to launch flood risk management or recovery initiatives as public-private partnerships by enlisting select private sector companies as partners in the project.

---

59 UNDP, *Gender, Climate Change and Community-Based Adaptation* (New York: UNDP, 2010), http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/climate-change/gender-climate-change-and-community-based-adaptation-guidebook-/Gender%20Climate%20Change%20and%20Community%20Based%20Adaptation%20%282%29.pdf.

60 Ibid. For more information from UNIFEM, visit www.gender-budgets.org.

61 See *ADPC 2020 Strategy*; also see UNISDR, "Private Sector."

62 See UNISDR and Roeth, *The Development of a Public Partnership Framework and Action Plan for Disaster Risk Reduction (DRR) in Asia*.

Private sector partners may contribute funds for flood risk management activities when they are equal partners. These may come through contracts or memoranda of understanding (MOUs) that honor private sector interests. Private sector resources also might be obtained as in-kind support, such as donations of equipment, material, labor or expertise, especially in cases where the private sector will benefit from flood risk management.

A number of corporations promote and/or benefit from what is sometimes called "natural infrastructure." For example, the Caterpillar Corporation held a summit on restoring natural infrastructure in 2015 that promoted plans to expand education, outreach and partnerships related to natural infrastructure. Private corporations may be potential partners and/or stakeholders in developing and using natural and nature-based methods.

3.7.8 FINANCE

Funding sources for flood risk management can be as varied as the stakeholders and issues involved. Financial support for community development, infrastructure, disaster risk reduction, disaster **response**, climate change adaptation, sustainable development, education, and environmental management can come from any number of government agency budgets, donors, NGOs, and the private sector. In the Philippines, for example, the Palo municipality conducted a review of its local planning and development tools to incorporate DRR in order to reduce the impacts of flooding. Once the assessment identified the most appropriate measures, responsibilities were allocated among relevant administrative bodies and incorporated into the municipality's Annual Investment Plan.[65]

When planning how to use natural and nature-based flood risk management methods, finances from multiple sectors should always be considered. In addition, communities may consider establishing links to microfinance sources and setting up a community-owned disaster fund to support development and management of certain flood management methods.

EXAMPLE:

The Philippines provides an example of a national-level framework for private sector participation in disaster risk reduction. In that country, a number of private sector associations, such as the Private Sector Network for Disaster Management (PSNDM) and the Corporate Disaster Response Network (CDRN), have been formed to expedite mobilization of resources through partnerships between nongovernmental organizations, private volunteer organizations, government offices and communities.[63] In 2007 and 2008 the PSNDM and CDRN participated in the "National Multi-stakeholder Dialogue on DRR" to help assess progress made on national DRR goals.[64]

63 UNISDR and Helen Roeth, *The Development of a Public Partnership Framework and Action Plan for Disaster Risk Reduction (DRR) in Asia* (Bangkok, Thailand: UNISDR, 2009), http://www.unisdr.org/files/12080_TheDevelopmentofPublicPartnershipFr.pdf.

64 Ibid.

65 Zhiyu et al., *Urban Flood Risk Management.*

3.8 ADDITIONAL RESOURCES

1. Associated Programme on Flood Management (APFM), http://www.apfm.info/.
2. APFM, *Flood Management in a Changing Climate*, 2009, http://www.apfm.info/publications/tools/Tool_09_FM_in_a_changing_climate.pdf.
3. APFM, *Formulating a Basin Flood Management Plan*, 2007, http://www.preventionweb.net/files/2626_ToolsBasinFloodManagementPlan.pdf.
4. FAO, *Forests and Floods: Drowning in fiction or thriving on facts?* 2005, ftp://ftp.fao.org/docrep/fao/008/ae929e/ae929e00.pdf.
5. USAID, *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change*, 2014, http://pdf.usaid.gov/pdf_docs/PBAAA245.pdf.
6. USAID, *Tips for Conducting a Gender Analysis at the Activity or Project Level*, 2011, https://www.usaid.gov/sites/default/files/documents/1865/201sae.pdf.
7. UNDP, *Gender, Climate Change and Community-Based Adaptation*, 2010, http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/climate-change/gender-climate-change-and-community-based-adaptation-guidebook-/Gender%20Climate%20Change%20and%20Community%20Based%20Adaptation%20(2).pdf.
8. UNISDR, *Making Disaster Risk Reduction Gender-Sensitive Policy and Practical Guidelines*, 2009, http://www.preventionweb.net/files/9922_MakingDisasterRiskReductionGenderSe.pdf.
9. UN Women, "Gender Responsive Budgeting," http://www.gender-budgets.org/.
10. Red Cross/Red Crescent Climate Centre, "Games," 2015. http://climatecentre.org/resources-games/games.
11. Engagement Lab at Emerson College, "Games for Social Change," http://elab.emerson.edu/projects/games-for-social-change.

CHAPTER 4

4. ASSESSING FLOOD RISK: DATA, METHODS AND ANALYSIS

4.1 SECTION CONTENT

This chapter covers elements involved in assessing the risk posed by flooding. For the purposes of the Flood Green Guide, flood risk involves knowing (1) who can be affected, (2) how they can be affected, and (3) where they can be affected. It is critical for the guide user to understand these issues in selecting and planning for the range of flood management methods in chapter 5. The chapter provides a review of flood risk management information needs, tells the guide user where to find the information, and offers a simple process to understand the nature of a watershed. Since a wide range of risk assessment techniques and tools are currently available to the guide user, this chapter focuses on the results that should be produced by any risk assessment and on how these results can be used to select and manage flood management methods. This chapter closes with a method to define institutional capacities to manage flood risk, a key consideration in deciding which flood management approaches are most appropriate for the local context.

4.2 FLOOD RISK ASSESSMENT

4.2.1 DEFINING FLOOD RISK

For the purpose of the Flood Green Guide, **flood risk** represents the threat of flood damage to individuals, households, communities and society. There are several sources for accepted definitions of flood risk; most definitions are understood as a function of hazards, exposure, vulnerability and **capacity**.

The guide user should understand flooding in terms of "the type, source and **probability** of flooding,"[1] the vulnerability to damage, and the capacities that exist to resist this damage.[2] These elements can be simply presented as

Flood Risk = *Flood Hazard, Exposure, Vulnerability* modified by the *Capacities* to resist this damage.[3]

- **Hazard** is a function of frequency, magnitude and extent.
- **Exposure** is the potential area covered by a flood.

1 Jha, Bloch and Lamond, *Cities and Flooding.*

2 Ibid; Zhiyu et al., *Guidelines on Urban Flood Risk.*

3 Zhiyu et al., *Guidelines on Urban Flood Risk*; IPCC, "A Special Report," 65-108.

- **Vulnerability** is the potential for harm.
- **Capacities** are attributes that can reduce negative impacts.

Procedures to assess flood risk are discussed in section 4.2.3. Selecting the most appropriate procedure depends on the data available for each of the four risk elements.

4.2.2 WHY ASSESS FLOOD RISK?

Although the process of assessing flood risk can seem complicated and time consuming, a good **flood risk assessment** will identify:

- How frequently floods of specific magnitudes and extents are likely to occur.[4]
- Where damage will occur – the location of people and physical and natural resources that will be affected by flooding.
- Who is vulnerable – people affected by floods for each frequency, indicating the gender and age of those vulnerable where damage is likely to occur.
- Why they are vulnerable – the physical, social, environmental and economic impacts expected from a flood of a given frequency and magnitude; how these differ by gender and age.
- What the capacities are to avoid or reduce the impacts of flooding before it occurs, or to alleviate the impacts after flooding.

Flooding can affect people in the same location differently, and flood impacts can vary significantly over relatively small distances. A risk assessment helps identify these differences so flood management efforts can be tailored to the specific locations and populations at risk.

Flood risk assessments help communities understand the extent and nature of their flood risk, an essential requirement for getting people to support risk management actions. A risk assessment should incorporate specific community concerns about flooding, increasing the credibility of the assessment results. Engaging communities in flood risk assessments creates a more participatory approach, which is essential when flood management methods depend on collective actions.

Finally, flood risk management involves time and financial resources. Many flood risk management methods involve changing the way society understands and addresses flooding; in other words, some methods require a change in human behavior. Choosing flood management options and convincing people to finance and support them, therefore, depend on the guide user's developing a clear understanding of flood risks and how they can be managed and reduced to an acceptable level. A clear and well-understood flood risk assessment can help build political and community support and engagement in the chosen flood management methods.

4.2.3 ASSESSMENT PROCEDURES

Flood risk assessment procedures include recording local knowledge of damages and who was affected in past flood events, and highly technical modeling. The latter may use remotely sensed data to assess possible levels of future flooding and calculate expected damage based on detailed spatial analysis of

---

4 Flood frequency is usually calculated by professionals using time series data and is often expressed as the probability a flood of a specific magnitude will occur sometime during a specific time period (also called the recurrence interval, the term preferred by hydrologists). For example, a flood of a specific magnitude occurring during a 100-year period will have a probability of occurrence in any given year as 1 in 100, or a 1% chance in any given year. This does not mean one flood in 100 years, but that there is a probability that a flood of a specific magnitude will occur at least once in any given 100-year period.

flood location, duration and assets at risk. In addition, risk assessments can consider the level of resilience of those who are affected by a flood, thus incorporating their capacities to recover from flood damage.

The Flood Green Guide anticipates that most users will have conducted, or will have access to, some type of flood risk assessment. Where this is not the case, users can refer to the following resources for information on risk assessment methods and identify a relevant approach:[5]

- PrepareCenter.org
- Disaster Assessment Portal
- PreventionWeb

The risk assessment methods available through these sources focus on low-cost and highly participatory approaches manageable at the community level. Depending on the local context, these methods can be fully adequate for community flood risk management planning purposes. However, it is essential to regularly update risk assessments to capture changes to the local context, including a changing climate, which may affect flood risk and thus require an adjustment to management approaches.

Guide users also should be aware that there are both commonalities and differences in concepts, conceptual frameworks, and methodologies for flood risk assessments and climate change adaptation (CCA) assessments, although all may be useful to understanding flood risk. The primary disaster risk reduction assessment tools are vulnerability and capacity assessments (VCA). The most common CCA assessment methodology is vulnerability (impact) assessments (VA or VIA).[6]

Finally, guide users should consider developing the Watershed Characterization Report (see section 4.5). The characterization report collects a range of information on a watershed that can be used in the risk assessment process as well as the selection of the optimal flood management options.

4.2.4 REPORTING FLOOD RISK ASSESSMENT RESULTS

For the purpose of the Flood Green Guide, a flood risk assessment report should ideally cover the six areas of information described in this section and be accompanied by several annotated maps with as much supporting information as possible. The guide uses the Flood Risk Data Summary table (see Framework Worksheet) to organize assessment results into a format that can be used in the Flood Green Guide Framework (framework) (see chapter 2) to help select the optimal flood management methods.

If the guide user is using a **geographic information system** (GIS), the information sets collected as part of the risk assessment process and the watershed characterization (described in section 4.5) can be established as layers (files) and used to generate maps indicating the results of the assessment. If GIS is not available, the results can be presented in narrative and tabular form supported by hand-annotated maps. (Read more about GIS in section 4.4 of this chapter. The information that should be collected for a GIS or presented as tables and in narratives is described in sections 4.2.4.1–4.2.4.6).

---

5 For flood risk assessment resources, see the PrepareCenter.org website, managed by the International Federation of Red Cross and Red Crescent Global Disaster Preparedness Center, http://preparecenter.org/topics/community-risk-assessment; the Disaster Assessment Portal, http://www.disasterassessment.org/; and PreventionWeb, http://www.preventionweb.net/english/professional/trainings-events/edu-materials/?tid=44 (search for risk identification and assessment).

6 More information on VCA, DRA and hazard assessments can be found at the websites in the previous footnote. Information on climate change adaptation assessments can be found at the Climate Adaptation Knowledge Exchange (search vulnerability assessments in the virtual library), cakex.org. Other resources include the CARE Climate Vulnerability and Capacity Analysis handbook, http://careclimatechange.org/tool-kits/cvca/, and Flowing Forward, http://www.flowingforward.org/.

© Lauren Kovach/WWF

An annotated map showing the extent of flooded areas and direction of flood water.

4.2.4.1 Spatial and Temporal Extent of Flooding

To make flood mapping easier, a separate map for each flood frequency can be developed. (If flood modeling is used, historical and projected flooding should be noted separately and marked differently on the maps.) Copies of the map developed in the Watershed Characterization Report (see section 4.5) can be used in recording flood information to compare the features of the watershed along with the impacts and causes of flooding.

Typically, five flood frequencies are identified:[7]

1. 1:1 (100% probability of flooding in any one year)
2. 1:5 (20% probability in any one year)
3. 1:10 (10% probability in any one year)
4. 1:20 (5% probability in any one year)
5. 1:50 (2% probability in any one year)

If data on all of these frequencies is not available, then the known flooding frequencies should be indicated.

7 See footnote 4. These frequencies/recurrence intervals may also be expressed as 100%, 20%, 10%, 5% and 2% chance of flooding in any one year.

4.2.4.2 Factors Contributing to Flooding

The factors identified as contributing to floods for each of the five probabilities should be identified. These factors can be classified as anthropogenic (the result of human action) and natural (the result of natural conditions). For instance, annual flooding may be caused by heavy rainfall at the beginning of the summer, while flooding once in five years is associated with several weeks of heavy rainfall and water backing up behind a bridge. The levee is an anthropogenic (engineered) factor, while several weeks of rainfall are a natural factor.

To the extent possible, contributing factors of flooding should be based on well-defined parameters (e.g., observed precipitation) and observations. These factors can be listed in a table, indicating their return period, the scope of flooding experienced, and other natural and anthropogenic factors related to the cause of floods. The same information can be added to an annotated map.

4.2.4.3 Damage Incurred or Expected

The locations affected at each flood frequency should be described and damage listed with as much detail as possible for each flood return period. Valuing damage in monetary terms is preferred. If this is not possible, then the listing should be a detailed catalogue of all damage that has occurred or is expected to occur for the five flooding frequencies. This inventory should be based on historical damage or on projected damage when a flood risk assessment has used modeling to anticipate future flood areas and damage.

Where a catalog of damage is developed, a monetary value should be determined for each type of loss based on replacement costs; these values should then be multiplied by the number of items and totaled for all losses. This process generates an indicative monetary loss estimate. The same process and values should be applied to all flood damage so that results are comparable.[8]

Damage information should be added to the annotated maps in summary form.

4.2.4.4 Vulnerable Groups

A list of the groups that have been most affected by flooding in the past and/or could be affected by future flooding should be developed.[9] This list should indicate the level of damage experienced for each group to the extent this information can be identified. It can include people who live in a specific flooded area; populations can be defined by social or economic conditions (e.g., elderly, less wealthy). An explanation for why specific groupings are considered vulnerable to flooding should be provided.

In most risk assessments, assumptions are made about who is most vulnerable, such as single-headed (as opposed to couple-headed) households, those households with limited assets, the elderly, people with disabilities and similar marginalized groups most vulnerable to hazards; these groups can be included in the list. It is necessary, however, to ask whether other groups are also vulnerable to flooding and to add these groups to the list.

To the extent possible, these groups' locations should be marked on the maps that indicated the spatial extent of the five flood frequencies.

4.2.4.5 Capacities – Vulnerable Groups

The listing of vulnerable groups should include an indication of the capacities that each vulnerable group has that will enable them to resist or respond to damage caused by flooding. **Capacities** can be described

---

8 While a comprehensive monetary loss number of each flood event is preferred, an indicative number for each event, using the same procedure for estimating losses for all floods, is an acceptable alternative.

9 Not all residents of a flooded area are assumed to be vulnerable, and the level of vulnerability will vary based on socioeconomic factors and location as well as the effectiveness of warnings, preparedness and evacuation capacities, all of which can be considered in assessing adaptive capacity.

as "the combination of strengths, attributes and resources available" to a vulnerable group to reduce the negative impacts of flooding[10] and often include coping strategies (what is done in the case of flooding) and adaptations (the changes that are made, or can be made, to reduce the impact of flooding).

4.2.4.6 Capacities – Institutions

Understanding the abilities of communities and organizations to implement flood management actions is critical to help select and manage the optimal flood management methods. To assess and capture information on capacities for use in selecting management methods and for use in the Flood Green Guide Framework process, the Institutional Flood Management Capacity Assessment table should be completed (see Framework Worksheet , chapter 2) as part of documenting the risk assessment results.[11] (Refer to chapter 3 for more information on institutions and policy-making.)

4.3 PRIORITIZING ASSESSMENT RESULTS

Risk assessments usually include a process for prioritizing results to identify which risks should be addressed first. Prioritization provided through the risk assessment process should be indicated in column 9 of the Flood Risk Assessment Data Summary table (Framework Worksheet , chapter 2). If the risk assessment does not produce a clear risk prioritization, an initial prioritization can be done—for example, by financial loss parameters:

- Add a 10th column to the table that divides the level of loss by the number of persons affected and then by the expected frequency of flooding, providing the expected per capita loss per year.[12]
- Rank the level of per capita loss per year from high to low.

The flood hazard events with the highest per capita losses per year are initially considered the highest priority, with the order of priority decreasing as the per capita loss decreases.

Those involved in the flood risk assessment, along with a wider group of relevant participants where possible, should confirm the initial ranking. In some cases, the per capita damage ranking can conceal other social factors important in the ranking process. To address this, the initial per capita damage ranking should be compared to the flood impact on specific vulnerable groups (column 6 in the Framework Worksheet Flood Risk Assessment Data Summary table). Taking into account adaptive capacities (column 7), identify whether priorities need to be adjusted to better reflect the expected impact of flooding on humans and livelihoods, or on another identified priority such as maintenance of ecosystem services. Any such changes should be made on an updated column 9 of the table. The prioritization process should involve careful consideration of the ranking factors and not be rushed in order to minimize the chance of discounting areas of social, cultural or environmental importance.

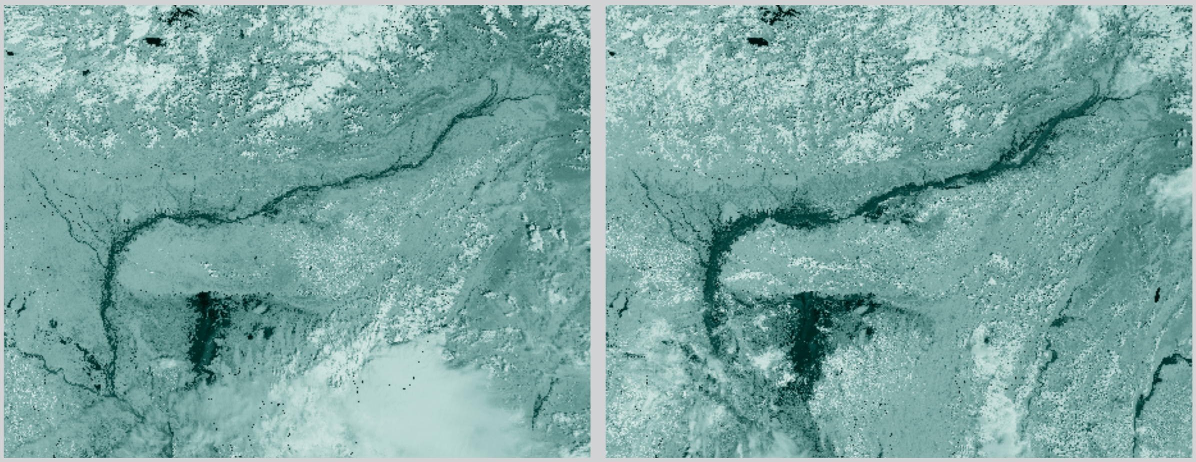
---

10 Marilise Turnbull and Edward Turvill, *Participatory Capacity and Vulnerability Analysis: A Practitioner's Guide, Oxfam Policy and Practice: Climate Change and Resilience* 8, no. 1, February 2012, 71-113.

11 For more information about institutional mapping methods, see SPICOSA Project Report, http://www.coastal-saf.eu/design-step/support/introducing_institutional_mapping.pdf, and the World Bank's *Institutional Perception Mapping*, http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTSOCIALDEVELOPMENT/EXTTOPPSISOU/0,,contentMDK:20591794~menuPK:1572522~pagePK:64168445~piPK:64168309~theSitePK:1424003~isCURL:Y,00.html.

12 For example, 20,000 people affected with losses of $400,000 from a flood that is expected to take place once in 20 years; or $20 of losses per person, then divided by 20, the number of years expected between floods, or an average loss of $1 per person per year over the period of when the flood is expected to take place.

4.4 FLOOD RISK ASSESSMENT AND MANAGEMENT-RELATED INFORMATION NEEDS AND SOURCES



Images courtesy of NASA

Satellite imagery from NASA shows the Brahmaputra River running through India and Bangladesh. The first photo shows the Brahmaputra River during a year of average rainfall, and the second shows the river swollen in 2014 after a year of severe flooding from above-average rainfall and meltwater from the Himalayas.

This section summarizes types of information helpful for both assessing and selecting flood management techniques. In addition, this section provides information on how to collect and use information on weather conditions and flood monitoring (useful in assessments and in flood management). It includes a discussion of the roles of GIS, remote sensing and watershed modeling in generating information for flood management.

4.4.1 TYPES OF INFORMATION

The information needed to understand risk and manage floods covers a range of topics, and can be organized into the following categories:

Hydrologic data: including water level or depth; flow rates (usually in cubic meters per second); precipitation (snow and rain, in millimeters); quantity totals and per period of time (per minutes or hours); runoff rates and (soil) retention; and flow rates for springs (cubic meters per second).

Geophysical data: including the nature of the geology, soil, watershed slope, aspect (direction the slope faces) and hazards present (e.g., landslide zones, volcanic activity, earthquake probability, frequency and type).

Natural and built environment data: including the locations of rivers, streams, lakes and other water bodies and natural resources as well as built infrastructure – including roads, buildings, irrigation systems, flood management structures and other engineered structures that can impact flooding. Built environment data should also include sites of cultural, religious or social importance.

Landscape and land use data: including the types of land cover (e.g., vegetation, hard surface); how the land as a natural resource is used (e.g., farming, pasture, housing); how land use has changed over time; and land use plans, if they exist.

Social data: including data on population numbers, composition and location; livelihoods and access to livelihood assets (financial, natural, fiscal, social and physical); education; perception and attitudes toward the use of the environment and natural resources; potential, past or actual conflicts related to the use of natural resources; and existence of organizations or social networks with roles in managing natural and other resources in a watershed (e.g., community forest committees, irrigation water users' associations).

Governance data: including information about flood management or related water management authorities (if they exist); the local disaster, land use and natural resource management administration authorities; and planning and procedures for dealing with flooding, including preparedness, warning, response, recovery and risk reduction plans and practice.

Flood impact and management data: including data on past losses from flooding, where these losses have taken place, and the economic and social impacts of these losses. This category also includes investment in reducing flood impacts with structural and non-structural interventions.

4.4.2 SOURCES OF INFORMATION

4.4.2.1 Human Sources (Informants)

Human sources – including longtime local residents and community groups, local government officials, and specialists working for the government, NGOs, the private sector or academia (together generally referred to as **informants**) – can provide detailed, locally relevant information on flood causes and consequences, as well as identify management options and lessons from past efforts to manage floods. Informants are an excellent source for understanding the social aspects of flooding.

Information provided by informants is often qualitative – for example, an elderly woman speaking about her experiences with flooding when she was young. This qualitative information, however, can be organized quantitatively through the use of questionnaires and/or guided interviews or group discussions.[13] Human sources of data can provide a deeper background to flooding issues from their experiences in a watershed over time.

Quantitative data and analysis of flood factors are often available from those working in local government or NGO offices and local or regional academic institutions. This data can be incorporated into more formal analysis, including a GIS (see section 4.4.4).

Finally, while many organizations document lessons learned, informants are often a source of specific and experience-based lessons about the causes and consequences of flooding, as well as what has or has not worked in flood management in the past. Interviewing local informants is an essential part of any flood risk assessment or management effort.

4.4.2.2 Reports and Documents

Listed below are resources that can help with a flood risk assessment. Many of these are available online.

- water level and flow records (e.g., stream gauges), often compiled into tables and reported on a monthly or annual basis by water resource managers
- official flood and flood damage reports—useful for the details of the process and timing when flooding occurred; comprehensive damage and recovery data; potential risk reduction measures and lessons

13 The guided process uses a formal set of questions to guide discussions, with responses appropriate for each question noted. However, the discussion should be allowed to move forward without posing and answering each question in order. This technique is more suited for the open discussions that take place in a group setting.

- flood management plans, project documents, and final reports detailing the scope of the flood hazard (often including flood maps) and the costs and benefits of flood management options
- academic research articles, reports and other publications that document flood risk and impacts and may include risk management options
- drawings, paintings and pictures depicting flooding, often useful in understanding the scale of a flood and communicating flood impact to target audiences
- newspaper articles and books on floods, often useful for providing a broader perspective on flood impacts by emphasizing human impacts and losses

4.4.2.3 Physical Evidence

While historical evidence of flooding impact is often included in reports and documents, and provided by informants, it is also available from physical evidence like on-site inspections of flooded areas after flood levels have dropped; markers recording historic flood levels; and other visual evidence of past flood events, including flood level marks on buildings. Such physical evidence will help the guide user understand how flooding affected a location in the past, and educate stakeholders about flood impacts and management options. While collecting physical evidence is best done immediately after a flood, hydrologic or flood specialists can often collect useful information well after a flood event. For instance, a hydrologist may be able to assess flood depth and flow rates by measuring stream channels and flooded areas, and a soil scientist specializing in flood impacts can identify the extent and impact of flood sediment.

Post-disaster housing reconstruction project built in floodplain in Aceh, Indonesia.

4.4.2.4 Flood and Other Maps

Maps of actual or potential flood areas are often included in government, academic, or NGO reports and documents. Flood maps can be used to

- verify actual flood damage in discussion with informants and when verifying physical evidence;

- indicate changes in flood impact areas based on changes in watershed conditions, including the worsening of flooding or reduced flood impacts due to management efforts. These can include maps produced using flood modeling and GIS to generalize different flood scenarios.

Also useful in flood risk assessment and flood management are maps covering the following:

- topographic information
- watershed composition and boundaries
- hydrologic, geological and topographic features
- floodplain composition and boundaries
- historic extent of flooding
- land cover and land use
- built infrastructure: roads, buildings, bridges, etc.
- land formations and water storage areas (e.g., wetlands)
- areas of potential or actual conflict
- protected areas and areas of unusual natural, cultural or social value

In using maps, the guide user should consider

- Whether a map is up to date. Floods, the development of the built environment and land use changes can quickly make maps dated. Where possible, maps should be updated before use, or the differences between information on the map and what is actually on the ground clearly noted. (In some cases, these differences can be used to assess flood impacts.)

- The scale of a map. When combined, information from maps of different scales is only as accurate as the least accurate map. If maps of 1:50,000 and 1:5,000 scales are combined, the resulting accuracy is 1:50,000 – much less than the 1:5,000 map.

If appropriate maps do not exist or are not up to date, participatory or crowd-sourced mapping can be used.[14] This is normally done by having one or more informants either mark up an existing map with changes or draw a new map covering the information required (e.g., extent of most recent flooding). This data can be used to update old maps or create new maps, usually by transferring the data into a GIS. Additional information on participatory mapping can be found in *Good Practices in Participatory Mapping.*[15]

Many maps useful for flood management are available online through a keyword search using technical terms (e.g., "flood mapping") or geographic terms (e.g., "flood map Jakarta").

4.4.2.5 Remote Sensing

Remote sensing is the science and art of obtaining information about an object, area or phenomenon by analyzing data acquired by a device that is not in contact with the object, area or phenomenon under

---

14 Participatory and crowd-sourced mapping examples include openstreetmap.org and Ushahidi.com.

15 Jon Corbett, *Good Practices in Participatory Mapping: A Review Prepared for the International Fund for Agricultural Development (IFAD)* (International Fund for Agricultural Development (IFAD), 2009), http://www.ifad.org/pub/map/pm_web.pdf.

investigation.[16] In recent years, remote sensing and GIS (digital, remote sensing data can be incorporated into a GIS) have become critical tools for flood prevention, flood risk reduction and flood monitoring.

Remotely sensed data is typically collected using a sensor that detects (passive) or emits and detects (active) electromagnetic waves on a satellite, airplane, helicopter, unmanned aerial vehicle (UAV), or balloon. The most common sources of remotely sensed imagery for flood management are

- aerial photos, often dating to the 1950s or earlier. Common challenges with aerial photos include expense and need to digitize hard copies for GIS. The use of UAVs means getting aerial photos is quick and low cost[17] but can involve legal restrictions and other issues.[18] A low-cost and generally less legally challenging method of aerial mapping is to use a balloon or kite to collect aerial photos.[19]
- satellite imagery, available from commercial (e.g., Google Earth, Digital Globe) and nonprofit sources. This imagery, which can date back more than 20 years, is useful for assessing changes to watersheds, land use, urban areas, coasts and river courses over time. Note that accessing the UN-based system at no cost normally requires a threatened or actual disaster.

Quite often, national agencies involved in remote sensing – or university-based programs in geography, remote sensing, cartography, land use, environmental management or disaster management – have access to satellite imagery and GIS and capacities to do at least basic analysis. These services can be free or low cost and can involve students doing a practicum, particularly at the graduate level.[20] In some cases, these organizations can access imagery through International Charter: Space and Major Disasters and perform detailed analysis locally.[21]

4.4.3 LOCAL DATA COLLECTION

It is critical for the Flood Green Guide user to understand the local context of flooding, including information on local precipitation, temperature,

ADDITIONAL INFORMATION

Selected Sources of Satellite Imagery and Analysis

International Charter: Space and Major Disasters is a unified system of space data acquisition and delivery to those affected by disasters (https://www.disasterscharter.org).

UN-SPIDER connects disaster risk management and space communities, and facilitates capacity-building and institutional strengthening (http://www.un-spider.org/links-and-resources/data-sources).

UNOSAT (via UNITAR) supports international humanitarian assistance operations to respond to crises (http://www.unitar.org/unosat/maps).

Hazards Data Distribution System (HDDS) provides access to before-and-after imagery of flooding and other disaster events (http://hddsexplorer.usgs.gov/).

---

16 Thomas M. Lillesand, Ralph W. Kiefer, and Jonathan W. Chipman, *Remote Sensing and Image Interpretation*, 7th ed. (Hoboken, NJ: John Wiley and Sons, Inc., 2015).

17 See blogs: DroneFlyersCraig I., “Quadcopter Aerial Photography and Video on a Shoestring Budget - Drone Flyers,” *Drone Flyers*, May 4, 2014, http://www.droneflyers.com/2014/05/quadcopter-aerial-photography-video-shoestring-budget/;SUAS News, “Drone Imagery Helps Map Flood Risk,” June 2015, http://www.suasnews.com/2015/06/drone-imagery-helps-map-flood-risk/.

18 See Daniel Gilman, *Unmanned Aerial Vehicles in Humanitarian Response*, OCHA Policy and Study Series 10, June 2014.

19 See Stewart Long, “An Illustrated Guide to Grassroots Mapping,” last accessed March 12, 2016, http://archive.publiclaboratory.org/download/Grassroots_Mapping_English_2_0.pdf.

20 For an example of free or low-cost mapping, see openaerialmap.org.

21 See United Nations Office of Outer Space Affairs (UNOOSA), “International Charter Space and Major Disasters,” UN-SPIDER Knowledge Portal, accessed February 2016, http://www.un-spider.org/space-application/emergency-mechanisms/international-charter-space-and-major-disasters.

and wind and water levels. Managers need this information for real-time monitoring and warning for potential floods, to understand how flood risk may change over time, and to assess the effectiveness of flood management efforts. A community can easily begin to collect climate data and conduct simple flood hazard analysis using easily available resources. In addition, a community-based system of monitoring weather conditions can contribute to community participation in, and ownership of, flood risk management. (For more information on how community participation benefits flood management, see chapter 3.)

4.4.3.1 Local Weather Station

Data on precipitation, temperature and wind are needed to define the conditions that could lead to flooding. This data is usually available from NMHSs, agricultural stations, or river basin authorities, among other locations.

To complement these sources (and to collect data close to flood risk areas), a simple station to collect precipitation, temperature and wind data can be constructed at minimal costs. A basic station consists of the following:

- A rain or snow gauge that is monitored once every 24 hours at the same time each day (preferably after the normal period of heaviest precipitation), with the total precipitation in millimeters (mm) recorded, and the gauge emptied once daily. Rain gauges can be purchased, or they can be constructed by cutting a 1.5-liter plastic bottle just below the top and inverting the top into the lower part of the bottle as a collector. The side of the bottle can be marked in millimeters, or a ruler can be used to measure water depth.[22]
- A thermometer that is recorded twice a day – for instance, at dawn and 1500 hours. (The thermometer should be protected from direct sunlight.)
- A windsock that is recorded at the same time as the temperature. The direction of the wind – using directions of a compass (e.g., north, southwest, etc.) – and the strength of the wind should be indicated (see appendix C, Beaufort Wind Scale). The windsock can be made of a meter-long piece of cloth and should be at least three meters above the ground, unobstructed by buildings or trees.

The data on precipitation, temperature and wind are recorded in a daily report (and can be posted on a public board) for later analysis.

Contact the local weather services office for more information on how to set up a weather station.[23]

4.4.3.2 Water-Level Gauge

A water-level gauge in the nearest stream or river can complement the weather station. This gauge, which can be a strong pole placed in a stream, or markings on the abutment of a bridge, should clearly indicate water depths in tens of centimeters (for instance, in alternative white and black bars, each marking 10 cm of height so that the water level can safely be seen from the shore). The water gauge should be monitored at the same time as the precipitation gauge is read, and the data should be recorded together with the weather data.

Advice from local weather station staff or the national hydrologic service can be used to set up the stream water gauge station.

---

22 For locations where snow is collected in the gauge, remove the collector (cut-off top of the bottle) before it snows. Melt the snow to measure the amount of water collected in the snow. Because of different types of snow, the amount of water resulting once the snow is melted is more important than the actual depth of snowfall.

23 Note that the same station can be used to monitor for drought.

4.4.3.3 Data Collection and Organization

Community groups (e.g., a water users' association, a women's gardening group) can organize climate data collection. Data collection can also be integrated into school activities via youth groups, such as a weather watcher's club, or as part of the normal curriculum.

4.4.4 DATA ANALYSIS TOOLS

4.4.4.1 Geographic Information System

A GIS is software that enables the manipulation of digitally stored spatial information. A GIS provides a framework to turn raw data into clear results and can be used to analyze, model, evaluate, plan, inform and make decisions (see figure 4.1). GIS software allows for mapping and analysis of information that can guide evaluation of risk and planning decisions.

In the context of flood risk management, GIS software can be used to

- evaluate the impact of historic flooding
- identify flood hazard zones and potential losses from floods of different levels
- plan evacuation routes, designating open areas that can be used in the event of a flood and plan flood impact reduction interventions
- monitor flood conditions in real time
- illustrate a local spatial plan and location in the watershed
- analyze social, economic and other data about populations at risk from flooding
- visualize and quantify damage to gray and green infrastructure

A GIS allows manipulation of different sets of stored data to assess variations in potential flood impact. For example, a GIS can be used to show how the addition of a flood retention basin might reduce the depth and area of a flood, thereby indicating the efficacy of different levels of flood management interventions. While modeling using a GIS can be complicated, making simple changes to specific data in the GIS (e.g., adding a retention basin) can show the effects of interventions (e.g., a reduction in flow), thereby contributing to decisions on flood management options.

A variety of GIS software packages are available, ranging from free to costly (>$1,000/year) and offering a range of capabilities. Commercial packages such as ESRI ArcGIS™ are most common and provide users with a broad set of extensions and tools, including a flood planning application template and hydrologic modeling. Open-source (free) GIS packages also exist, including GRASS, QGIS and SAGA GIS.[24]

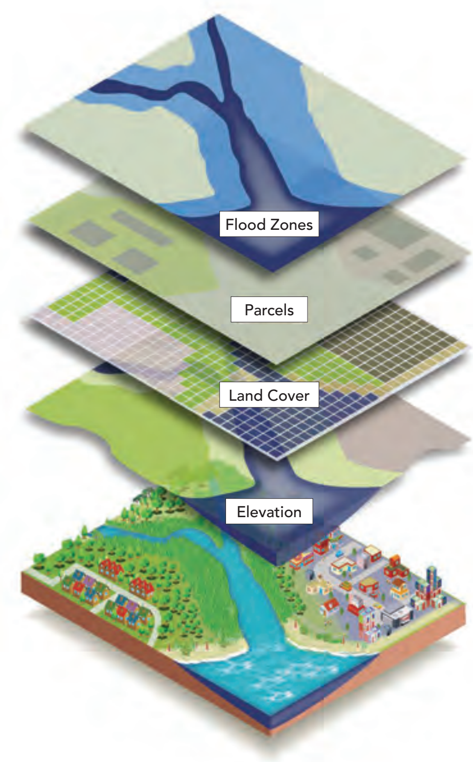


Image courtesy of NOAA

FIGURE 4.1 A SCHEMATIC OF GIS LAYERS USED IN ANALYSIS

24 Sources for open-source operating system software include, for Linux, http://www.linuxmint.com/ and http://www.ubuntu.com/; for Windows, Mac, and Linux, http://www.osgeo.org/.

4.4.4.2 Flood Modeling

Modeling floods involves collecting data on precipitation, **stream flows**, land use and land cover, and other factors; accessing topographic information; and using formulas to project the height and extent of floodwaters under the specific conditions set in the model. An overview of flood modeling can be found in the book *Flood Mapping*, which is available online for free use.[25]

The **rational method** is a simple process to model runoff in urban areas and small watersheds.[26] The model uses data on rainfall intensity, watershed slope, area of the drainage and the nature of the land cover to project peak water discharge at the lower end of the watershed.

While the rational method is not as precise as other, more complex modeling, it provides results that are useful in defining the peak volume (cubic meters per second) of water expected from a watershed for a given level of precipitation. By changing the volume of expected precipitation, different discharge rates can be estimated. While peak discharge alone does not indicate the area that will become flooded, it can be used to determine the maximum capacity requirements for flood channels, drains, and gutters, and the impact of flood retention or diversion.

Instructions on using the rational method are available on the web, particularly from academic courses and in drainage system guidance. "A Study Guide on the Empirical Version of the Rational Method to Estimate Peak Discharge Runoff" provides an overview of the rational method and how it can be applied.[27] More complex flood modeling is appropriate for medium to large watersheds and should be undertaken if there are sufficient resources to hire a hydrologist or through work with a university.

4.4.4.3 Local Weather and Stream-Level Analysis

Local weather and stream level data can be analyzed in a number of ways. A simple but useful approach is to use data collected over the course of a year or more to answer the questions in table 4.1. The answers to these questions provide a basis for identifying possible weather and water level conditions that could lead to flooding. Answers should be updated annually as new data becomes available. To better engage a community in the management of flooding and other climate risks, a monthly report (using charts of the data collected) can be posted near the weather station or in another frequently visited location.

---

25 Associated Programme on Flood Management (APFM), ed., *Flood Mapping*, Integrated Flood Management Tools, no. 20 (Geneva, Switzerland: World Meteorological Organization: Associated Programme on Flood Management, 2013), http://www.apfm.info/publications/tools/APFM_Tool_20.pdf.

26 Gordon Keller and James Sherar, *Low-Volume Roads Engineering: Best Management Practices Field Guide* (Washington, DC: USAID, 2003), http://pdf.usaid.gov/pdf_docs/Pnadb595.pdf.

27 Bruce Carey, "A Study Guide on the Empirical Version of the Rational Method to Estimate Peak Discharge Runoff," July 2014, http://landcare.org.au/wp-content/uploads/2013/01/Empirical-version-of-the-Rational-method-to-estimate-peak-discharge-Runoff.pdf.

TABLE 4.1 QUESTIONS TO GUIDE A SIMPLE WEATHER AND STREAM-LEVEL DATA ANALYSIS	
QUESTION	**IMPLICATION**
When (which months, days) during the year does the most precipitation fall?	Knowing peak precipitation times helps identify times of year when flooding is possible.
When (which months, days) during the year are river/stream levels the highest?	Knowing when river/stream levels are the highest helps identify when flooding is possible.
Do periods of high precipitation and high river/stream levels occur at the same time, or close to the same time, during the day?	Knowing whether precipitation and high river/stream levels occur near the same time helps identify when flooding may occur due to precipitation.
Do periods of high temperature and high river/stream levels occur at the same time, or close to the same time?	Knowing whether high temperature and high river/stream levels and flooding occur near the same time helps identify when flooding may occur due to high temperatures (e.g., from the melting of snow or ice).
Do periods of high wind speeds and high river/stream levels occur at the same time, or close to the same time?	High winds are often associated with storms that can trigger heavy precipitation. Knowing whether high wind speeds and high river/stream levels occur near the same time helps identify when flooding may occur due to storms that may not occur where the data is being collected.

4.5 CHARACTERIZING THE WATERSHED

The guide recommends that managers understand the basic features of a watershed (see chapter 3). Knowing these features, and being able to compare the features to those in other watersheds, helps build understanding of what causes floods and the measures required to manage them.

Very large watersheds may require breaking down the characterization by sub-watershed (e.g., upper elevation, lower elevation), especially if there are significant differences in the characteristics throughout the watershed.

A manager can use a range of informational sources to characterize a watershed. (Section 4.4 of this chapter provides an overview of sources.) Mapping (also described in this chapter) is one of the most effective ways to record and present information. In addition, possible sources of information for watershed characterization are identified in the Watershed Characterization table (see Framework Worksheet).

The watershed characterization process involves two steps:

1. Completing the Watershed Characterization table
2. Completing the Watershed Characterization Report

Both steps involve using a map of the watershed to document the information collected.

4.5.1 WATERSHED MAPS

A map of the watershed is needed for both characterization steps (see section 4). The map should be detailed enough to identify key physical aspects of the watershed—including infrastructure and occupied areas, streams, rivers, and other physical features—and have space for making notations. In general, a minimum of two copies of the map are needed: one for completing the Watershed Characterization table and one for the Watershed Characterization Report. (The first map can be considered a working document, and the second should be a more formal presentation of the information collected.)

4.5.2 WATERSHED CHARACTERIZATION TABLE

The Watershed Characterization table (Framework Worksheet , chapter 2) should be completed by those living in the watershed, based on their knowledge and observations, including the key information detailed in chapter 3. While one person familiar with the watershed can complete the table, it is recommended that groups of community members be involved in the process. Specialist input – for instance, from water managers, agricultural stakeholders, natural resource managers and/or forest agents – can also be used to complete the form or add technical details.

The manager completes the table by circling the appropriate answers to the 13 questions in the first column and by adding text. The answers should also be noted where appropriate on the watershed map.

At a minimum, a working map should be attached to the characterization report (see section 4.5.1). The following information should be noted on the map:

- areas of different slope
- soils
- vegetation
- wetlands
- lakes and marshes
- dominant land use
- key infrastructure
- built-up urban areas

The map used for the Watershed Characterization table can provide a focal point for discussions, and users should feel free to revise and change markings and notations over the course of the characterization process.

The table also provides summary information on the implication of different answers or input in terms of flooding and flood management options. (See chapter 5 to learn how these implications can be used in selecting appropriate approaches to managing flooding.)

4.6 ADDITIONAL RESOURCES

1. Associated Programme on Flood Management (APFM). *Flood Mapping*. Integrated Flood Management Tools Series, no. 20, (Geneva: WMO, 2013), http://www.apfm.info/publications/tools/APFM_Tool_20.pdf.
2. Disaster Assessment Portal, http://www.disasterassessment.org/default.asp.
3. International Charter: Space and Major Disasters, https://www.disasterscharter.org.
4. International Fund for Agriculture (IFAD). *Good Practices in Participatory Mapping: A review prepared for the International Fund for Agriculture*, 2009, http://www.ifad.org/pub/map/pm_web.pdf.
5. International Federation of Red Cross and Red Crescent Global Disaster Preparedness Center, PrepareCenter.org, http://preparecenter.org/topics/community-risk-assessment.
6. UNISDR, PreventionWeb, http://www.preventionweb.net/english/professional/trainings-events/edu-materials/?tid=44.
7. UNOSAT (via UNITAR), http://www.unitar.org/unosat/maps.
8. UN-SPIDER, http://www.un-spider.org/links-and-resources/data-sources.
9. USAID, NOAA, SERVIR, https://www.servirglobal.net/default.aspx.
10. USGS, Hazards Data Distribution System (HDDS), http://hddsexplorer.usgs.gov/.

CHAPTER 5

5. STRUCTURAL AND NON-STRUCTURAL METHODS

5.1 SECTION CONTENT

This chapter discusses key structural and non-structural methods for flood risk management (see fig. 5.1). The IFM approach in flood risk management (see chapter 3) goes beyond just implementing hard or soft methods; it includes the entire process of carefully selecting and carrying out the best combination of engineering and natural/nature-based structural and non-structural methods.

Floods happen in a watershed – an area with a variety of intrinsically connected geological, ecological and social components. The success of flood risk management methods depends on their suitability to the nature of the intended interventions, the scale of the intervention, and where in the watershed they are applied.

Table 5.1 (p. 118) gives a framework of selected flood risk management methods based on the type and level of the intended interventions.

Typically, flood risk management objectives broadly fall into three categories based on the nature of interventions:

- **REDUCE, RETAIN AND DETAIN FLOOD FLOWS**
- **IMPROVE CONVEYANCE AND ENHANCE RESISTANCE TO DAMAGE IN WATERWAYS**
- **ADAPT TO FLOODS**

Table 5.1 identifies which methods are applicable to these categories.

Flooding has consequences at multiple levels, including national/regional, watershed, floodplain, community and household. Therefore, methods should be selected based on the specific requirements at different scales (see fig. 5.2).

The Flood Green Guide recommends managers first apply IFM non-structural methods and then, if needed, include structural (hard and or soft) methods as part of an integrated approach. Guide users should note that rarely, if ever, will the use of a single flood management method be helpful. Managers should select methods that will enhance the efficacy of any existing flood risk management methods.

The remainder of this chapter is structured as follows:

Sections 5.2 and 5.3 introduce selected structural and non-structural flood risk management methods, briefly describing important design considerations. Section 5.4 discusses the applicability of different methods based on the flood type and location in the watershed. Sections 5.5 and 5.6 discuss the important considerations in implementation, operation and closure. Section 5.7 compares the benefits of combining different hard and soft methods. Section 5.8 provides guiding information for cost and resource requirements for different methods. Section 5.9 provides an overview of monitoring and evaluation of flood risk management projects.

The guide does not provide specific technical guidance on tasks required in the design and implementation of these methods, such as hydrological studies, feasibility studies, environmental assessment, comprehensive engineering/bioengineering design, cost analysis, project appraisal or construction management. These tasks are specific to the local context and follow established scientific methods; therefore, the guide user should involve a multidisciplinary team, as may be required for the local context, to plan a specific flood risk management project and acquire specialized expertise. The guide will assist the user to identify the expertise and resources required for some of these tasks.

GUIDANCE: Information provided in this chapter should always be used in conjunction with the Flood Green Guide Framework presented in chapter 2.

ADDITIONAL INFORMATION: This figure is used throughout the chapter to indicate whether methods are structural-hard, structural-soft, or non-structural. For example, upper watershed restoration AY1 is the first structural-soft method described.

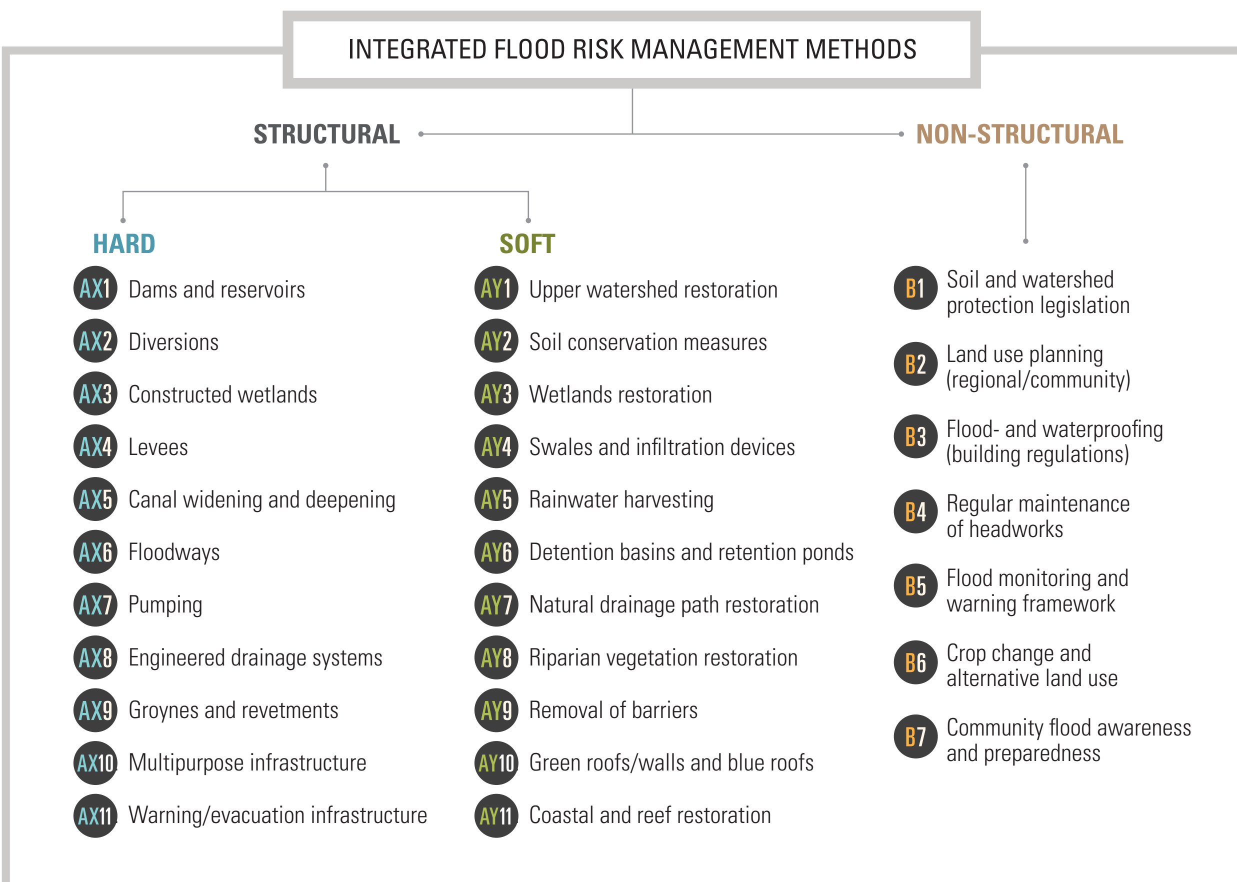
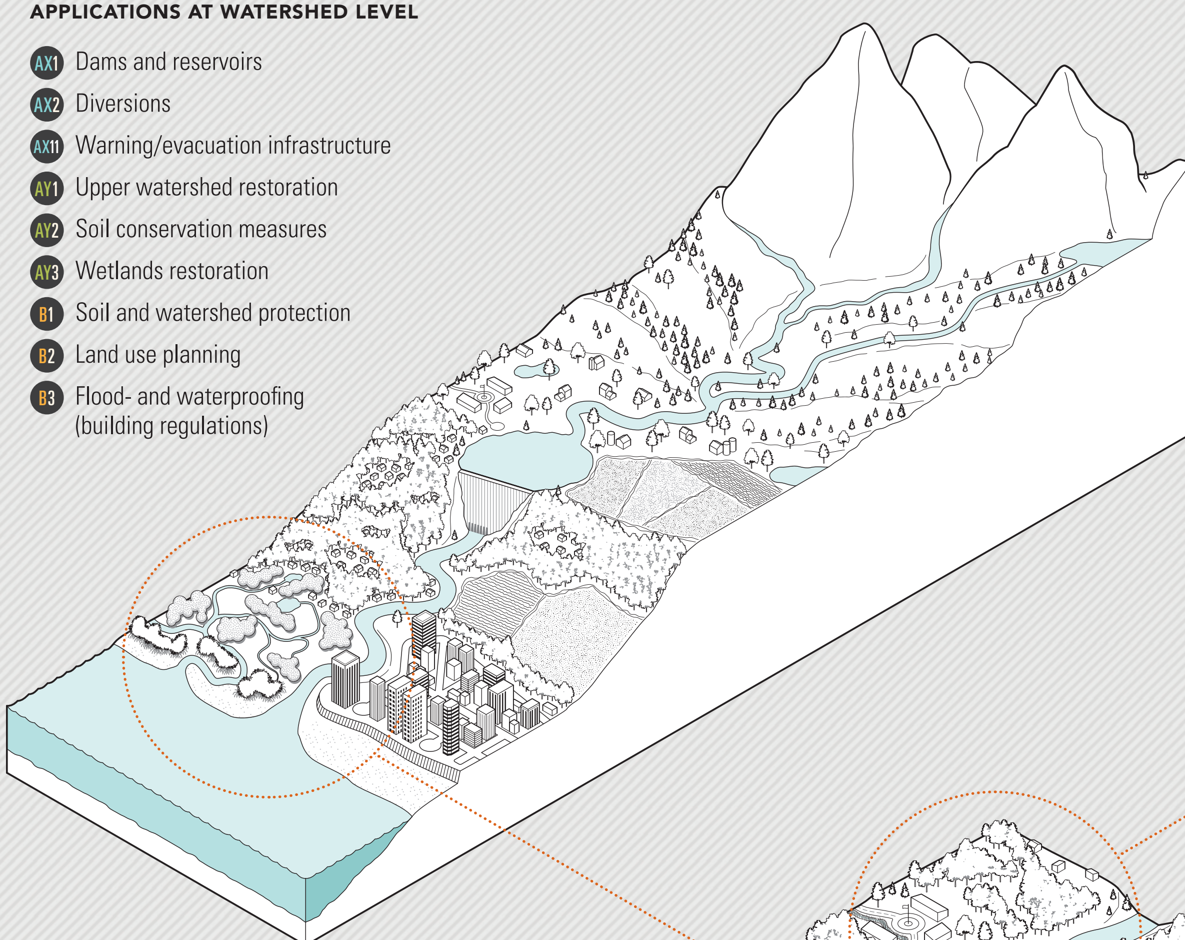


FIGURE 5.1 STRUCTURAL AND NON-STRUCTURAL FLOOD RISK MANAGEMENT METHODS

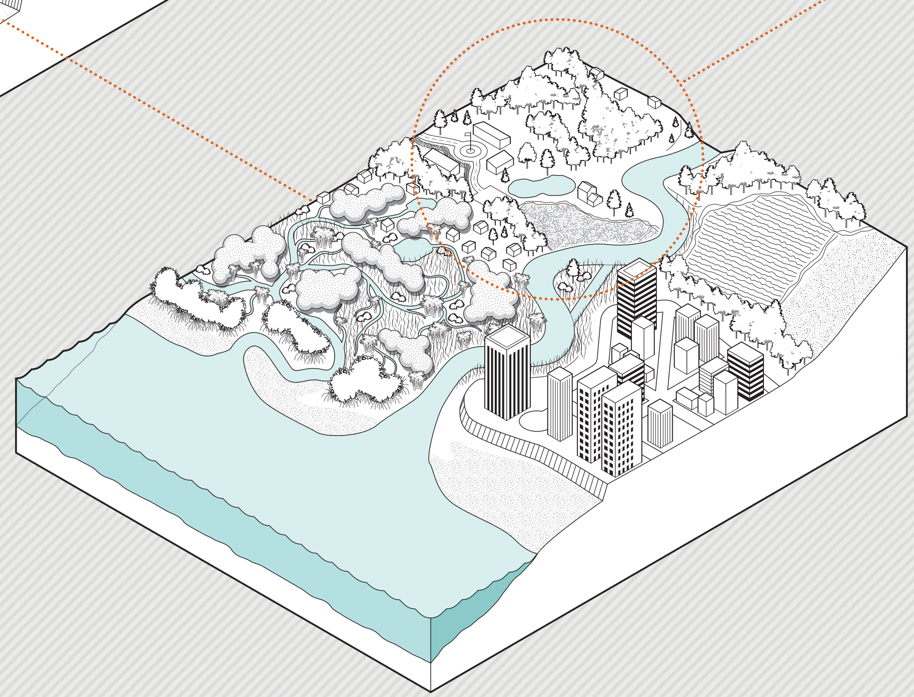
APPLICATIONS AT WATERSHED LEVEL

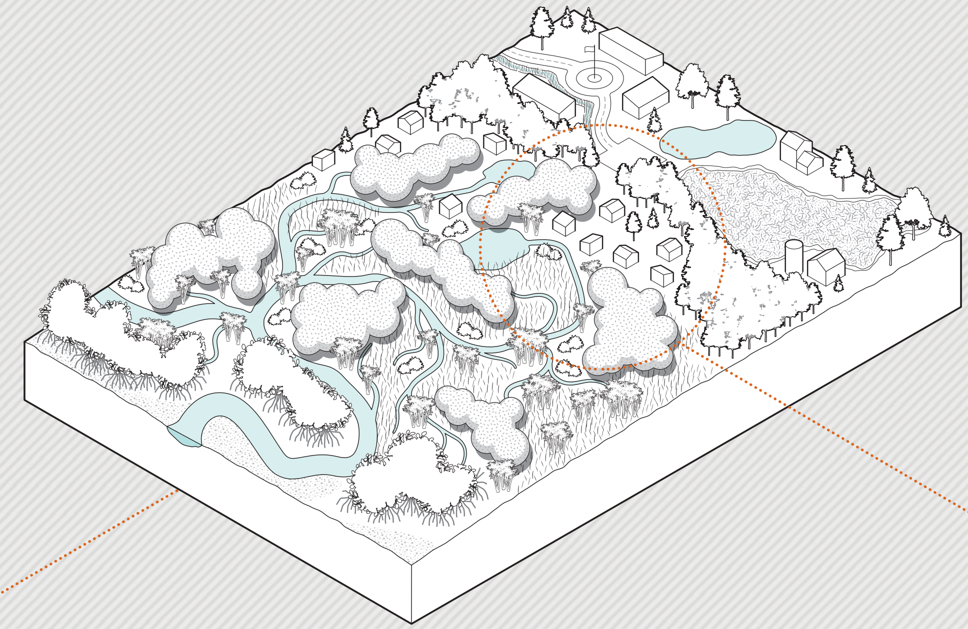
- AX1 Dams and reservoirs
- AX2 Diversions
- AX11 Warning/evacuation infrastructure
- AY1 Upper watershed restoration
- AY2 Soil conservation measures
- AY3 Wetlands restoration
- B1 Soil and watershed protection
- B2 Land use planning
- B3 Flood- and waterproofing (building regulations)



APPLICATIONS AT FLOODPLAIN LEVEL

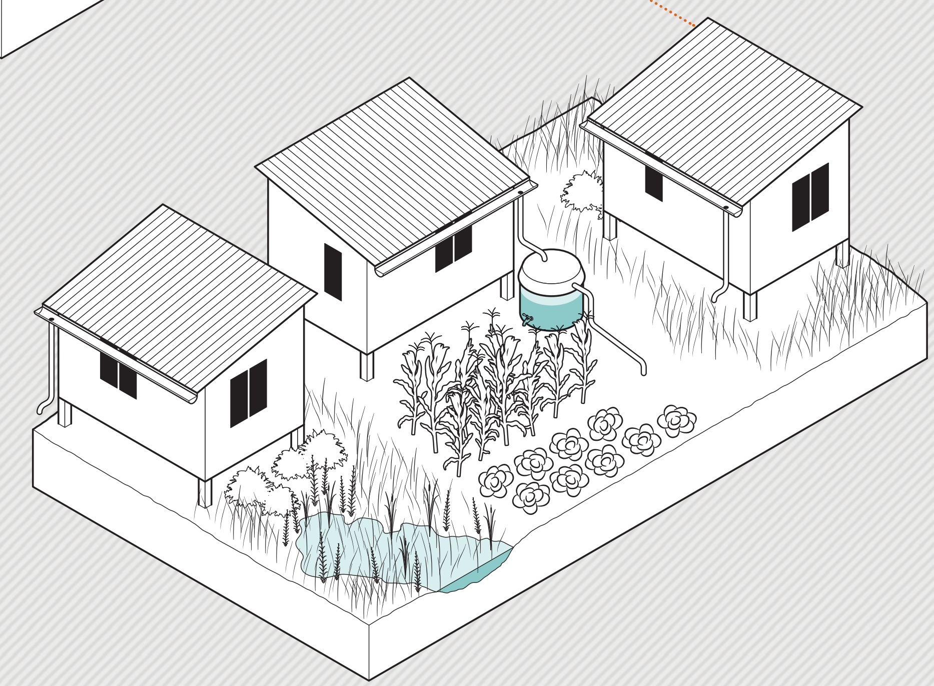
- AX3 Constructed wetlands
- AX4 Levees
- AX5 Canal widening and deepening
- AX6 Floodways
- AX7 Pumping
- AX8 Engineered drainage systems
- AX9 Groynes and revetments
- AX10 Multipurpose infrastructure
- AY6 Detention basins and retention ponds
- AY7 Natural drainage path restoration
- AY8 Riparian vegetation restoration
- AY9 Removal of barriers
- B2 Land use planning
- B4 Regular maintenance of headworks
- B5 Flood monitoring and warning framework
- B7 Community flood awareness and preparedness





APPLICATIONS AT COMMUNITY LEVEL

- AX7 Pumping
- AX10 Multipurpose infrastructure
- AY4 Swales and infiltration devices
- AY5 Rainwater harvesting
- AY6 Detention basins and retention ponds
- AY7 Natural drainage path restoration
- AY8 Riparian vegetation restoration
- B2 Land use planning
- B3 Flood- and waterproofing (building regulations)
- B6 Crop change and alternative land use
- B7 Community flood awareness and preparedness



APPLICATIONS AT HOUSEHOLD LEVEL

- AY4 Swales and infiltration devices
- AY5 Rainwater harvesting
- B3 Flood- and waterproofing (building regulations)
- B7 Community flood awareness and preparedness

FIGURE 5.2 SCALE OF APPLICATION OF STRUCTURAL AND NON-STRUCTURAL METHODS

FLOOD GREEN GUIDE SCALE OF APPLICATION OF STRUCTURAL AND NON-STRUCTURAL METHODS

USAID FROM THE AMERICAN PEOPLE

WWF

World Wildlife Fund. 2016. Natural and Nature-based Flood Management: A Green Guide. Washington, DC: World Wildlife Fund. http://envirodm.org/flood-management

5.2 STRUCTURAL METHODS

For thousands of years, civilizations have used structural methods for flood risk management. Ancient flood embankments dating from around 1000 BCE can be found in certain reaches of the Nile River.[1] The earliest settlers in the Indus and Ganges plains of India (2500 BCE) used such deterrents as ring bunds – or low walls along the contours of hills – to protect from flooding.[2] The agrarian revolutions and the expansion of urban settlements in the 19th century drove engineers to develop a systematic approach to structural flood risk management methods – commonly known as flood control and drainage engineering. Structural flood risk management involved both engineering interventions (hard engineering), such as flood embankments and dams, and ecological interventions (soft methods), such as soil conservation and wetland restoration (also known as natural and nature-based methods). Integrated flood management (IFM) gives equal attention to hard, soft and non-structural methods.

WARNING: Periodic inspection, maintenance, cleaning and repair of hard engineering structures are critical to stability of the structure. Significant functional and safety issues are possible if the integrity and proper functioning of these systems are compromised.

In this chapter, the structural methods are discussed under three flood risk management objectives (table 5.1):

- **REDUCE, RETAIN AND DETAIN FLOOD FLOWS**
- **IMPROVE CONVEYANCE AND ENHANCE RESISTANCE TO DAMAGE IN WATERWAYS**
- **ADAPT TO FLOODS**

5.2.1 METHODS FOR REDUCING, RETAINING, DETAINING FLOOD FLOWS

The first category of **structural flood risk management** interventions is reducing, holding (retaining) or delaying (detaining) the inflow (flood flow) of water. Conventionally, these methods are designed to handle a flood event of a given magnitude – normally referred to as **design flood** – statistically determined to occur once in a certain number of years, called the **return period**. However, managers should note that when uncertainties due to climate change and climate variability are considered, strictly abiding by such probabilistic norms (which assume a stationary climate) to select and design the methods may reduce their effectiveness. Therefore, provisions for uncertainties should be made, as discussed in chapters 3 and 4. In floods caused by precipitation (refer to appendix A, Flood Typology), a maximum flow, known as the **flood peak** (fig. 5.3), occurs during or after the precipitation event. The time between the start of the event and its peak is called **lag time** (also referred to as basin lag). Most of the methods described in sections 5.2.1.1 and 5.2.1.2 are designed to reduce the flood peak and increase the lag time.

---

1 Douglas J. Brewer, *Ancient Egypt: Foundations of a Civilization* (New York: Routledge, 2014).

2 A. L. Basham, *The Wonder That Was India*, 3rd ed. (New Delhi: Pan McMillen, 2014).

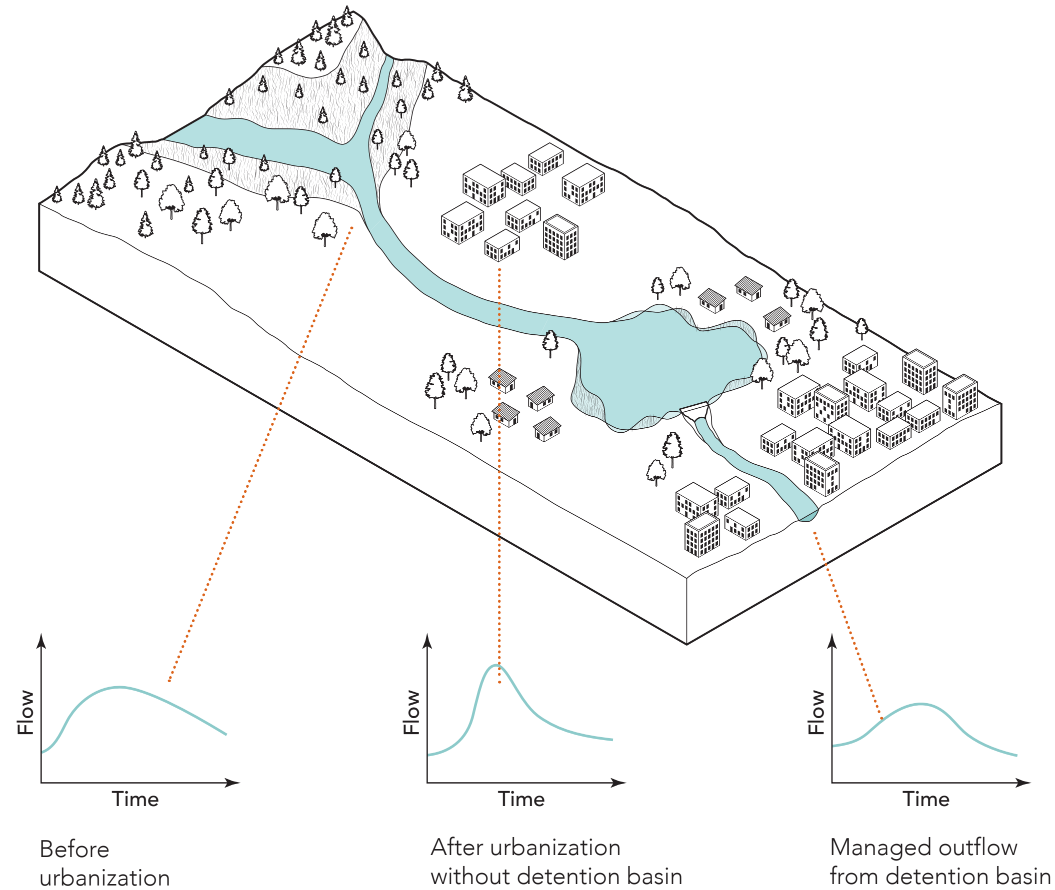


FIGURE 5.3 HOW THE FLOOD PEAK AND LAG TIME CHANGE WITH STRUCTURAL FLOOD RISK MANAGEMENT METHODS THAT REDUCE, RETAIN OR DETAIN THE FLOOD FLOWS

5.2.1.1 Hard Engineering Methods

DAMS AND RESERVOIRS AX1

A flood control reservoir is a widely used flood risk management method to retain floodwater by temporary storage. Water can be detained for a short period (a few days) or retained long term for other purposes, such as irrigation or hydroelectricity generation. Normally, a reservoir is created by building a dam across a main waterway. To manage riverine floods, managers can build watershed dams in lower, narrow points upstream of the floodplain or the target area. Dam types vary based on the structure and type of construction material (earth, concrete, rocks, wood, steel). The dam holds water up to a particular height, forcing an area upstream to be inundated, thus creating the reservoir. The stored water is then released by a pipe, tunnel or gate at the bottom of the dam (fig. 5.4).

WARNING: Dams only protect a small area within the given floodplain from frequent floods and carry the risk of dam failure, which can be catastrophic. Dams can increase the flood risk in other areas and can be extremely disruptive to the river ecosystem process. Thus the Flood Green Guide does not encourage dams to be considered as a viable solution in flood risk management. We include dam information here because they are commonly found in many countries and thus may need to be addressed.

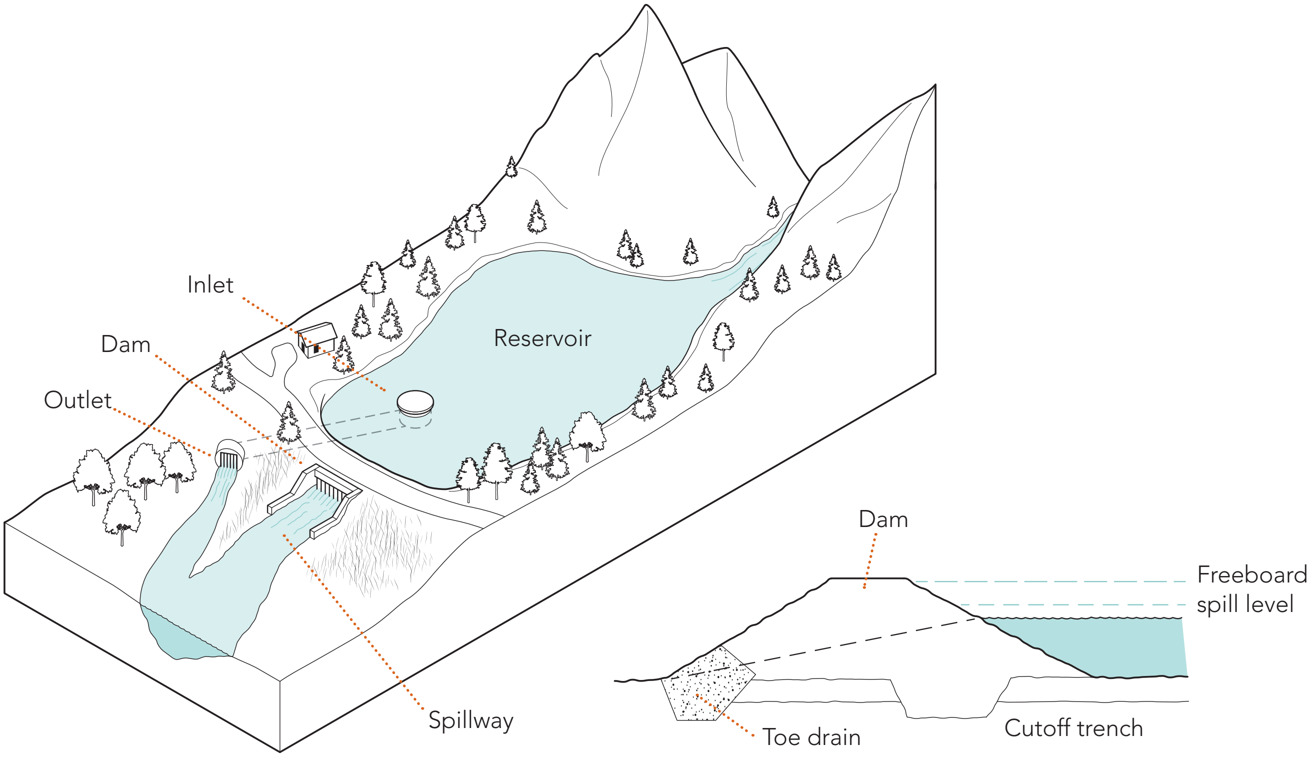


FIGURE 5.4 A GENERIC LAYOUT AND CROSS SECTION OF A SMALL DAM

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Reduce the flood peak and increase the lag time by storing water.

Main components: Dam, inlet, sluice/outlet, **spillway**, gates (optional).

Functionality: The size of a dam (and a reservoir) is determined by the volume of water (e.g., cubic meters or acre-feet) it stores during a storm event. The larger the storage, the more capable a reservoir will be in reducing the flood peak and increasing the lag time. This storage volume corresponds directly to the height (spill level) of the dam (fig. 5.4). In a storm event where inflow exceeds the designed storage volume, excess water has to be spilled from the dam using a spillway. A dam should have a carefully designed outlet structure (outlet pipe, sluice gate, tunnel) to regulate and release water regularly, and also to empty the reservoir if required. As the dam height increases, it puts massive pressure on the dam at its base. Therefore, structural design of the dam is very important for its functionality and safety. This includes selecting the proper foundation type and material for dam construction (soil, rock fill, concrete, steel, wood) and size. Regardless of the size, the dam foundation and construction materials should be carefully selected and designed to withstand the water pressure.

Safety: If the water **spills over** the dam or significantly seeps under it, the dam may fail. Therefore, three safety measures are advised in design. First, an additional height called the freeboard can be added to the spill level in determining the dam height (fig. 5.4). Second, the spillways should be carefully sized to allow effective spilling. Third, measures should be taken to prevent large quantities of water from seeping beneath the dam. There can be major safety issues and a dam breach due to inappropriate design, construction, and maintenance. Also, if design flow is exceeded, there can be catastrophic results. Periodic inspection and repair are required to ensure stability.

DIVERSIONS AX2

Diversion devices divert some of the flood flow away from a floodplain into a nearby floodplain or a watershed. For example, a weir or **barrage** built across a river can divert some of the water from its natural course, reducing the risk of downstream floods. A **weir** is a static structure that blocks the flow in a stream. Barrages are similar but have gates to control the flow. Diversion is useful in watersheds too small for reservoirs or when there is a nearby watershed with less flood intensity. Diversion devices are also useful in managing tidal floods and diverting rising tidal water away from human settlements to a nearby wetland or lowland.

IMPORTANT DESIGN CONSIDERATIONS

Design objective: Reduce the flood peak by diverting part of the inflow into a floodplain.

Main components: Weir, intake/inlet, diversion canal/tunnel, gates (optional).

Functionality: A diversion structure (for flood abatement) is designed based on the flow that has to be diverted from the floodplain (as a portion of the design flood). The diverted flow can be changed by changing the height of the weir and also by altering the size of the intake. A weir will reduce the velocity of the water and cause minor upstream impoundment, which should be considered in design. Weirs (or barrages) are designed to spill, but over the top or through the structure, and are sometimes controlled by gates built into the structure. Weir type and gate type (if applicable) have to be carefully selected and designed. Structural design of the weir is very important for both functionality and safety.

Safety: The strength of the foundation and durability of materials used for the weir/barrage are the main safety considerations in design. Breach of a weir/barrage may cause serious damage to communities.

CONSTRUCTED WETLANDS AX3

A **wetland** is an ecosystem in which the soil is permanently or intermittently saturated (or inundated) with water and has vegetation that tolerates high moisture levels.[3] Wetlands are often found as transitional ecosystems between terrestrial and aquatic ecosystems, and serve to regulate hydrological flows. They frequently retain and detain flood flows and stormwater. Wetlands gradually release water into the downstream ecosystems (sea, rivers and groundwater aquifers) and do not need sluices or spillways; wetlands can also handle more flow variability over time. The time that a unit volume of water is retained in a wetland before being released to downstream ecosystems is known as the **retention time**. In addition to detaining and retaining water, wetlands can improve the water quality. This is an added advantage in stormwater scenarios, where contaminated water from urban/agricultural areas is released to downstream aquatic ecosystems.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Reduce the flood peak and increase lag time by detaining floodwater.

Main components: Controls (inlet, outlet, gates/valves), bunds, substrate, vegetation.

3 W. J. Mitsch and J. G. Gosselink, *Wetlands*, 4th ed. (Hoboken, NJ: John Wiley and Sons, 2007).

Functionality: Stormwater management wetlands are designed to provide the maximum retention time. The retention time corresponds to the area of the wetland and its water-holding capacity. Water-holding capacity is a complex function of the porosity of soil, vegetation and microtopography of the wetland. The flow pattern is also an important design parameter. In a wetland, water can flow above the soil substrate (surface flow wetlands), through the soil (subsurface flow wetlands), or both. In flood management, a mixed flow is important, as it allows more storage and a slow release. However, contaminants are more effectively retained by the soil substrate and the plant roots in subsurface flow wetlands.

Safety: To enhance safety, the design should incorporate an optimum retention time that will not allow stagnation, vector breeding or eutrophication.

In cases where the natural wetlands have been destroyed or damaged, managers can create wetlands (constructed wetlands) as a flood management method. **Polders** are similar to wetlands but are created by building dikes around subsided land. Wetlands and polders can be constructed to receive stormwater along a river, upstream of an estuary, or in an urban/agricultural area. It may take several years for a constructed wetland to become fully functional and able to provide ecosystem services such as flood management.[4]

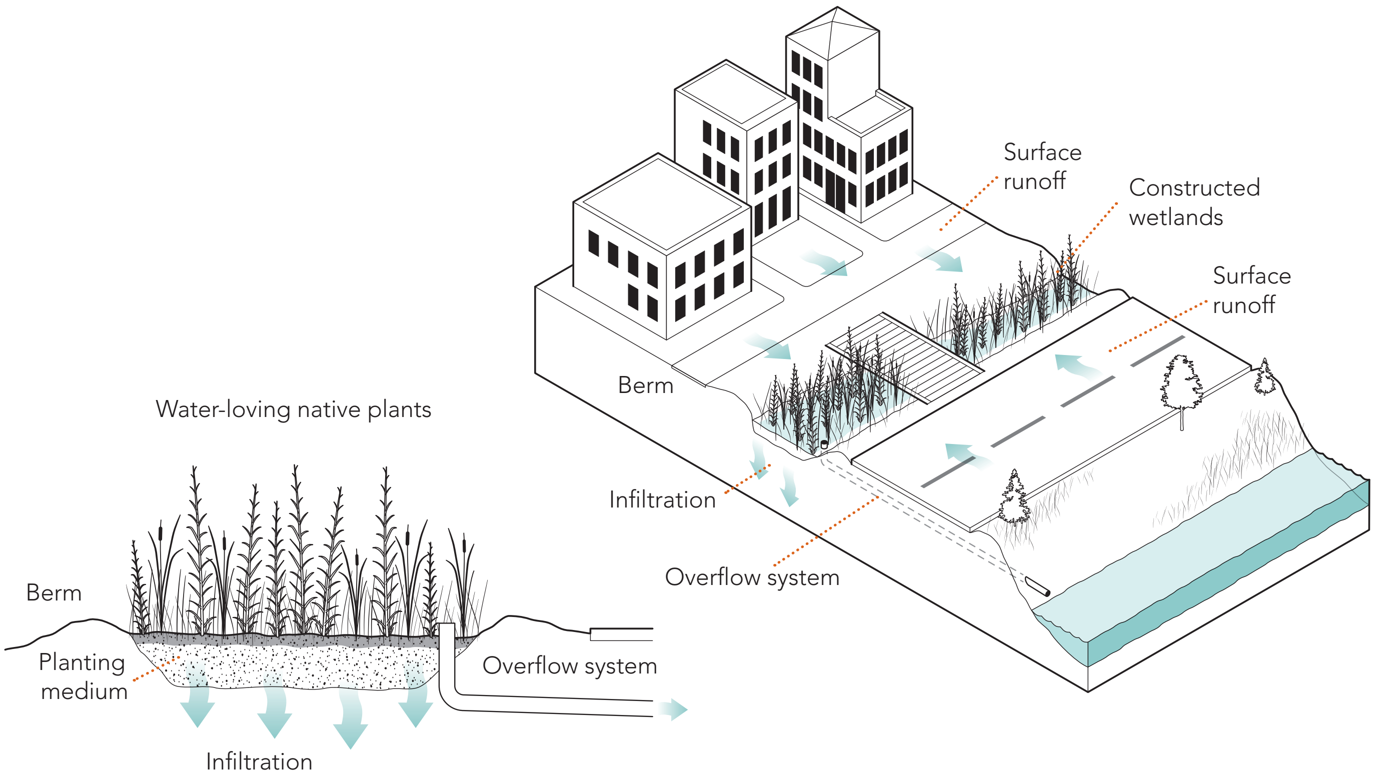


FIGURE 5.5 A TYPICAL CONSTRUCTED WETLAND DESIGN

4 Ibid.

5.2.1.2 Soft Measures

UPPER WATERSHED RESTORATION AND SOIL CONSERVATION MEASURES AY1 AY2

As discussed in chapter 3, when a watershed receives precipitation, a portion of that water will not reach the ground, due to evaporation and interception by vegetation. Another significant portion of water infiltrates the ground, without flowing as runoff to surface waterways. This infiltrated water is then released slowly to streams, lakes or wetlands as groundwater (**base flow**). Downstream flood risk can be reduced if managers can ensure optimum interception and infiltration are maintained in the upper part of a watershed and runoff is reduced.

Managers can use a number of techniques for climate-informed watershed restoration and **soil conservation**. These techniques include providing more leaf surface area for interception, enhancing ground infiltration, and reducing the velocity of water. The most common approach, **revegetation**, restores natural vegetation cover in the area and is especially effective where natural vegetation was at one time cleared for plantations – such as tea, coffee and oil palm. Restoration can encompass an entire area, like a decommissioned plantation, or strategic sections, like natural gullies, to achieve maximum infiltration or velocity reduction (fig. 5.6). Revegetation can be used in conjunction with soil erosion and slope stabilization solutions, such as terracing and erosion barriers (fig. 5.6), especially in hilly areas. These new plantings also might provide useful forest products, firewood, fodder or even timber. Tall trees with lush foliage increase interception of water; low plants help infiltration and reduce water velocity. The best approach is a natural combination of trees and undergrowth with species that will tolerate anticipated climate changes. (For more information on addressing climate change, see chapters 3 and 4).

Managers also can use soil bioengineering techniques for watershed restoration and soil conservation. Soil bioengineering is a sub-discipline of civil engineering in which living material (mainly plants) is used for near-natural construction and to complement conventional methods for slope and embankment stabilization and erosion control.[5] Several well-established soil bioengineering techniques, such as bush-layering, live crib walls and erosion control blankets, exist.[6]

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Reduce the runoff by increasing infiltration and base flow (fig. 5.6).

Main components: Vegetation, erosion control structures, bioengineering features, drainage.

Functionality: Watershed restoration projects (for flood management) are designed to achieve improved infiltration – for example, a proportion of a unit precipitation that infiltrates the ground without flowing as runoff. Decreasing the erosivity – measure of vulnerability of soil to erosion – is also often considered in the design. When physical features such as terraces or soil bioengineering features are used for erosion control, their spacing, sizing, structural design and construction material should be selected very carefully (fig. 5.6).

Revegetation should be carefully planned to avoid changing the natural habitat (e.g., grasslands to forest). Sections or strategic locations, however, may be converted with care. A well-designed revegetated area should not require extensive watering or fertilizer. Avoid using exotic, fast-growing ground-covering plants at all times (e.g., Wadelia [*Sphagneticola trilobata*], Guinea grass [*Megathyrsus maximus*]) because they can become invasive and ultimately interfere with flood risk

5 Donald H. Gray and Robbin B. Sotir, Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control, (New York: John Wiley and Sons, 1996).

6 L. Lewis, Soil Bioengineering an Alternative for Roadside Management: A Practical Guide, (San Dimas, CA: USDA, 2000).

management objectives. Though some exotic trees may be suitable, avoid revegetation with fast-growing timber-rich tree species like eucalyptus and pine in habitats where they are not native.

Safety: Safety parameters are not critical in revegetation. However, collapsing of physical features (e.g., benches, walls) can cause safety issues; therefore, proper structural design is essential.

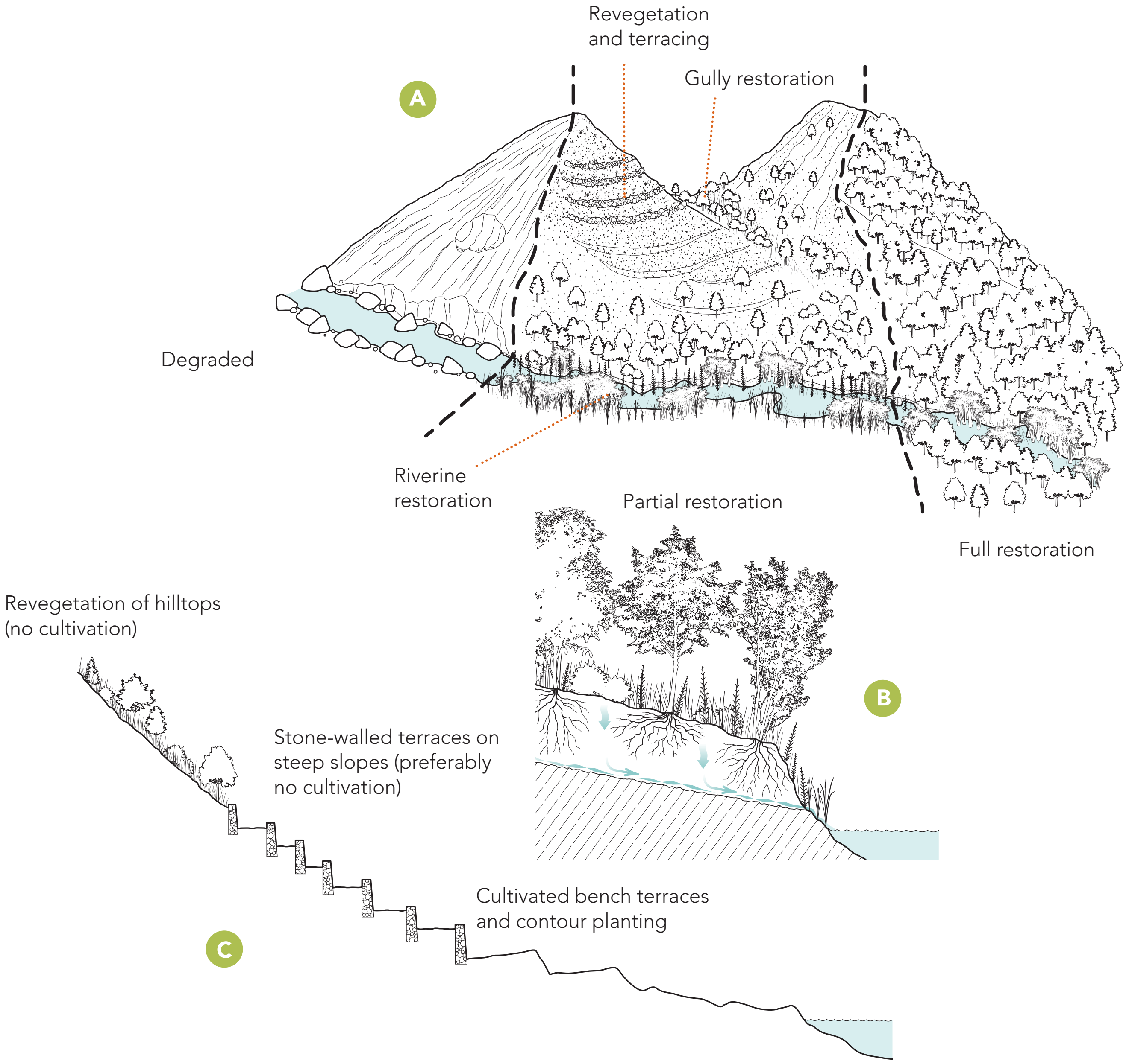


FIGURE 5.6 UPPER WATERSHED CONSERVATION: (A) TECHNIQUES APPLIED IN DIFFERENT SCALES AND LOCATIONS IN A TYPICAL UPPER WATERSHED LANDSCAPE, (B) CROSS SECTION OF A REVEGETATED AREA, (C) SOME LOW-COST SOIL CONSERVATION MEASURES

WETLAND RESTORATION AY3

As discussed in Constructed Wetlands AX3, natural wetlands in a floodplain can act as a sponge to store floodwaters and filter pollutants. Wetlands can reduce water velocity and detain runoff, thereby helping to reduce flash floods and storm surge. Especially in paved urban areas with low infiltration and higher-velocity runoff, wetlands can detain stormwater and minimize localized floods. A range of natural wetland types can be found in different parts of a watershed.[7] Some of these include the following:

- **Marshes:** Common in floodplain areas near the lower reaches of a river; characterized by low grassy vegetation and peaty soil that can hold very large amounts of water.
- **Estuarine or tidal wetlands:** Reed beds, salt marshes, mangroves or mudflats at a river mouth or landside of a lagoon; can provide protection from tidal floods.
- **Riverine wetlands and forested wetlands:** Wooded or shrub areas immediate to a river; can absorb small increases in flow and prevent localized floods.
- **Shallow lakes and ponds:** Occur in depression areas of a landscape; can act as a reservoir during a storm and release water slowly to the aquifer or natural waterways; important in urban or agricultural areas to regulate overland floods.

A wetland is degraded when it loses its characteristic vegetation and soil properties or when it is converted into non-wetland use (e.g., a built-up area or pasture). Vegetation and soil properties can change due to activities such as altering the water paths of a wetland (e.g., building canals or ditches), untreated **wastewater** disposal, excessive siltation, or clearing vegetation. When a wetland is degraded, water depth, vegetation and soil properties can change and may reduce its ability to absorb or detain water. The common symptoms of wetland degradation are

- transformation of vegetation patterns (e.g., marshes to shrubs)
- sediment buildup
- frequent and sudden water level change
- algal blooms
- proliferation of invasive or exotic species

Wetland restoration is the process of supporting the wetland to regain its health and function, thereby restoring its ability to contribute to flood management. Restoring a natural wetland involves reestablishing both its extent and ecological functions by removing the non-wetland features and recreating portions of the wetland that were lost. This may include excavation, removal of hydraulic structures, clearing of invasive and non-wetland vegetation, diversion of polluted runoff away from the wetland, and flooding some sections. Because wetlands are multifunctional ecosystems, their restoration can lead to multiple social benefits, including recreation, fishing, and the production of reeds, fodder and fruits that can be harvested.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Enhance the water-holding capacity of the wetland and restore its ecological functions (fig. 5.7).

Main components: Restored wetland, fencing, bunds, hydraulic control structures, paths.

7 Definitions are adopted from the US Fish and Wildlife Service, Ramsar Convention and the US Army Corps of Engineers and simplified for the purpose of this guide.

Functionality: In wetland restoration, it is impossible to assign a simple set of denominators for water-holding capacity. Generally, qualitative improvement of the habitat as a whole is more important than a quantitative increase in water-holding capacity. Generally, wetland restoration planning is the first step to remove the causes of degradation (pollution sources, filled-up areas, invasive species) and let the wetland regenerate naturally. However, in highly degraded wetlands, carefully planned replanting and reintroduction of fauna might be required. Improvement is evaluated with a range of ecological indicators, including hydrological patterns, water quality, percentage of invasive species, percentage of obligate wetland species, and soil properties. Because the plant and animal species associated with wetlands help mitigate flood damage, wetland restoration design should include plans for reestablishing natural vegetation, animal paths, and spawning and nesting locations.

Safety: Safety parameters are not critical in wetland restoration. However, steps should be taken to manage vector breeding when applied in urban areas.

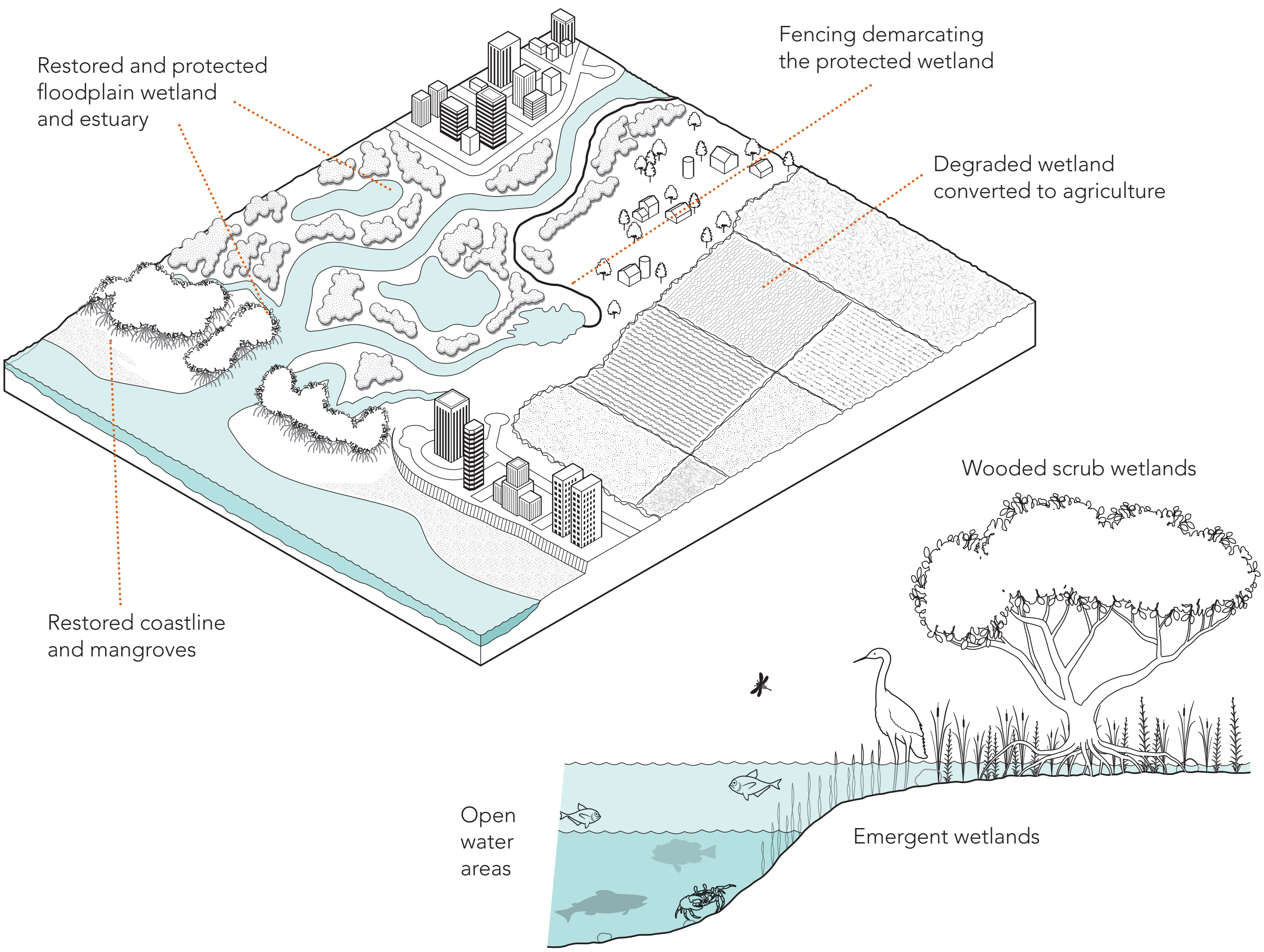


FIGURE 5.7 WETLANDS RESTORATION IN LOWER REACHES OF A WATERSHED AND CROSS SECTION OF WETLANDS

SWALES AND INFILTRATION DEVICES AY4

Swales and infiltration devices are used to increase infiltration of stormwater into the ground and slowly release it into drainage systems. These methods can also filter stormwater by trapping pollutants.

Infiltration devices: Soakways, infiltration trenches, filter drains and infiltration basins receive water from impermeable surfaces such as roofs and car parks. They help maximize the infiltration of water into the ground before it reaches engineered drainage systems. These devices can be designed and constructed with minimal technical expertise.

Permeable pavements: Any type of pavement that allows partial infiltration of water through a porous paving material or gaps between paving blocks (fig. 5.8) is designated permeable. Managers can use this method in car parks, driveways and lightly trafficked roads. The water can either infiltrate the ground or be collected in a sand bed beneath the pavement and allowed to flow very slowly into the drains (fig. 5.8).

Rain gardens, swales and filter strips: Vegetated channels or strips that allow infiltration, conveyance and storage of stormwater (fig. 5.8). Managers generally use rain gardens in household plots, swales on roadsides, and filter strips in more open landscapes.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Enhance infiltration and detain water from a storm event to reduce flood peak and increase lag time.

Main components: Vegetation, permeable surface or pavement, porous substrate, underdrains, geotextiles.

Functionality: All these devices are designed to enhance the infiltration rate and achieve optimum temporary storage capacity to reduce stormwater flowing into drainage systems as runoff. Sizing and choice of materials for these devices should be selected to optimize temporary retention/storage, infiltration and controlled conveyance to drainage systems. Where vegetation is used, plants also should be selected to increase infiltration, **evapotranspiration** and bioretention of pollutants. Plants should be selected carefully to avoid invasive species or species that require extensive watering, fertilizer or frequent pruning and weeding.

Safety: Since all these features are constructed in open or public spaces, managing vector breeding is an important safety measure in design.

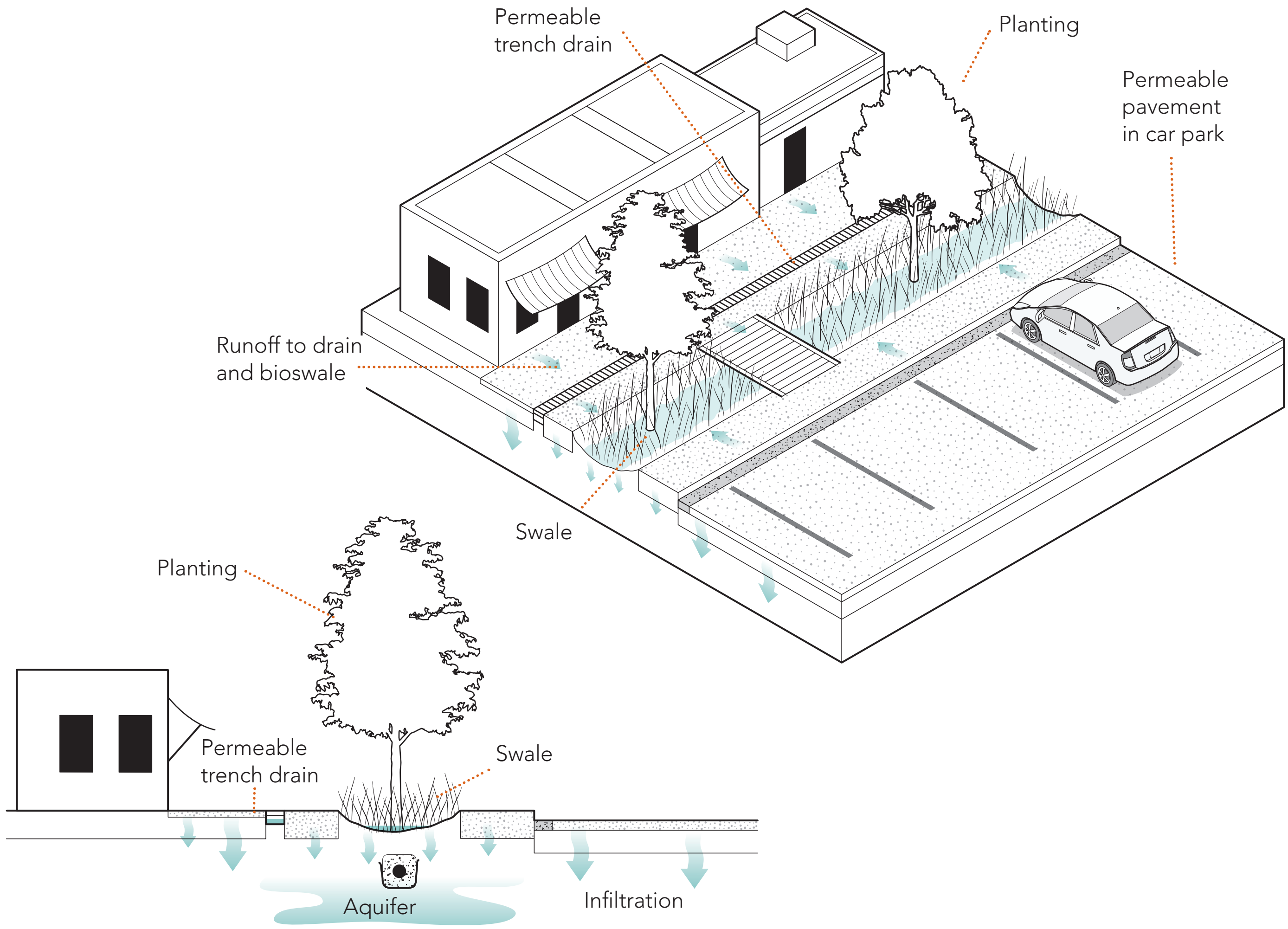


FIGURE 5.8 SWALES, PERMEABLE PAVEMENTS AND INFILTRATION DEVICES

RAINWATER HARVESTING AY5

Rainwater harvesting can be used to reduce flood peak (stormwater peak) and lag time. Rainwater collected from the roof of a building is stored in a tank and used for regular household purposes (fig. 5.9). Usually a gutter or rooftop gully collects the rainwater and conveys it to an above-ground or underground tank. An above-ground tank allows water to be easily distributed by pipes, while an underground tank saves space in small household compounds.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Reduce runoff from household plots by temporary storage and use.

Main components: Roof collection system, rainwater tank, distribution system.

Functionality: In designing rainwater harvesting systems, the storage capacity of the rainwater tank is the most important design consideration (fig. 5.9). Capacity should be decided based on the volume of water to be retained in a given storm event and the amount of rainwater required for household use. To ensure good functionality, systems should be designed with a proper roof collection system (roof plumbing), use proper materials for the tank (plastic, ferro-cement, concrete, brick), and include plumbing for distribution.

Safety: Tank strength and stability are important safety concerns with a rainwater harvesting system. Collapse of an above-ground or underground tank may cause serious damage to humans as well as adjacent structures. Furthermore, it is important to ensure the quality of captured water if it is meant to be used for household purposes. Some systems use nets and filter to prevent solids from getting into the tank. Some designs allow diversion of the first flush (water from the first few minutes of a rainfall) to ensure better water quality. Steps should be taken to manage vector breeding in above-ground collection systems.

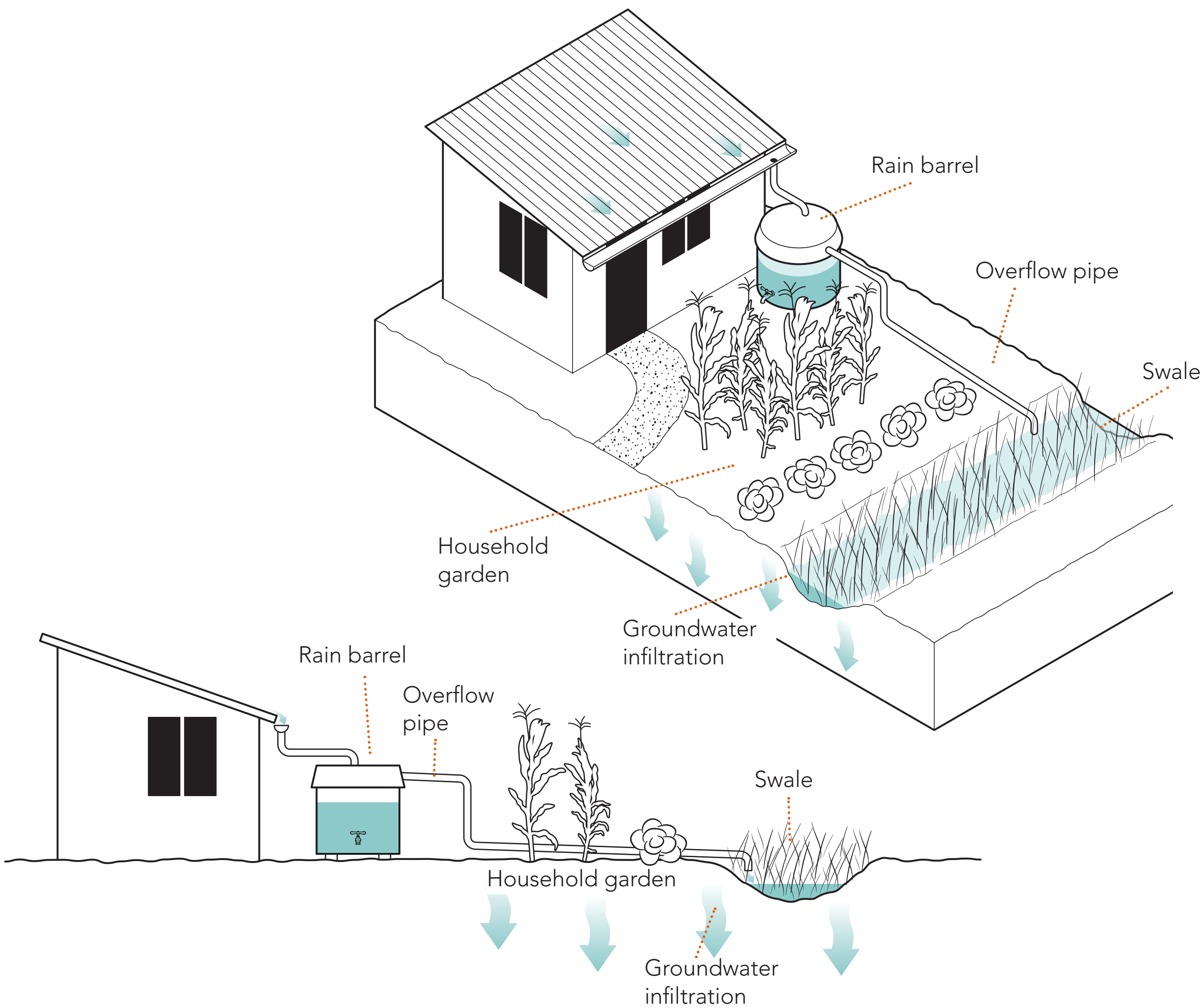


FIGURE 5.9 RAINWATER HARVESTING AND RAIN GARDENS AT THE HOUSEHOLD LEVEL

DETENTION BASINS AND RETENTION PONDS AY6

Detention basins are natural depressions or developed open spaces (e.g., car parks) in the landscape that can temporarily hold stormwater and then release it slowly through a controlled outflow (fig. 5.10). This will control runoff into downstream drains or waterways and reduce the flood risk. Detention basins are not meant for permanent impoundment.

Retention ponds, on the other hand, hold water permanently and detain additional flows during a storm. Typically, the water level in the ponds will drop during dry periods due to evaporation. The ponds also have the added advantage of trapping silt. In urban catchments, retention ponds can also be used for recreation.

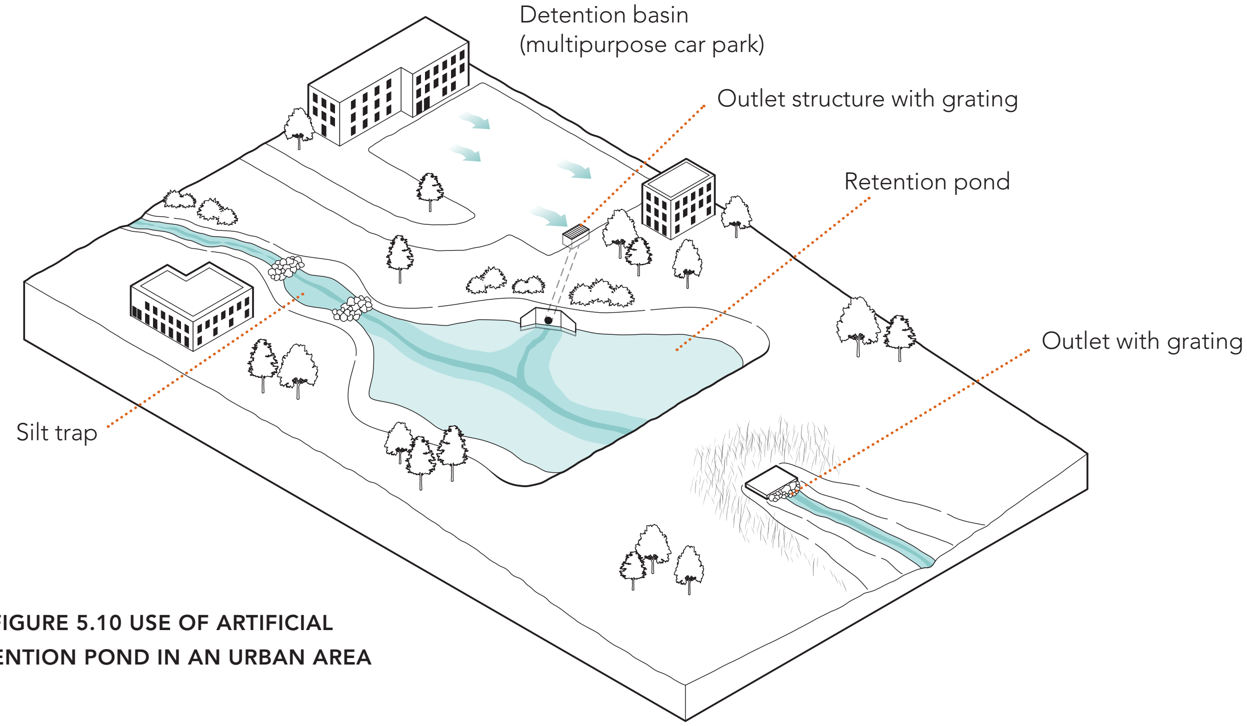


FIGURE 5.10 USE OF ARTIFICIAL RETENTION POND IN AN URBAN AREA

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Temporary storage of stormwater to reduce stormwater peak and lag time.

Main components: Pond/basin, outlet structure and pipe, grill, bund/weir (retention ponds only), silt trap (retention ponds only).

Functionality: Both detention basins and retention ponds are designed to have adequate storage volume and to substantially reduce the flood peak based on runoff generated in the sub-catchment during a design storm and the discharge rate from the pond or basin. Most basins and ponds are designed to be fully discharged within less than one day. A retention pond should have a gate or a valve to let out water from the bottom. Ponds should be periodically emptied for cleaning and desilting.

Safety: The main safety concern in ponds and basins is the risk of localized flooding. Because they hold stormwater in one place in order to reduce flood risk in another, they may **overflow** and cause unanticipated local floods if not properly designed and managed. The possibility of vector breeding is a safety issue in retention ponds.

A green roof in Western Cape, South Africa.

A vertical garden, or green wall, also known as a biowall.

GREEN ROOFS/WALLS AND BLUE ROOFS AY10

Green roofs and walls, and blue roofs, are designed to temporarily retain water from local storm events and reduce **stormwater runoff**. Green roofs and walls can improve local air quality, improve a building's energy efficiency, and reduce the **urban heat island** (UHI) effect through **evapotranspiration**.

Green roofs: Green roofs consist of vegetation, a growing medium, drainage materials, and a waterproof membrane on top of a roof system.[8] The two main types of green roof systems in common use are extensive and intensive. An extensive green roof has a soil depth of 7-15 cm (3-6 inches), is lightweight at 73-244 kg/m² (15-50 lb/ft²), consists of only 10%–20% organic matter in soil, has limited plant species options, and requires few, if any, structural adjustments to the roof.[9] Green roofs require lower maintenance, nutrients and irrigation.

Intensive green roofs require greater soil depths, usually 15 cm or more, and additional structural support, which increases their cost. They are heavier but offer more plant options, including trees and shrubs. Intensive green roofs require irrigation, fertilization and maintenance.[10]

Container or modular gardens can be placed on structurally sound flat roofs to enhance stormwater retention.

Green walls: Green walls, or vertical gardens, are typically constructed using modular containers to hold a growing medium, the growing medium itself and vegetation. Typical green wall systems are constructed using panels, felt, and containers or trellis systems.[11] Pre-planted panels or felt pockets can be attached to the exterior of a building, along with some type of irrigation system, or constructed using containers or trellis systems to direct plants grown at the base of the building.

---

8 EPA, "Urban Heat Island Basics," in *Reducing Urban Heat Islands: Compendium of Strategies*, October 2008, accessed March 21, 2016. http://www.epa.gov/heatisland/resources/pdf/GreenRoofsCompendium.pdf.

9 Ibid.

10 Ibid.

11 Susan Loh, "Living Walls: A Way to Green the Built Environment," August 2008, http://math.unife.it/lm.ecologia/Insegnamenti/management-degli-ecosistemi/materiale-didattico/Loh%202008%20living%20walls.pdf.

Blue roofs: Blue roofs are non-vegetated rooftop detention systems designed to temporarily store and slowly drain water through the use of waterproofing membranes and weirs on roof drains.[12] They are typically cheaper to construct than green roofs.

© New York City Department of Environmental Protection

A water retention or "blue" roof in New York City. The roof is designed to temporarily retain water and gradually release it through weirs on roof drains.

IMPORTANT DESIGN CONSIDERATIONS

Design objective: Temporarily detain water from a localized storm event and increase lag time.

Main components: Vegetation, growing media, and/or containers or rooftop detention system.

Functionality: The main design parameters of green and blue roofs are the slope of the roof and how much water needs to be detained. Steeper roofs retain less water and may not be suitable for a blue roof. The load-bearing capacity of the building, or how much weight the roof can handle, will determine which type of green or blue roof is appropriate or whether retrofitting is an option.

Safety: Green roofs and walls, and blue roofs, should be carefully designed to prevent water damage to the structure and fit within its load-bearing abilities. Before adding these features, the building should be assessed for structural soundness and ability to accommodate the extra weight of a green or blue roof. Fire safety is another consideration when using these techniques. Fire risk can be reduced by avoiding plants that dry out during hot months and by including firebreaks on the roof or irrigation systems.

12 NYC Environmental Protection, "Blue Roof and Green Roof," accessed December 30, 2015, http://www.nyc.gov/html/dep/html/stormwater/green_pilot_project_ps118.shtml.

5.2.2 METHODS FOR IMPROVING CONVEYANCE AND RESISTANCE TO DAMAGE IN WATERWAYS

The second category of flood risk management methods includes effective conveyance of flood flows and stormwater and enhancing the resistance of waterways (streams, rivers, canals, drains) to flood-related damage (e.g., bank erosion, scouring).

Conveyance improvements should enhance the carrying capacity of major water bodies and provide effective drainage of runoff in a floodplain.

Deeping/widening a waterway, increasing bank heights, or providing alternative flow paths can improve the carrying capacity, or discharge capacity, of major waterways. Providing effective drainage in a floodplain can include improving conveyance in defined drainage pathways (natural gullies, engineered drains, canals, pipes), so they can effectively carry the maximum runoff produced in a storm (stormwater peak). These defined pathways ultimately connect to the main water bodies, such as streams, rivers, lakes or the sea.

In addition to improving conveyance, the waterways should also be protected against flood damage (e.g., erosion and scouring of banks). Protecting the banks and beds of waterways (such as rivers, canals, streams) from damage will enhance their ability to function properly and reduce the potential for flooding.

5.2.2.1 Hard Engineering Methods

LEVEES AX4

A riverine flood occurs when the water level of the waterway (river, stream) rises above the height of the banks and flows over. One method used to manage such a flood is to raise the bank height along a given stretch of the waterway. Structures built to raise bank levels are commonly known as **levees**.

Levees are typically made from soil (or rock-filled) structures built along riverbanks. In certain cases, levees are built only along one side (bank) of the waterway to protect a certain area along that bank; in other cases, both banks are raised. Levees are often used as roads, railway tracks or footpaths.

Most levees are massive engineering structures and will invariably hinder the natural drainage of the areas they protect. Therefore, hydraulic features such as **culverts** and lock gates should be included to allow drainage from the landward side to the waterside through the levee (internal drainage). Pumping over the levee might be necessary in certain cases. In stream stretches with high-velocity flows, levees should be protected using lining, vegetation or revetments (see AX9).

WARNING: Levees can only protect a small area within the given floodplain from frequent floods, and they are not effective against extreme events. Levees can increase the flood risk in other areas and are extremely disruptive to the river ecosystem process. Thus the Flood Green Guide does not encourage levees to be considered as a viable solution in flood risk management. We include levee information here because they are commonly found in many countries and thus may need to be addressed.

There are also smaller-scale flood bunds, which are usually designed to protect a particular village or agricultural field from floods. Similar to the way levees function, a flood bund can be constructed along the banks of a waterway, or, similar to a dam, a bund can be constructed at a strategic point of a floodplain. Bunds are structures significantly smaller in scale than a levee or a dam, and are usually constructed using earth or earth reinforced with timber, bamboo or other vegetation. It should be noted, however, that small flood bunds are engineering structures and thus should be designed by qualified professionals using the same design principles as levees or dams.

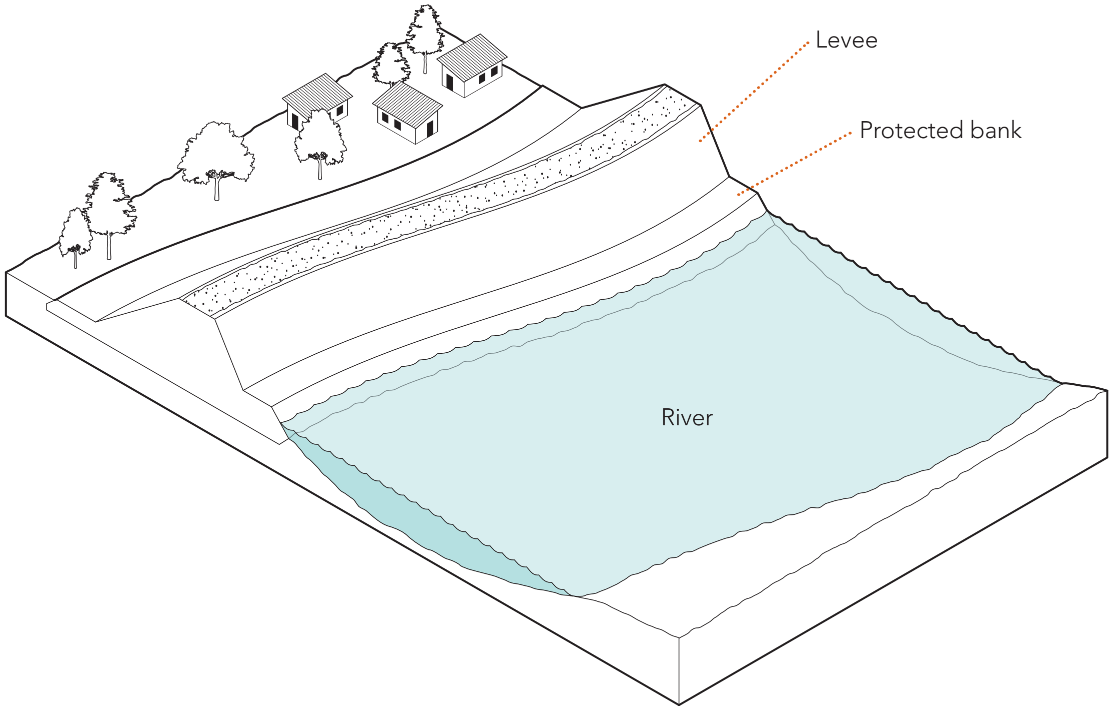


FIGURE 5.11 A LEVEE BETWEEN A WATER BODY AND DEVELOPED AREA

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Increase the carrying capacity of a main waterway by raising the bank height using artificial structures to prevent overbank flooding.

Main components: Levees, banks protection (lining, vegetation, revetments), lock gates, pumps.

Functionality: Levees are designed based on the water level that corresponds to the design flood in the waterway. Levee height (bank height) should exceed this water level. A standard freeboard height is also added to the design flood water level for operational safety. Sizing and structural strength of the levee are also determined to withstand the water pressure of design flood water level. If the levee is used for other purposes, such as roads and rail tracks, the load stress on the system should be considered. Structures and devices included in levees to facilitate internal drainage (lock gates, pumps) need careful hydraulic design.

Safety: There are two safety concerns with regard to levees. One is the stability of the structure and its ability to withstand water pressure, scouring and erosion without sudden breach. Sudden breach of a levee can cause disastrous flash floods. In addition, other levee concerns include the possibility of **overtopping** if a flood exceeds the design flood; the upstream and downstream impacts of altered river characteristics; risk associated with a false sense of security that can encourage settlement near the structure; and eliminating potential flood benefits. Spillways to allow safe spilling of excess water should be incorporated into levee designs to minimize unexpected damages due to overtopping. Breach or leaking of a levee or damage to accessory structures, such as lock gates, can cause catastrophic harm to both human communities and the environment; thus, periodic inspection, maintenance, cleaning and repair of these structures are very important.

CANAL WIDENING AND DEEPENING AX5

The amount of water that can be carried by a natural or manufactured waterway is a function of the width, depth, slope and smoothness of the canal bed. Enhancing any of these variables will increase the waterway's carrying capacity and reduce the risk of overflow and flooding. This process is also known as channel improvement.

Widening – increasing the width by cutting the banks – is the most common and usually the cheapest way to increase a waterway's flow. Because the depth and slope of a canal are usually constrained by the nature of the terrain, deepening is only used in special conditions. Lining the natural bed and banks of a canal with cement, **gabions**, or geotextiles makes the surface smoother and increases the flow velocity. Lining is costlier than widening and is usually done to control bank erosion. Changes to any of these canal parameters can have serious effects on upstream and downstream flow, and environmental effects on the waterway.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Enhancing the carrying capacity (also known as discharge capacity) of a channel by changing width, depth, slope and smoothness.

Main components: N/A

Functionality: Channel improvement projects are designed to gain the maximum discharge capacity by changing the width, depth, slope and/or bed smoothness of the waterway. The velocity of water in the channel is maintained at around 2 m/s to control sedimentation or scouring of the banks. The channel banks should be designed with proper slopes or lined to minimize erosion.

Safety: The main safety concern in design is the stability of the banks after modification. If the bank collapses under the weight of adjacent structures or due to erosion, it may cause serious damage to people and property.

FLOODWAYS AX6

Another approach to increasing the carrying capacity of a waterway is to provide an alternate path for part of the flow. A **floodway** is a parallel canal or an enclave or reservoir that receives overflow when the flood flow exceeds the waterway's carrying capacity (fig. 5.12). The floodway is expected to be dry in normal conditions and can be used for other purposes, such as cultivation. The floodway's inlet and outlet should be carefully designed and constructed to prevent localized flooding. Managers can either use existing natural depressions and drainage paths in the area or construct an entirely new engineered channel.

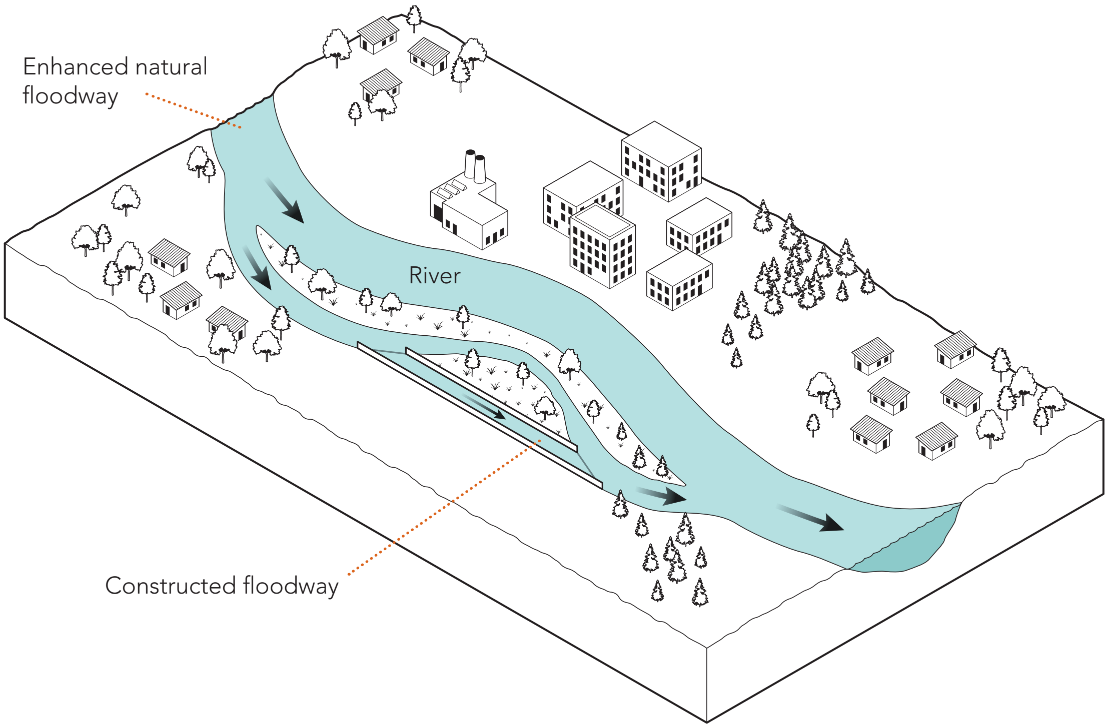


FIGURE 5.12 FLOODWAYS IN A RIVER SYSTEM

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Enhancing the carrying capacity (discharge capacity) of a channel by providing an auxiliary path.

Main components: Existing channel, auxiliary channel (floodway), inlet, outlet.

Functionality: Floodways are designed in a way that combined discharge capacity of the existing and auxiliary pathways can safely accommodate the design flow. As in any channel design, the discharge capacity is determined by the width, depth, slope and bed smoothness of the auxiliary path/channel. It is always economical to have auxiliary pathways that can be used for other purposes during dry periods (agriculture, for example). However, these land uses may affect the surface roughness of the channel bed and significantly slow the water flow.

Safety: The most important safety concern in floodways is the risk of secondary floods along the auxiliary pathway. The stability of the channel and the banks is also critical for safety.

PUMPING AX7

Another method of providing an alternate pathway to reduce flood risk is to mechanically shift part of the flow downstream using pumps. Pumping can be used to increase conveyance along a channel or improve drainage in a floodplain. However, pumping requires energy and costly infrastructure; typically, it is used only in specific conditions and as a last resort. Pumping can also be used to

- convey a large flow quickly away from a concerned stretch of the river, managing rapid-onset floods, such as urban flash floods;
- remove water from a small, localized floodplain to prevent urban flash floods;
- create drainage when the floodplain is lower than the sea level and natural drainage is not possible;
- avoid salinity intrusion in cases where there are lock gates along streams; and
- drain groundwater floods that can't be naturally drained.

Usually the pumps are installed in a structure called a pump station upstream of the area where managers want to reduce the flood risk. Water is pumped through pipes to downstream locations. Since the water is pumped at a faster rate than the natural flow of the source (stream, river, tidal flow), the pipes require far less capacity than an auxiliary channel. Pumps can also transport water to a higher elevation (if required).

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Mechanically shifting part of the flow in a water body to a location with less flood risk.

Main components: Inlet, pump station, conduits, fittings and fixtures (e.g., valves, anchors), outlet.

Functionality: Pumps should be selected according to the flow that has to be diverted and the elevation or distance that the water needs to be conveyed. The capacity of a pump is the flow that a given pump can deliver to a given elevation with maximum energy efficiency. If you use a large-capacity pump to carry a small flow, a lot of energy will be wasted. The sizes of pipelines should be carefully calibrated to provide minimal resistance to the flow and reduce energy loss.

Safety: Breach of a conveyance pipeline can cause localized flooding. Large electrical or fuel-operated pump stations may cause a fire hazard.

ENGINEERED DRAINAGE SYSTEMS AX8

Manufactured infrastructure built to effectively collect and convey runoff away from a given area is called an **engineered drainage** system. Drainage systems include collection drains (surface or underdrains) that connect water from sub-watersheds, a main stormwater canal or underground sewer, and an outfall into a main water body (fig. 5.13). Surface drains are generally rectangular or semicircular channels made of earth, concrete or brick; under drains are submerged PVC, clay or concrete pipes that have been perforated along the bottom or have gaps in their connections (fig. 5.13). Circular or ovoid underground sewers are used in urban areas when there is no open space for surface canals or when greater depths are needed. In some cases, stormwater mixes with human waste in sewers (known commonly as combined sewers), but this can cause serious pollution and water management issues, so it is largely avoided in new designs.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Effectively collect the runoff generated in a design storm from a landscape and convey it to major waterways to prevent localized floods.

Main components: Surface drains, under drains, gully boxes, manholes, silt traps, tunnels, outfalls.

Functionality: The most important design concern in an engineered drainage system is to have sufficient carrying capacity in all the devices (e.g., drains, pipes, canals, tunnels, manholes and outfalls), effectively conveying a flow corresponding to the stormwater peak. Each device should be sized carefully with precise calculation of flow; failure to do so will cause overflow and local flooding. Moderately sized drains can carry large amounts of water. For example, a drain that is 30 cm wide and 20 cm deep can carry a flow of 50-80 liters per second. The speed of water is also a very important design factor. If the speed is excessive (>2 m/sec), the drains tend to erode or scour; very low speeds allow sediment deposition and blockage. Where the speeds are high, drains should be lined with concrete. The designs should ensure that roadside drains are strong enough to withstand the impact of moving traffic. Where the speeds are low and stormwater tends to carry large amounts of silt or dirt, silt traps should be included in appropriate locations, with a plan in place to have them cleaned regularly (typically 2-3 times per year). Drainage outfalls to water bodies should be carefully designed. If the water level in the water body exceeds the water level in the drains, water flows upward, causing back-flushing and floods. This can also happen if the outfalls are too narrow and the water builds up rapidly in an intense storm event. All underground systems should include manholes for maintenance purposes; these are generally spaced in 100-200 m intervals.

Safety: Covering deep surface drains properly (>50 cm covers) in urban areas is an essential safety measure. The same applies to manholes in underground systems. Leaking underground sewers can cause subsurface erosion and create hazardous sinkholes. Keep in mind that stormwater can have many contaminants and connecting a stormwater drain to a water body used for drinking may create serious health risks. If absolutely necessary, combined sewers (sewage and stormwater) should be designed very carefully to prevent contaminating water bodies and introducing health and environmental risks.

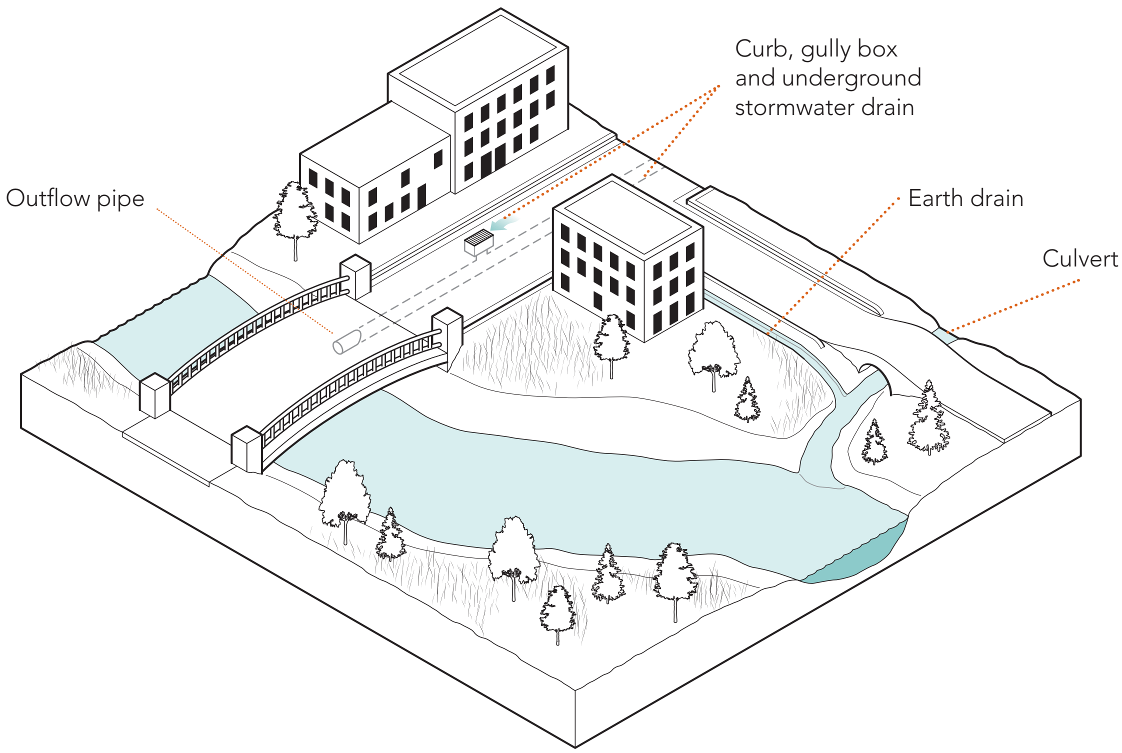


FIGURE 5.13 ENGINEERED DRAINAGE SYSTEMS

GROYNES AND REVETMENTS AX9

In addition to enhancing flow conditions, engineering measures are commonly used to artificially strengthen the banks of waterways against erosion. This is achieved by either building structures that will reduce the velocity of the water at the edges (groynes) or altering the structural properties of the bank material to make it less erodible (revetments and bank stabilization). Methods commonly used include the following:

Groynes: Groynes are built against movement of the water flow along the banks of a waterway. They break the flow, reduce velocity, and allow time for bank material carried by the flow to resettle. These structures usually have a simple, linear shape and are constructed at right angles (90 degrees) to the bank. Groynes are effective in preventing erosion in the lower reaches of a river with moderate velocities. They are usually constructed using heavy material such as rock or concrete; smaller groynes can be constructed with wooden piles and soil. Groynes were originally designed to manage coastal erosion and are not generally suitable for river systems. However, they have been introduced in some river systems to protect levees from heavy erosion. Groynes can significantly change the river hydrology, constrict flow and cause excessive silt accumulation. Thus the Flood Green Guide does not encourage groynes to be considered as a viable solution in flood risk management.

Revetments and bank stabilization: Revetments are structures built as a cover or apron to protect a stream/lake bank with loose material. They are usually constructed by packing boulders, using gabion walls or concrete lining, which cannot be carried by the force of water along the waterway. The other option is to improve the strength of the existing material in the bank by compaction, slope alteration, or introducing chemical binders or other soil stabilization methods. Revetments are very effective in sections with high velocity and in protecting other constructed flood defense structures, such as levees. Bank stabilization is useful in places where velocities are low and where space prohibits construction of groynes or revetments. However, both revetments and bank stabilization will affect the hydraulics of the river and other ecological processes. They cause significant damage to ecosystems along the banks (e.g., riverine vegetation, mangroves) and also destroy the habitat for fauna like water birds, otters and crabs. Therefore, both options should be carefully designed by a team of hydraulic/geotechnical engineers and aquatic ecologists. Groynes and revetments will also restrict access to the waterway and potentially impact its uses (e.g., fishing, recreation); therefore, it's important to provide proper access structures.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Reduce bank erosion in a water body by dissipating the energy of the flow or enhancing resistance to erosion.

Main components: Groynes, protected bank (revetments or bank stabilization), access structures.

Main design parameters: Groynes are designed to dissipate the energy carried by the flow (or waves) before it reaches the bank and causes erosion. In revetments and bank stabilization, the energy calculations are used to determine the structural strength and stability required. In most cases, the velocity of the water is proportional to the energy it carries. The structural strength and stability are a function of material selected for construction, size and shape.

Safety: Structural strength and stability are the most important safety concerns. Breach can cause serious hazards. Groynes and revetments should be designed to ensure safety in other uses of the river (fishing, boating, recreation).

5.2.2.2 Soft Measures

NATURAL DRAINAGE PATH RESTORATION AY7

Often natural drainage paths (gullies, small streams, sloping land strips) in a landscape are modified or eliminated with urbanization and agriculture. However, these drainage paths require little or no maintenance and are the most stable conveyance paths in the landscape. Most of these drainage paths are not perennial and barely distinguishable as waterways during dry periods. Thus, when their surroundings are modified, these paths may get blocked with debris, silted, overgrown with weeds, or intentionally cut or filled. A manager can often improve stormwater drainage by identifying such natural drainage paths and monitoring, maintaining and restoring them (fig. 5.14). Often culverts are also installed where drainage paths cross roads, pathways, or pipelines, which are often undersized due to the complexity of calculating natural flows. Flows may increase over time, especially in growing urban areas. In such cases, culvert opening has to be done (culverts widened or replaced with bridges or low-water crossings that allow overflow), and the managers must continue to maintain them to prevent blockage.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Identify and restore the original carrying capacity of natural drainage pathways in a landscape.

Main components: N/A

Functionality: The main design task in natural drainage restoration is to identify natural drainage paths and calculate the discharge capacity (both width and depth) that must be restored. Identification is a challenging task in most modified landscapes because no water will be flowing in dry conditions. Both expert and community knowledge will be useful in identifying discharge requirements and restoring the original conditions. Remote sensing and GIS can be very useful in identifying the natural drainage paths.

Safety: Safety issues are not critical unless removal of large engineered structures is required.

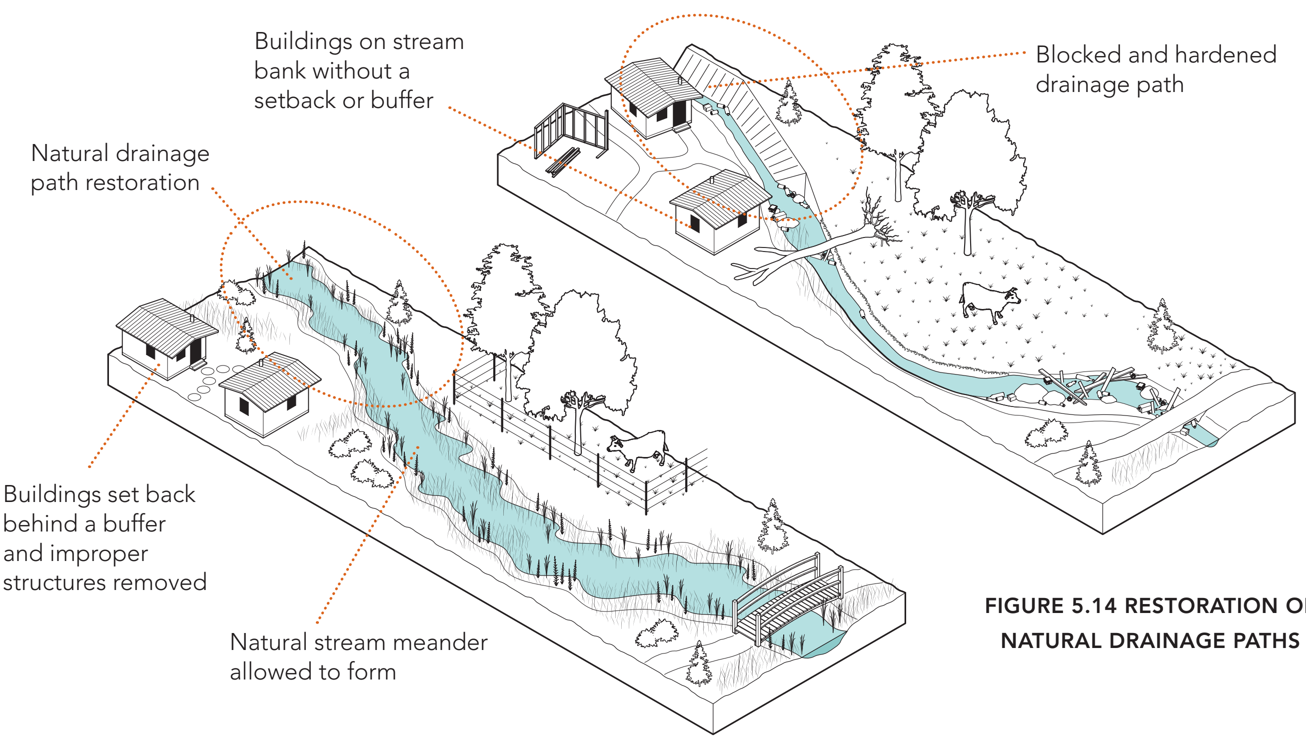


FIGURE 5.14 RESTORATION OF NATURAL DRAINAGE PATHS

RIPARIAN VEGETATION RESTORATION AY8

Most **riparian** ecosystems (habitats that exist adjacent to or along streams) are naturally resistant to erosion and scouring from high-velocity flows and floods. When riparian ecosystems are modified or damaged, they lose their ability to protect waterways, and the waterways experience excessive erosion. Most riparian plant species have adapted to withstand high water velocities and fluctuating water levels. Formations such as buttresses and adventitious roots stabilize the plants and firmly hold root-zone soil (fig. 5.15). Riparian habitats provide a barrier to sudden surge in water level. In upper watershed streams, riparian habitats also break the energy in high-velocity flows and reduce the flash flood or erosion threat downstream. Fallen trees and organic litter in the banks help break water velocity and provide extra cover for the soil. A number of other processes are carried out by microorganisms in the root zone and larger animals in the habitat (e.g., crabs, ants) that continually stabilize the soils. Restoration of riparian habitats will contribute to reducing erosion and protecting the banks.

Degraded riparian habitat can usually be reestablished through restoration and revitalization of riparian vegetation. The restoration projects should be carefully planned and the correct plant species selected. It is also important to recreate conditions for animal habitats – such as roosting and nesting sites, hideouts, shades and dens – and it is recommended to include aquatic or wetland expertise in the design and planning. Riparian restoration projects can affect the existing community uses of waterways, such as fishing, water collection and recreation. Restoration projects should take these uses into account and try to preserve them with community consultation.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Enhancing the natural resistance in streams to withstand high-velocity and high-flow conditions.

Main components: Restored vegetation, restored habitats, access structures (pathways, pears), fences.

Functionality: The most important design tasks in riparian restoration are to identify the areas to restore and to select the correct plant species for revegetation. Most plants won't grow in highly moist riparian conditions, and introducing the wrong plant species might cause excessive silt trapping and filling up of the banks. The selected plants should support the other ecological processes of the ecosystem and provide for nesting, breeding and feeding of fauna. Small artificial structures like hideouts, shades or caves may have to be designed for habitat restoration. Depending on the existing level of human modification and erosion damage, supplementary measures like artificial bank stabilization or revetments may have to be designed.

Safety: Safety concerns are not critical in riparian restoration unless supplementary methods such as revetments are involved.

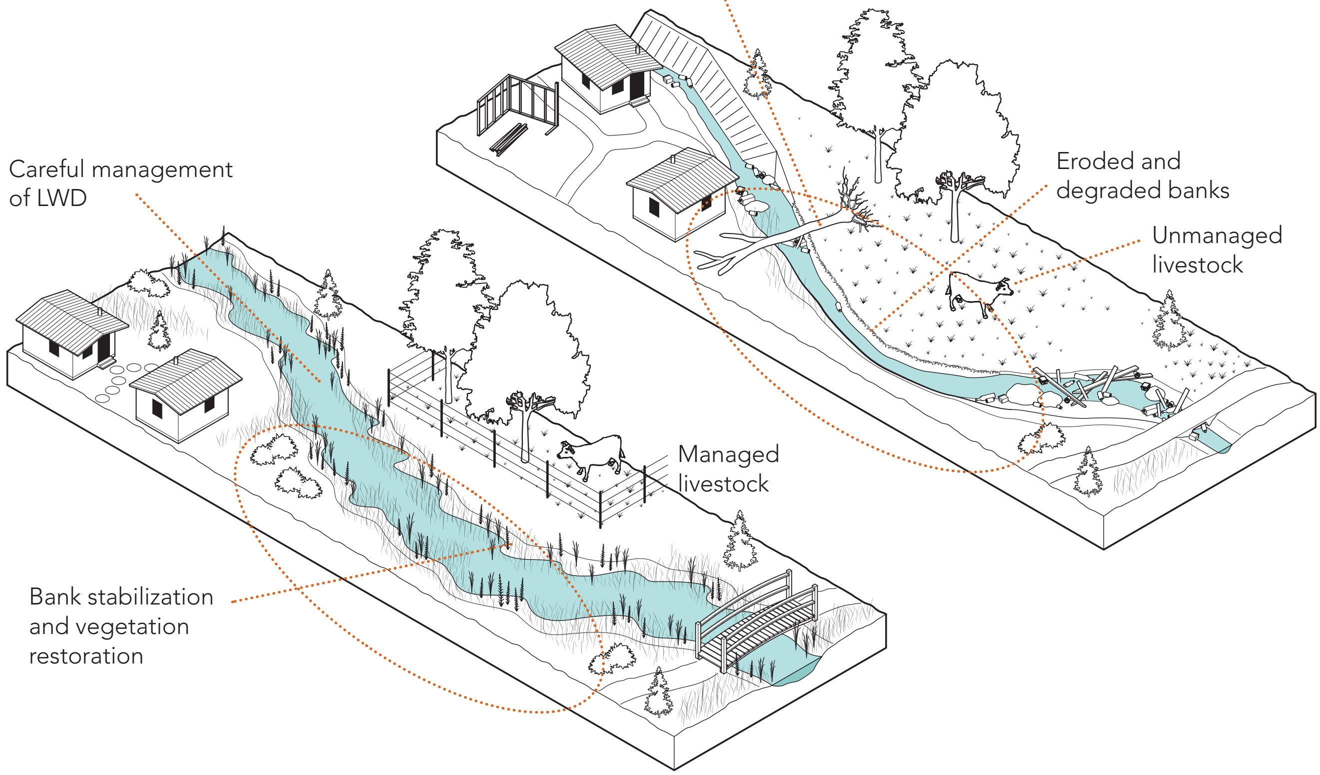


FIGURE 5.15 RESTORATION OF RIPARIAN VEGETATION AND HABITATS

REMOVAL OF BARRIERS AY9

Another way to improve conveyance capacity of waterways (especially small and medium streams) is by removing the barriers to flow. In natural systems this involves removal of boulders, vegetation and debris on the streambed that hinder flow (fig. 5.16). In small streams with habitual high velocities, regular removal of large woody debris can substantially reduce the local flood risk, especially for flash floods. Removing weeds in streams is also an effective way to restore flows. Streams in urbanized or agricultural areas are often overgrown with weeds that block the natural flows, and regular weeding is required. Floating weeds can be removed by mechanical collectors, and emergent and submerged weeds can be removed by volunteer weeding groups.

Regular removal of large trash (plastic items, rags, cardboard) is also important in urban streams. Large trash may include polythene/plastic bags, discarded household items (containers, furniture, electrical items), packaging material and rags. Such items accumulate in streambeds, bends or narrow points in channels, and culverts or control structures (sluices, weirs), and they block water flow. Trash also interferes with the functioning of natural streams and can decrease water quality. Trash removal is usually done manually by municipal workers, environmental volunteers or community groups in periodic stream cleaning programs. To restore highly degraded streams, machinery and vehicles may be necessary to remove and transport trash. In these cases, careful project planning and substantial investments are essential. Large trash removal programs should be accompanied by

- local government-level solid waste collection and disposal;
- public awareness programs on solid waste management (reducing, separation for recycling, composting);
- public awareness programs on stream health and ecology; and
- strict enforcement of solid waste management regulations.

In human-modified systems, removing obsolete structures like old bridges and narrow culverts is also required. The process of carefully removing (replacing with bridges) or widening narrow culverts is also known as culvert opening. Removing such barriers can be particularly useful in areas undergoing urbanization, where the runoff (overland flow) has increased over time. Many structures that block urban streams were built without considering buffer distance regulations for the existing stream. Removing these structures is an effective way to increase or restore the conveyance capacity of a waterway. However, certain unauthorized structures are common in low-income settlements and are essential to everyday life. Removing them should be done with extreme care and with community participation.

Conveyance capacity also can be improved by moving levees further away from the edges of the waterway (also known as levee setback). Levee setbacks increase conveyance and reconnect the waterway to portions of the floodplain. Widening the boundaries of the waterway slows the velocity of water during flooding, which can reduce downstream bottlenecks and back-flushing. This approach also helps to restore riverine habitats and reduces operations and maintenance costs associated with levees, which degrade more quickly under pressure from high-velocity water.

A more intrusive approach to removing barriers in waterways is to eliminate natural features, such as sandbars and rocks, in river mouths to prevent back-flushing during high flows. This method can interfere with the stream's natural flows and functions, including fish migration, and should be carefully planned by professionals working with the communities using the waterways.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: Restore or enhance the carrying capacity of a waterway by removing features that reduce the cross-sectional area or increase the roughness of the channel.

Main components: N/A

Functionality: Barrier removal projects are designed to optimize the carrying capacity (discharge capacity) and reduce the surface roughness of waterways. However, it is extremely difficult to accurately calculate the increase in flow after a barrier is removed in a natural stream. The general rule is that any barrier that alters the natural flow conditions of a waterway is worth removing. When it comes to removing natural barriers in order to artificially enhance discharge capacity, precise hydrological design and environmental assessment is critically important.

Safety: Safety issues are not paramount in regular weeding or debris clearance operations. However, dismantling old engineered structures, demolishing unauthorized buildings, or removing natural barriers (e.g., large boulders) may cause serious hazards to people and property and should be planned by a safety team.

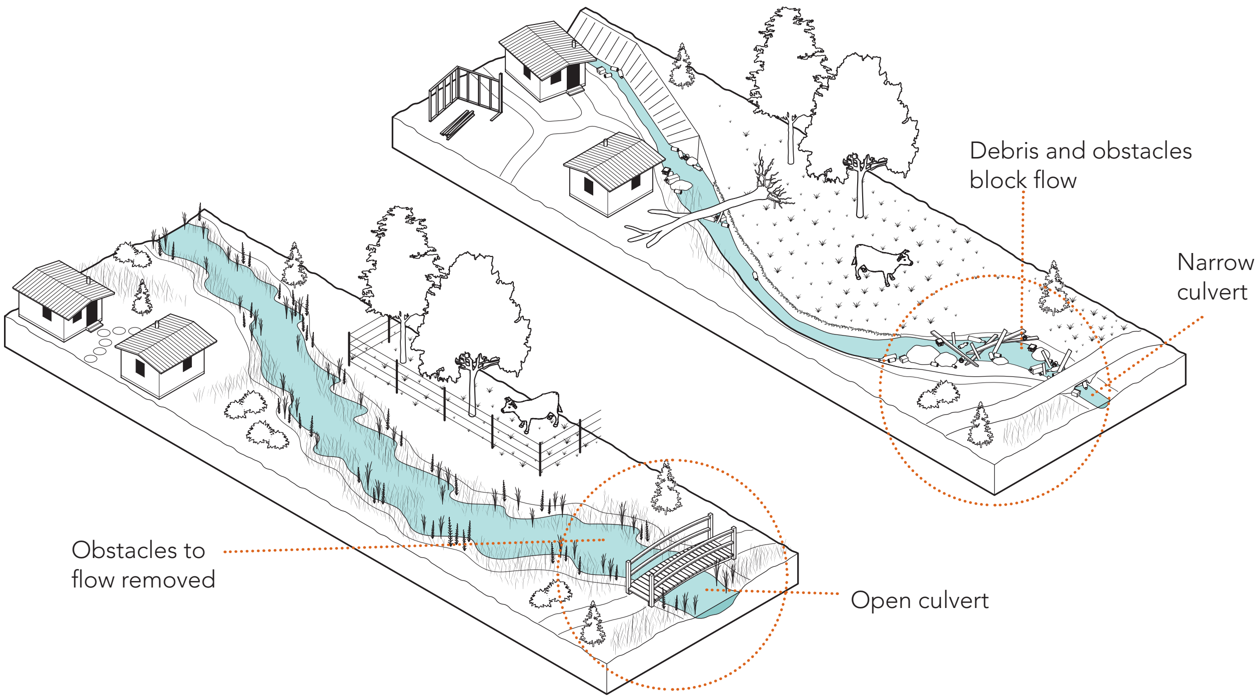


FIGURE 5.16 REMOVING BARRIERS TO FLOW

COASTAL AND REEF RESTORATION AY11

Coastal ecosystems can provide natural protection from coastal and tidal flooding and can significantly dissipate wave energy, break offshore waves, and reduce inland flooding. When mangroves, dunes, beaches, seagrass beds, and coral or shellfish reefs are damaged or degraded by, for example, development or climate change, their ability to provide protective services is greatly reduced. (See wetland restoration AY3).

Along some coastlines, beaches and sand dunes may be at a higher elevation than the land behind them, and they can provide a barrier to flooding and dissipate wave energy. Naturally occurring sand dunes are sand deposits formed by the wind. Dunes can provide a natural supply of sediment to replenish the surrounding beaches based on winds and tides and reduce coastal erosion. Sand dunes are often degraded by human activity and development, thereby diminishing their potential to serve as a buffer against coastal storms and flooding. Dunes and beaches, however, can be restored by trapping sand with fences – for example, constructed with branches or reed stakes – or can be stabilized by planting vegetation. Native vegetation can be transplanted from intact dune systems or acquired from nurseries, and artificial dunes can be created to buffer coastlines. It is important that dune restoration projects consider the source of sand and the types of vegetation species used. Coastal projects should also consider the relationship between the coastal area and the back bay or lagoon to ensure that dune restoration does not impede sand replenishment or increase the risk of flooding elsewhere. It's also important to allow the restored or managed ecosystem to adapt to climate change.

Coral reefs are underwater ecosystems that provide habitat for a multitude of marine species with rigid structures built by coral. These underwater structures can act as natural breakwaters and break up waves, reducing their velocity and force. Coral reefs are degraded by human activities like coral mining, pollution and sedimentation from coastal development. Warming ocean temperatures and ocean acidification – results of climate change – further degrade coral reefs, reducing their effectiveness as a buffer against coastal storms.

Shellfish reefs, such as those colonized by oysters and mussels, provide similar benefits to coral reefs, but since shellfish reefs are typically smaller, they have less impact on wave dampening.

In some cases, degraded reefs can be restored to some level of function, while artificial reefs can in some places be created to carry out similar functions. Although technically challenging and potentially costly, it is sometimes possible to transplant coral or shellfish to appropriate substrates, or construct artificial barriers to colonize damaged sites. During restoration, particular attention should be given to the types of species used in colonization, the environmental conditions, the type of substrate used for attachment and, for coral, the type and shape of the transplant. In most cases, restoring or creating reefs will be more expensive and time consuming, and less successful, in returning reef functioning than protecting and managing existing reefs. Reefs should be protected from human threats. Protection and management include allowing for climate change adaptation as ecosystems will respond and/or adapt.

© Fragments of Hope/WWF

Coral nurseries are used to grow coral for reef restoration.

Coastal restoration projects should be undertaken with planning and technical expertise. Depending on the scope and context, it is highly recommended that coastal managers and aquatic ecologists be consulted during the planning and design stages of the project.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: To enhance the natural ability of coastlines to withstand high-velocity and high-flow conditions.

Main components: Restored vegetation, substrate and habitat.

Functionality: Identify areas to restore, and select the correct species and substrates for restoration. The existing level of human modification, erosion damage, and degradation will affect the types of restoration projects possible and may require the use of artificial reefs or dunes. Coastal and reef restoration projects are similar to wetland and riparian restoration in that a primary concern is that they restore the preexisting habitat in addition to creating an extra buffer or breakwater along the coastline. Projects should allow for adaptation to a changing climate.

Safety: Safety concerns are not typically critical in coastal restoration unless supplementary methods, such as revetments, are involved.

5.2.3 METHODS FOR ADAPTING TO FLOODS

The third category of flood risk management methods is **adaptation** to floods. These methods focus on helping communities adapt to floods, rather than on preventing or mitigating floods (or flood damage). Instead of managing the hazard, these methods strive to reduce the vulnerability and increase the capacity of communities to live with floods.

5.2.3.1 Hard Engineering Methods

MULTIPURPOSE INFRASTRUCTURE AX10

Public infrastructure that can be used for flood conveyance or detention during the wet season and for other purposes in the dry season is generally referred to as multipurpose infrastructure. Some examples are

- multilevel traffic tunnels that serve as drainage tunnels during the wet season
- playgrounds that can serve as detention basins
- tennis courts/basketball courts constructed below ground level to serve as detention ponds during rain
- parks and recreation areas designed to accommodate temporary flooding during heavy rains

Designers should plan such infrastructure based on a location's specific needs and to provide maximum benefits to all constituents. Multipurpose infrastructure should provide the required hydraulic conveyance and/or storage capacity for flood management and be structurally and functionally suitable for its other purposes. For example, a multipurpose park should be designed so that several days of flooding will not damage its paths, benches or open areas.

IMPORTANT DESIGN CONSIDERATIONS

Design objectives: To incorporate hydraulic functions (storage, conveyance, infiltration) into common infrastructure.

Main components: N/A

Functionality: There are three essential points to designing multipurpose infrastructure:

1. It should be structurally and functionally designed to fit primary purpose (car park, tunnel).
2. It should be hydraulically designed for the secondary flood-related purpose (storage, conveyance, detention).
3. It should be ensured that the structure is safe under exposure to water and additional loads/pressure exerted in the secondary flood-related purpose.

Safety: All the safety concerns that apply to designing the corresponding hydraulic structure (detention basin/pond, infiltration device, stormwater tunnel) apply here. Strict design measures should be taken to avoid exposing infrastructure users to any hazard during flooding. For example, in a multipurpose traffic-drainage tunnel, there should be a safe and reliable closing mechanism to prevent traffic from entering during flooding. In addition, consideration should be given to risks of water contamination, vector breeding, and post-flood physical hazards in a public place. Safety concerns that apply to the infrastructure's other uses (e.g., playground, traffic tunnel) should be considered separately by the relevant experts.

5.3 NON-STRUCTURAL METHODS

Non-structural flood risk management methods do not involve any physical interventions (engineering or ecological). Non-structural methods can be categorized mainly into two categories, depending on the nature of the interventions:

1. Governance changes
2. Changes in community and household practices

Governance changes include modification or introduction of laws, regulations or organizational procedures to induce practices (at different levels) that will contribute to prevention, **mitigation** or adaptation to floods.

Changing community and household practices includes approaches that will actively engage the community and households to induce behaviors that contribute to prevention, mitigation or adaptation to floods.

5.3.1 GOVERNANCE CHANGE

SOIL AND WATERSHED PROTECTION LEGISLATION B1

Most countries have legislation and policies in place to prevent environmental degradation, deforestation and soil erosion in upper watershed areas. These laws or procedures are important in flood risk management, as they regulate human activities that may increase soil erosion and cause hydrological changes, thereby exacerbating flood risk. The specifics of flood protection are different from country to country. Soil conservation in many places is regulated by national or state-level parliamentary acts. These laws outline conservation measures, permitted and prohibited activities, and compensation procedures for landowners. Some countries form exclusive agencies to enforce soil and watershed conservation regulations, while others use agriculture departments or regional administration offices for enforcement. Where national legislation has been enacted for soil and watershed protection, regulations and procedures may be enforced at local government levels. In some cases, watershed and river basin development agencies may have specialized approaches to watershed conservation.

Regardless of their technical effectiveness or legal enforceability, such laws, regulations and procedures should be considered at all stages and scales of flood risk management planning. Legislation and procedures may have weaknesses that a specialized flood risk management project can address. An integrated flood risk management project can, as a secondary goal, strive to improve the soil and watershed conservation regulations and procedures. Changing national legislation can be challenging, and improving local soil conservation regulations can be accomplished with local advocacy.

LAND USE PLANNING (REGIONAL) B2

Land use planning can influence the causes and consequences of floods. A country's land use planning is carried out at different administration and policy levels and is determined by a range of legislations and procedures, including land-use and urban development acts, national physical plans, environmental laws, and long-term development plans. Decisions begin at the level of national planning commissions, moving down to the level of local council offices. Proper land use planning is an essential element in any flood risk management project.

Although land use planning is transdisciplinary, zoning is the most critical aspect for flood risk management:

- **Zoning** identifies the geographical distribution of different land uses and what should be permitted or barred in specific locations.
- Careful planning of permissible land-cover and development in different sections of a landscape can help a manager manage hydrological flows and is central for soil conservation.

- In urban areas, zoning can help minimize flood damage (e.g., allowing flood buffer zones free of buildings along a river) and enable efficient flood evacuation.

A flood risk management project of any scale must incorporate land use planning. Moreover, land use planning should involve all relevant stakeholders, including government agencies and community organizations, while encouraging public participation. Details of integrated decision-making and public participation are discussed in chapter 3, and land use planning in urban areas is discussed in chapter 6.

FLOOD- AND WATERPROOFING (BUILDING REGULATIONS) B3

Improved building designs can minimize flood damage at household and neighborhood scales. There is a global trend to formally incorporate **flood-proofing** features into building designs. Some municipalities have made this mandatory. Such design concepts have several objectives:

- to make the buildings more flood tolerant (e.g., use of moisture-tolerant material)
- to improve the functionality of the building during the floods (e.g., elevated buildings and pathways)
- to improve drainage, infiltration and temporary water storage in the compound (e.g., domestic rain gardens)

Designs that combine traditional knowledge with modern technology and recent innovations can help achieve flood risk reduction objectives.

Building standards can be adopted at different administrative levels. The most common way is to prepare a technical document describing preferred approaches to be incorporated into building requirements at local government (city or village council) levels. Such standards may change from place to place according to the intensity and types of floods. For example, protecting buildings from groundwater floods may require a different approach than protecting against river floods.

Environmental implications should be carefully considered when preparing building codes. This applies to both materials and construction practices. For example, toxic or environmentally harmful construction chemicals are not recommended for flood-proofing. Building codes should take local environmental issues into consideration, guiding builders to sustainably source material, and recommending environmentally certified material when importing (e.g., certified timber).

REGULAR MAINTENANCE OF HEADWORKS B4

As discussed in the previous sections, flood risk management often involves physical structures (**headworks**) such as dams, canals, drainage systems and pumping systems. Once built, most of these structures need some level of regular maintenance. Certain headworks, including pumping stations or barrages with mechanical gates, may require daily maintenance and a regular operating staff. Others, such as open drainage systems or small watershed dams, may need occasional maintenance – to clean debris and silt that accumulate over time. Lack of maintenance will invariably lead to reduced capacity or malfunctions that will trigger floods.

Headworks maintained by large state agencies like irrigation departments or municipal councils generally have written maintenance protocols. However, maintenance of projects at the local government or neighborhood level is often neglected. It is important to document the maintenance needs for any project and establish a mechanism for regular monitoring. Community organizations, local flood committees and council representatives should be educated about the importance of regular maintenance so they can demand, allocate and monitor funds for the work.

FLOOD MONITORING AND WARNING FRAMEWORK B5

Monitoring, predicting floods and issuing flood warnings are vital components of flood risk management. Flood patterns can be observed over time, enabling predictions about flood likelihood and potential damage. Once predictions are made, vulnerable communities should be warned about dangers.

Flood monitoring and warning involve a range of activities at different levels and must be organized and scientific, regardless of the scale. Without proper coordination, an operation can lose efficacy, and false warnings may create unnecessary public chaos.

Most countries have established a flood monitoring and warning process as part of the national disaster management framework. The World Meteorological Organization (WMO) supports meteorological agencies at the national level through the Global Observing System. Individual national meteorological agencies work with irrigation departments and river basin agencies to gather weather and hydrological data and make predictions. Other international and regional networks, such as International Flood Network (IFNet) and Asian Disaster Preparedness Centre (ADPC), work directly with national-level agencies to issue flood warnings. As a result, predictions and warnings in certain flood-prone areas can be made before a storm or rainy season. While national disaster management authorities can issue warnings, effective communication to communities should involve local government and village leaders, local flood committees and community-based organizations. The local government in any flood-prone area should have its own flood monitoring and warning framework to work with the national disaster management agencies to communicate reliable information and issue warnings to the public. National agencies can partner with community-based organizations to form local flood committees. Media and cellular technology offer effective ways to issue flood warnings to individuals. Local television, radio channels and mobile text messages can inform the community promptly about flood situations. However, care should be taken to ensure that consistent warnings to the media come from a single source.

5.3.2 CHANGING COMMUNITY AND HOUSEHOLD PRACTICES

CROP CHANGE AND ALTERNATIVE LAND USE B6

Soil and watershed protection laws can sometimes discourage harmful land management practices, but most intense land degradation occurs where it is difficult to enforce national-level laws. For example, communities – especially those engaged in agriculture – might depend on the land for their livelihoods, and some of their practices may be environmentally destructive. In such situations, pragmatic approaches can improve a community's planting, harvesting and management practices to ensure the land's long-term viability. Rather than structural measures, these changes involve community training, building awareness, and, in some cases, reviving indigenous technology.

On the other hand, certain traditional land management practices can be environmentally beneficial–such as terraced farming and forest garden systems that may reduce soil erosion, reduce runoff, and prevent silting and blocking of streams and flood-control headworks.

© Chris Reij/WRI

Traditional and community land practices include stone terrace walls in Ethiopia for rainwater infiltration.

However, such traditional practices frequently disappear when intensive agriculture, cash cropping and animal husbandry are introduced. Likewise, community-maintained infrastructure is often neglected as more residents are employed in salaried jobs and agriculture becomes market oriented. A flood risk management project should take specific steps to reintroduce some of these lapsed good practices with communities. It is important to carefully identify which traditional practices should be encouraged and which should be replaced by alternative methods, both with expert advice and community consultation.

© Galen Rowell/Mountain Light/WWF-US

Terraced farm and fields in Kyumnu, Nepal. Terracing and stone walls help rainwater infiltrate steep slopes and recharge groundwater sources.

The first step in sustainable community land management practices is to build community awareness on the issues of soil erosion and land degradation. This should be done at all levels, from households to farmers' and women's organizations. It may also be necessary to build awareness among local agricultural extension officers. Changes in community practices may come at a cost to both the community and individuals, so it's important to create incentives for adopting new practices.

5.4 APPLICATION OF METHODS ACCORDING TO TYPE OF INTERVENTION, LOCATION (IN THE WATERSHED) AND SCALE

Suitability and applicability of different flood risk management methods to a given flooding problem depend on a number of factors. The selected methods should suit the desired type/category of intervention (objective). Different methods are effective at different geographical scales (i.e., watershed, floodplain, community and household). In addition, the effectiveness of methods varies depending on the geographic location in a watershed at which they are applied. Finally, the selected methods should be suitable for the type of floods experienced in the given case. Tables 5.1 and 5.2 categorize the flood risk management methods discussed in sections 5.2 and 5.3 according to these factors.

TABLE 5.1 FLOOD RISK MANAGEMENT METHODS AND SCALES OF APPLICATION

OBJECTIVE		STRUCTURAL METHODS		NON-STRUCTURAL METHODS	
Type of intervention	Intervention scales	Hard methods	Natural and nature-based methods	Governance change	Community and household practices
Reduce, retain, detain and divert flood flows	Transnational/ national	AX1 Dams and reservoirs AX2 Diversions	AY1 Upper watershed restoration	B1 Soil and watershed protection legislation (national level)	*Not applicable*
	Watershed	AX1 Dams and reservoirs AX2 Diversions	AY1 Upper watershed restoration AY2 Soil conservation measures AY3 Wetlands restoration	B1 Soil and watershed protection legislation B2 Land use planning B4 Regular maintenance of headworks	*Not applicable*
	Floodplain	AX3 Constructed wetlands and polders	AY6 Detention basins and retention ponds	B2 Land use planning B4 Regular maintenance of head-works	*Not applicable*
	Community	*Not applicable*	AY4 Swales and infiltration devices	*Not applicable*	B6 Crop change and alternative land use
	Household	*Not applicable*	AY5 Rainwater harvesting AY10 Green roofs/ walls and blue roofs	*Not applicable*	*Not applicable*

OBJECTIVE		STRUCTURAL METHODS		NON-STRUCTURAL METHODS	
Type of intervention	**Intervention scales**	**Hard methods**	**Natural and nature-based methods**	**Governance change**	**Community and household practices**
Improve drainage and enhance resistance to damage	Transnational/ national	*Not applicable*	*Not applicable*	*Not applicable*	*Not applicable*
	Watershed	*Not applicable*	*Not applicable*	*Not applicable*	*Not applicable*
	Floodplain	AX4 Levees AX5 Canal widening and deepening AX9 Groynes and revetments AX6 Floodways AX7 Pumping AX8 Engineered drainage systems	AY4 Swales and infiltration devices AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY11 Coastal and reef restoration	B4 Regular maintenance of headworks B2 Land use planning	*Not applicable*
	Community	AX7 Pumping	AY8 Riparian vegetation restoration AY9 Removal of barriers	*Not applicable*	*Not applicable*
	Household	*Not applicable*	*Not applicable*	*Not applicable*	*Not applicable*
Adapt to floods	Transnational/ national	*Not applicable*	*Not applicable*	B5 Flood monitoring and warning framework B3 Flood- and water-proofing (building regulations)	*Not applicable*
	Watershed	AX11 Warning/evacuation infrastructure	*Not applicable*	B3 Flood- and water-proofing (building regulations)	*Not applicable*
	Floodplain	AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	*Not applicable*	*Not applicable*	*Not applicable*
	Community	AX9 Removal of barriers AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY7 Natural drainage path restoration AY11 Coastal and reef restoration	*Not applicable*	B3 Flood- and waterproofing (building regulations)
	Household	*Not applicable*	*Not applicable*	*Not applicable*	B3 Flood- and waterproofing (building regulations)

TABLE 5.2 APPLICABILITY OF STRUCTURAL METHODS TO DIFFERENT FLOOD TYPES AND LOCATIONS IN THE WATERSHED

FLOOD TYPE	HARD ENGINEERING METHODS	SOFT METHODS
Riverine floods	AX1 Dams and reservoirs AX2 Diversions AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY8 Riparian vegetation restoration AY9 Removal of barriers
Overland floods	AX1 Dams and reservoirs AX8 Engineered drainage systems AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY6 Detention basins and retention ponds AY7 Natural drainage path restoration
Flash floods	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs
Coastal floods	AX7 Pumping AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration AY11 Coastal and reef restoration
Lake floods	AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration
High groundwater floods	AX7 Pumping AX8 Engineered drainage systems AX10 Multipurpose infrastructure	AY3 Wetland restoration AY6 Detention basins and retention ponds AY7 Natural drainage path restoration
Rain on ice floods	AX5 Canal widening and deepening AX8 Engineered drainage systems AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration

LOCATION IN THE WATERSHED	HARD ENGINEERING METHODS	SOFT METHODS
Upper watershed	AX1 Dams and reservoirs AX2 Diversions AX5 Canal widening and deepening AX8 Engineered drainage systems AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers
Middle watershed	AX1 Dams and reservoirs AX4 Levees AX5 Canal widening and deepening AX8 Engineered drainage systems AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers
Lower watershed	AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers
Coast and estuaries	AX2 Diversions AX4 Levees AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration AY9 Removal of barriers AY11 Coastal and reef restoration
Urban areas	AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs

5.5 FACTORS AFFECTING SUCCESSFUL IMPLEMENTATION OF STRUCTURAL METHODS

A given structural method may be technically appropriate for an intended objective, flood type or scale of application. However, there are a number of factors (economic, operational, social and environmental) that may affect its successful implementation. All of these factors should be considered during the method selection process. Table 5.3 describes key advantages and disadvantages of economic, operational, social, and environmental issues.

TABLE 5.3 FACTORS CRITICAL TO SUCCESSFUL IMPLEMENTATION OF STRUCTURAL METHODS

METHOD(S)	ECONOMIC AND OPERATIONAL		SOCIAL AND ENVIRONMENTAL	
	DISADVANTAGES	ADVANTAGES	DISADVANTAGES	ADVANTAGES
AX1 Dams and reservoirs AX2 Diversions	• High capital and maintenance costs	• High flood peak reduction • More predictable management of regular floods • Moderate construction time • Effective with high and fluctuating flows	• Inundation, habitat loss, geological issues • High toll on natural resources for construction • Community displacement and impacts on traditional livelihoods • Danger of dam breach	• Potential livelihood development through multipurpose schemes
AX3 Constructed wetlands	• High capital cost • May consume significant land extents in high-property-value areas	• Low maintenance costs • Co-benefits include uses for recreational areas or farming • Long-term resilience	• Vector breeding • May introduce fire hazards	• Low environmental impact (if properly designed) • Bioretention of contaminants
AX4 Levees	• High capital and maintenance cost • Highly technical design and construction • Blocks local drainage and increases local flooding when design storm exceeded, leading to catastrophic losses	• More predictable management of regular floods • Reduces small-scale floods	• Blocking of natural flow paths and animal migration • High toll on natural resources for construction • Danger of levee breach • Property acquisition and impacts on livelihoods • Up- and downstream flood impacts • False sense of security, which promotes increased floodplain activities • River access cut off, which reduces benefits for agricultural land	

METHOD(S)	ECONOMIC AND OPERATIONAL		SOCIAL AND ENVIRONMENTAL	
	DISADVANTAGES	ADVANTAGES	DISADVANTAGES	ADVANTAGES
AX5 Canal widening and deepening	• High capital cost • Needs regular maintenance	• More predictable management of regular floods • Quick implementation	• Intense hydrological modification • Disturbance of streambed and changes in sedimentation • Property procurement and impacts on livelihoods	• Potential recreational co-benefits in urban areas
AX6 Floodways	• High capital cost • May consume significant land extents in high-property-value areas	• Low maintenance cost • More predictable management of regular floods	• Potential habitat loss, seasonal inundation • Community displacement and impacts on traditional livelihoods • May introduce new flood risks	• Potential livelihood development through multipurpose schemes
AX7 Pumping	• High capital and maintenance costs • High energy consumption	• More predictable management of regular floods • Effective with high and fluctuating flows • Quick implementation	• Changes in sedimentation patterns, downstream bed erosion	
AX8 Engineered drainage systems	• High capital and maintenance costs	• More predictable management of regular floods	• May change natural drainage patterns	• If properly designed, can reduce water stagnation, reducing waterborne diseases and vector breeding
AX9 Groynes and revetments	• High construction cost	• Can withstand high flood flows	• Changes in sediment patterns, habitat disturbance • May conflict with fishing and other community uses	
AX10 Multipurpose infrastructure	• Advantages and disadvantages may vary significantly based on the type of infrastructure. Combining flood management infrastructure with other infrastructure needs will generally save cost, but can be operationally complex.		• Advantages and disadvantages may vary significantly based on the type of infrastructure. However, combining two types of infrastructure generally gives environmental and social benefits.	
AX11 Warning/ evacuation infrastructure		• Effective in saving lives • Quick implementation	• Some communities may not be receptive	• Significant lifesaving benefits

METHOD(S)	ECONOMIC AND OPERATIONAL		SOCIAL AND ENVIRONMENTAL	
	DISADVANTAGES	ADVANTAGES	DISADVANTAGES	ADVANTAGES
AY1 Upper watershed restoration AY2 Soil conservation methods	• Longer time needed for implementation • Difficult to quantitatively predict attenuation effect	• Moderate cost • Extends life of downstream infrastructure • Long-term resilience	• May impact livelihoods such as livestock grazing	• Positive ecological impacts • Reduced sediment transport • Groundwater recharge • May create new livelihood opportunities
AY3 Wetland restoration AY11 Coastal and reef restoration	• Longer time needed for implementation • Difficult to quantitatively predict attenuation effect	• Moderate cost • Long-term resilience	• May result in community relocation • May impact livelihoods such as livestock grazing, fishing	• Positive ecological impacts • May create new livelihood opportunities • Recreational benefits
AY4 Swales and infiltration devices AY5 Rainwater harvesting	• Only applicable in small scale	• Low cost • Quick implementation	• May increase vector breeding	• Groundwater recharge • Bioretention of contaminants • Reduced sediment transport • Recreational benefits
AY6 Detention basins and retention ponds	• Only applicable in medium scale • May consume significant land extents in high-property-value areas	• Moderate cost • Quick implementation	• Modification of drainage paths and stagnation • Vector breeding • Property procurement • May create polluted water bodies	• Reduced sediment transport • Helps groundwater recharge • Recreational benefits
AY7 Natural drainage path restoration	• Less applicability under changed flow conditions • Difficult to quantitatively predict attenuation effect	• Low implementation cost • Less complex design • Long-term resilience	• May trigger social resistance in highly modified areas	• Reduced sediment transport • Cleaner and healthier environment

METHOD(S)	ECONOMIC AND OPERATIONAL		SOCIAL AND ENVIRONMENTAL	
	DISADVANTAGES	ADVANTAGES	DISADVANTAGES	ADVANTAGES
AY8 Riparian vegetation restoration	• Not effective in high-velocity conditions • Difficult to quantitatively predict attenuation effect	• Low cost	• May constrain some existing uses of streams or lakes	• Positive ecological impacts • Recreational benefits
AY9 Removal of barriers	• Mostly applicable in medium scale • Difficult to quantitatively predict attenuation effect	• Low cost	• Removal of natural features (rocks, sandbars, beaver mounds) may cause environmental damage • May trigger social resistance in highly modified areas	• Cleaner and healthier environment
AY10 Green roofs/ walls and blue roofs	• Only applicable in small scale • May need additional structural strengthening of the building	• Low cost • Fast implementation	• May increase vector breeding • May cause fire hazard in dry season	• Improves aesthetic appeal and thermal comfort of buildings • Increases urban agriculture and park space • Reduces urban heat island effect

5.6 IMPORTANT CONSIDERATIONS FOR DESIGN, IMPLEMENTATION, MAINTENANCE AND CLOSURE OF STRUCTURAL METHODS

There are a number of design and implementation considerations for any structural flood risk management method that should be considered at the method selection stage and integrated into planning. Table 5.4 provides managers with information about common issues raised by experts during design and implementation, and highlights potential challenges at each stage.

TABLE 5.4 STRUCTURAL METHOD DESIGN, IMPLEMENTATION, MAINTENANCE AND CLOSURE CONSIDERATIONS

METHOD	DESIGN AND IMPLEMENTATION	OPERATION AND CLOSURE
AX1 Dams and reservoirs AX2 Diversions	• Should be designed by qualified professionals • Should be designed for multiple community uses • Poor designs can be costly and cause hazards • Community consultations and pre-feasibility studies are essential before site selection • Environmental impact study, feasibility study and community consultations are essential before design • Should minimize community relocation • Comprehensive relocation program should be developed if community relocation is required • Professional safety plans for construction are essential: heavy machinery movement, excavation, rock blasting	• Requires specifically dedicated trained staff for operation and monitoring; large dams need full-time staff • Frequent (e.g., once in three months) monitoring by a professional team is essential; may need advanced monitoring systems • Needs dedicated professional staff and a documented protocol to operate sluices and gates • Some reservoirs may need desilting every few years • Closure and removal are extremely expensive • If discontinued, a careful closure, decommissioning and restoration plan should be prepared; neglected structures can cause serious hazards and environmental issues
AX3 Constructed wetlands	• Should be designed by qualified professionals • Should be designed for multiple community uses • Environmental study and community consultations are essential before design	• Occasional (e.g., once in two years) monitoring/ inspection by an environmental engineer is required • Maintenance is generally low; however, some weeding may be necessary • Community volunteers can be involved in maintenance • Community awareness programs are essential where community use of wetlands is involved
AX4 Levees	• Should be designed by qualified professionals • Poor design can be costly, and mishaps and malfunctions can be dangerous • Environmental impact study, hydrological study, feasibility study, and community consultations are essential before design • Should not interfere with existing community uses (e.g., fishing, navigation) • Professional safety plans for construction are essential: heavy machinery movement, excavation, rock blasting	• Frequent monitoring by a team of professionals is essential • May need advanced monitoring systems • Dedicated operators needed if design includes lock gates • Removal is expensive • If discontinued, a comprehensive decommission plan should be prepared to remove the levees and restore the ecology; if the levees are entirely removed, regular safety inspections are required even after decommissioning the project
AX5 Canal widening and deepening	• Should be designed by qualified professionals • Environmental impact study, hydrological study, feasibility study, and community consultations are essential before design • Should minimize property acquisitions in urban areas • Professional safety plans for construction are essential (e.g., heavy machinery movement, excavation, rock blasting)	• Moderate (e.g., once a year) monitoring/ safety inspection by an engineer is required • May need desilting and bank stabilization every few years • Community volunteers can be involved in maintenance

METHOD	DESIGN AND IMPLEMENTATION	OPERATION AND CLOSURE
AX6 Floodways	• Should be designed by qualified professionals • Environmental impact study, hydrological study, feasibility study and community consultations are essential before design • Should be designed for multiple uses if possible • Design should keep property damage and land acquisition at a minimum • Comprehensive relocation program should be developed if community relocation is required	• Moderate (e.g., once a year) monitoring/safety inspection by a professional team is required • Seasonal cleaning, desilting and removal of large vegetation may be necessary • Community volunteers can be involved in maintenance • If discontinued, a comprehensive decommission and restoration plan should be prepared and implemented
AX7 Pumping	• Should be designed by qualified professionals • Poor designs can be energy inefficient • Environmental impact study, hydrological study, feasibility study and community consultations are essential before design • Pumping rate (flow) should be carefully selected when pumping groundwater floods – excessive pumping may cause ground subsidence	• Dedicated full-time operators required in pumping stations • Frequent monitoring by a professional team is essential; may need advanced monitoring systems • Replacement or overhaul of pumps necessary at regular intervals • If discontinued, machinery, electrical connections and structure must be carefully removed and the ecology of the site restored
AX8 Engineered drainage systems	• Can be constructed following standard guidelines, but larger systems require expert inputs • For larger systems, hydrological study and community consultations are essential before design • Combine with infiltration devices and sustainable urban drainage systems (SUDS) to minimize flow • Proper culvert design is very important; external professional inputs may be necessary	• Maintenance requirements are moderate; however, inspection for blockages and damage (by an engineer/technician) essential at least twice a year • Regular removal of silt and vegetation from drains and culverts required in most systems • Underground sewers/stormwater tunnels should be inspected annually by professional staff • May need advanced electronic monitoring systems • Community volunteers can be involved in maintenance
AX9 Groynes and revetments	• Should be designed by qualified professionals; poor design can exacerbate problems • Environmental impact study, hydrological study, feasibility study, and community consultations are essential before design • Should not interfere with existing community uses (e.g., fishing, navigation) • Professional safety plans for construction are essential (e.g., heavy machinery movement, excavation, rock blasting)	• Low maintenance requirements • Moderate monitoring/safety inspection by an engineer required • Removal is expensive • If discontinued, a comprehensive decommission plan should be prepared to remove the structures and restore the ecology
AX10 Multipurpose infrastructure	• May vary according to the type of structure	• May vary according to the type of structure
AX11 Warning/ evacuation infrastructure	• Larger structures should be designed by qualified professionals • Community consultations are essential • Considerations vary according to the type of structure	• Low maintenance requirements; however, regular (e.g., once a year) inspections are essential • Where electronic warning systems are used, frequent inspection by professionals is required • Community awareness programs for proper use and protection of the warning infrastructure are required

METHOD	DESIGN AND IMPLEMENTATION	OPERATION AND CLOSURE
AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY11 Coastal and reef restoration	• Should be designed with both expert and local knowledge • Environmental impact study and community consultations are essential before design • Use only native plants and animals in restoration • Never change ecosystem or wetland type to gain better infiltration • Plan to maximize multiple community benefits	• Low maintenance requirements once restoration has matured • Occasional monitoring and inspection by a restoration ecologist are required • Weed management necessary in some cases • Combine with community use to minimize maintenance • Community awareness programs essential (on importance of restoration, protection and maintenance of restored areas)
AY4 Swales and infiltration devices AY5 Rainwater harvesting	• Can be designed with little expertise; best to use established guidelines and maximize multiple uses • Maximize recreational benefits • Never use for wastewater disposal	• Moderate maintenance once features have matured; annual inspections, weeding, and pruning required • Occasional monitoring and inspection by a trained professional are required • Vector management required • Community volunteers can be involved in maintenance • Volunteer training and awareness building about features helpful in user communities
AY6 Detention basins and retention ponds	• Should be designed by qualified professionals • Hydrological study and community consultations are essential before design • Avoid unnecessary water impoundment • Maximize recreational benefits	• Desilting required every few years • Vector management required • If discontinued, efforts required to prevent further impoundment/stagnation • Community volunteers can be trained in maintenance; if a retention is closed, it should be fully restored to avoid unintended water collection
AY7 Natural drainage path restoration	• Community consultations are essential and should be carried out with maximum community participation • Consult experts if the historical drainage paths are unclear • If culverts are required, culvert design should be done by professionals	• Annual maintenance and inspection programs are essential • Community volunteers can be involved in maintenance • Training and awareness building about restoration programs can involve volunteers in target communities
AY8 Riparian vegetation restoration	• Should be designed with both expert and local knowledge • Environmental assessments and community consultations are essential before design	• Annual inspection and weeding programs are necessary • Involve community volunteers in maintenance • Training and awareness building about restoration programs can involve volunteers in target communities
AY9 Removal of barriers	• Community consultations are essential and should be carried out with maximum community participation • Consult experts if removal of large natural features or unauthorized structures is required • Environmental assessments and hydrological studies are essential before design if removal of large natural features is involved	• Removal of weeds, large woody debris and silt has to be carried out in regular intervals (every one to two years) • Involve community volunteers in maintenance • Training and awareness building about restoration programs can involve volunteers in target communities
AY10 Green roofs/ walls and blue roofs	• A qualified civil engineer should check whether the building is fit for the modification and for the additional weight load, or in the case of a blue roof design, the water retention system • Waterproofing should be properly designed • Plants and soils should be selected carefully by a specialist knowledgeable about green roof/wall technology	• Green roofs/walls require regular weeding, watering and fertilizing • Yearly inspection (by professionals) of the roof for damage to the structure is necessary • Removal of a green roof/wall can be costly

5.7 USING THE OPTIMUM COMBINATIONS OF HARD AND SOFT STRUCTURAL METHODS

Managers should strive to use hard engineering and soft methods (natural and nature-based) in combination to meet objectives. The appropriate combination of methods will optimize the project's flood risk management, as well as its social and environmental benefits. A structural method's effectiveness can be substantially enhanced by pairing it with other structural and non-structural methods. Doing so will help managers reduce the capacity/size/area of such hard methods as dams, diversions or levees, which can be costly structures. For example, lower dam heights or levee heights will be possible if runoff from the upper catchment has been reduced by watershed conservation. The Flood Green Guide also recommends exploring options for enhancing the effectiveness of existing hard methods with soft methods. For example, upper watershed conservation in existing dam or levee systems can minimize the need for future dam and levee expansion. Since hard structural methods can lead to negative social and environmental impacts, it is better for the community to use complementary hard and soft methods. For example, a mix of revetments and riparian restoration can be used in high-risk areas, and areas exposed to lower risk of flooding can be protected only with riparian restoration. The combined-method approach will minimize disturbance to the ecological functioning of the riparian system and, therefore, potentially provide enhancement to livelihoods and recreation benefits of the waterway. On the other hand, riparian restoration should also further strengthen the risk reduction function of revetments by reducing amount and flow of floodwaters. Table 5.5 illustrates options for combining soft methods with specific hard structural methods.

5.8 RESOURCE AND COST PLANNING IN SELECTION AND IMPLEMENTATION OF STRUCTURAL METHODS

Planning, regulatory, resource (both human resources and material inputs), and cost requirements are all important feasibility parameters of a flood risk management project. Planning and execution of any flood risk management method will require human, financial and material resources, beginning with the design stage. Structural and non-structural methods that are technically applicable to a given flood risk management problem may not be practical in certain contexts due to their multiple requirements. This section provides guiding information for cost and resource requirements in a table for each structural method. However, in flood warning and evacuation infrastructure/multipurpose infrastructure (AX10, AX11), costs and inputs will vary significantly depending on the type of infrastructure (e.g., multipurpose tunnels, developing evacuation paths, flood warning signs). Therefore, the section will not provide cost and resource requirement guidelines for these two methods.

5.8.1 PLANNING AND REGULATORY REQUIREMENTS

National and/or local government regulations influence the feasibility of flood risk management methods in a given area. Regulations related to flood risk management projects might include

- land use and land tenure-related laws and land use plans
- environmental laws and Environmental Impact Assessment (EIA) regulations
- local government bylaws on building permits, land subdivision and drainage
- national or provincial development plans and policies
- national or provincial disaster management regulations and action plans

5.8.2 HUMAN RESOURCES

From the start of any flood management project, appropriate human resources are essential. Acquiring the proper expertise to undertake feasibility studies and design of structural and non-structural methods is key. For example, engineers, hydrologists, ecologists, conservation specialists, surveyors and sociologists might all be part of the team. Most projects also will need the services of community organizers or mobilizers.

	SOFT METHODS							
HARD ENGINEERING METHODS	AY1 Upper watershed restoration AY2 Soil conservation methods	AY3 Wetland restoration	AY4 Swales and infiltration devices AY5 Rainwater harvesting AY10 Green roofs/walls and blue roofs	AY6 Detention basins and retention ponds	AY7 Natural drainage path restoration	AY8 Riparian vegetation restoration	AY9 Removal of barriers	AY11 Coastal restoration
AX1 Dams and reservoirs AX2 Diversions	• Reduces runoff • Less dam/diversion capacity required	• Increase downstream retention • Less dam/diversion capacity required	Not applicable	Not applicable	Not applicable	Increases downstream resilience to high velocity and flow conditions	Not applicable	Capacity of tidal flood barriers/diversions can be reduced
AX3 Constructed wetlands	Not applicable	• Complements the retention capacity • Less constructed wetland area required	• Detains runoff and improves water quality • Enhances endurance of wetland	Not applicable	• Better flow conditions • Less siltation	Not applicable	Not applicable	
AX4 Levees	• Reduces runoff and velocity • Lower levee heights required • Reduced threat of breach due to scouring	Not applicable	Not applicable	Not applicable	Not applicable	Complements bank strengthening	Not applicable	Lower levee heights required (in the case of tidal floods and storm surges)
AX5 Canal widening and deepening	Not applicable	Not applicable	• Detains runoff • Reduced widening required	• Detains runoff • Reduced widening required	Not applicable	Complements bank strengthening	Improves flow conditions	
AX6 Floodways	• Reduces runoff • Less floodway capacity required	• Retains overflow • Less floodway capacity required	Not applicable	Not applicable	Not applicable	Increases downstream resilience to high velocity and flow conditions	Not applicable	
AX7 Pumping	• Reduces runoff • Less pump capacity required	• Retains overflow • Lower pump capacity and pumping frequency required	• Retains runoff and controls silt • Lower pump capacity and pumping frequency required • Long pump life	• Retains runoff and controls silt • Lower pump capacity and pumping frequency required • Long pump life	Not applicable	Not applicable	• Improves flow conditions • Lower pump capacity and pumping frequency required	
AX8 Engineered drainage systems	Not applicable	• Retains overflow • Small drain size can be used	• Retains runoff and controls silt • Small drain size can be used • Less maintenance	• Retains runoff and controls silt • Small drain size can be used • Less maintenance	Improves flow conditions	Not applicable		
AX9 Groynes and revetments	• Reduces runoff, flow fluctuations and velocity • Reduces erosion	Not applicable	Not applicable	Not applicable	Not applicable	Complements bank strengthening	Not applicable	Complements groynes and revetments by dissipating the energy of storm surges and tidal waves

TABLE 5.5 COMBINATIONS OF HARD AND SOFT STRUCTURAL METHODS TO ENSURE OPTIMUM FUNCTIONALITY, COST, AND SOCIAL AND ENVIRONMENTAL BENEFITS

COMBINATIONS OF HARD AND SOFT STRUCTURAL METHODS TO ENSURE OPTIMUM FUNCTIONALITY, COST, AND SOCIAL AND ENVIRONMENTAL BENEFITS

World Wildlife Fund. 2016. Natural and Nature-based Flood Management: A Green Guide. Washington, DC: World Wildlife Fund. http://envirodm.org/flood-management

Disclaimer: This *Guide* is made possible by the generous support of the American people through the United States Agency for International Development (USAID). The contents are the responsibility of World Wildlife Fund and do not necessarily reflect the views of USAID or the United States Government.

Regardless of the scale of the project, it is important to have a dedicated project manager or coordinator and an accountant involved from the initial stage. Field-level staff (field assistant, survey assistants, drivers) and labor are also important human resource requirements. Managers should plan well in advance on how to acquire these human resources and prepare a plan of recruitment. Care should be taken to ensure that recruiting for skilled or unskilled tasks is done locally, thereby supporting the local community and economy. Managers should plan training for personnel and develop a training plan from the design stage of the project.

5.8.3 MATERIAL SOURCING

Most structural methods (hard and soft) will involve significant sourcing of materials. Though material requirements invariably affect a project's cost, other factors should also be considered in sourcing materials. Flood risk management projects often require a wide range of materials, including construction material (sand, gravel, cement, timber, soil, seeds and seedlings, and synthetic material like geotextiles). Managers should consider the following criteria in addition to cost-effectiveness:

- Material should be environmentally and responsibly sourced without depleting or damaging ecosystems.
- Any material that carries a human health or environmental risk should not be used.
- Procurement of any biological material (plants, seeds, animals) should be done with expert consultations.
- Imported material should conform to existing environmental certification.
- Local material sourcing should not adversely affect traditional livelihoods, but instead should strive to support them where possible.
- Material transport and storage should be done with no adverse impacts on local communities and their livelihoods.

5.8.4 COST ANALYSIS

Cost is often a limiting factor in flood risk management projects, as finances are often limited and, in many cases, inadequate. Therefore, cost analysis, budgeting and cost management are crucial for the success of a project.

First, the managers should work out preliminary cost estimates for the potential combination of methods. Costs involved in planning, design, construction/implementation, operation, maintenance and monitoring should be included in these preliminary estimates. For hard engineering works, the services of a qualified engineer and a budget consultant should be enlisted to prepare initial estimates. Some guidelines for preparing preliminary estimates are provided in appendix D. Based on preliminary cost estimates, some options may need to be ruled out. When an economically feasible set of methods is selected, detailed budgeting of the project should be completed, in consultation with an accountant or finance officer. Based on these detailed budgets, the project design should be carried out with the participation of managers, technical experts, communities, donors and finance officers.

The cost of structural methods is scale dependent. For example, a project that covers larger areas or handles a bigger flood flow will cost more. However, it should be noted that while certain cost components, such as materials or construction labor, will be directly proportional to the scale of the project, other components, such as preparation of designs, community consultations or building access to roads, will vary only marginally between different scales. Different cost components for different types of projects are discussed in appendix D. The cost of a project also may increase with qualitative changes. For example, in an engineered drainage system, installing underground drains is significantly more expensive than constructing surface drains.

For all construction work, detailed bills of quantities should be prepared by a qualified expert (quantity surveyor, cost engineer, civil engineer, civil engineering technician) based on the measurement standards followed in the country or locality. Detailed budgets should be prepared for each phase of the project, even for nonengineering works such as replanting and wetland restoration. During project implementation, costs should be monitored and managed according to bills of quantities or budgets.

All works entrusted to another party (other than the manager's organization) should be agreed upon by a standard written contract clearly stating the nature and value of the work. Most countries have standard formats for construction contracts. See appendix D for resource and cost planning guidance.

5.9 MONITORING AND EVALUATION

Managers should carefully plan and implement monitoring and evaluation as an essential part of the planning process for flood risk management projects. The following are general requirements for effective monitoring of a flood risk management project:

1. Monitoring should cover both the project as a whole and individual methods separately.

2. Monitoring parameters should be carefully selected. They should cover all aspects of the project and methods – technical, ecological, social, financial, and program management issues.

3. Selecting too few parameters will make the monitoring program ineffective. Too many parameters will make it too time consuming and costly.

4. Different types of monitoring are used for different parameters, mainly based on who's involved in monitoring and what resources are required: (a) official monitoring conducted by the responsible agencies and organizations, (b) monitoring conducted by external experts, or (c) community monitoring done in conjunction with responsible agencies. A good monitoring program will have a combination of official, expert and community monitoring.

5. Different parameters will require different monitoring frequencies: short-term, intermediate and long-term. Selecting the proper monitoring frequency for each parameter will be vital for effective maintenance and evaluation of the project.

Table E1 in appendix E provides a detailed guide for selection of parameters, types and frequencies for monitoring and evaluation programs.

5.10 ADDITIONAL RESOURCES

1. Steve Adair et al., *Management and Techniques for Riparian Restorations: Roads Field Guide*, (Fort Collins, CO: US Dept. of Agriculture, Forest Service, Rocky Mountain Research Station, 2002), http://www.fs.fed.us/rm/pubs/rmrs_gtr102_1.pdf.

2. Philip Roni and Tim Beechie (eds.), *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats* (West Sussex, UK: Wiley-Blackwell, 2012).

3. US Environmental Protection Agency (EPA), *A Handbook of Constructed Wetlands, vol. 1*, https://www.epa.gov/sites/production/files/2015-10/documents/constructed-wetlands-handbook.pdf.

4. W.J. Mitsch and J.G Gosselink, *Wetlands* (Hoboken, NJ, USA: John Wiley and Sons, 2007).

5. W.J. Mitsch and S.E. Jorgensen, *Ecological Engineering and Ecosystem Restoration* (Hoboken, NJ: John Wiley and Sons, 2004).

6. D. Butler and J.W. Davies, *Urban Drainage*. 2nd ed. (New York, London: Spon Press, 2004), https://vannpiseth.files.wordpress.com/2015/07/urban-drainage-butler.pdf (Also see the third edition published in 2011).

7. D.H. Gray and R.B Sotir, *Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control* (New York: John Wiley and Sons, 1996).

8. Lewis L., *Soil Bioengineering, an Alternative for Roadside Management: A Practical Guide* (San Dimas, California: USDA, 2000).

9. Water by Design, *Concept Design for Water Sensitive Urban Design*, version 1. (Brisbane: South East Queensland Waterways Partnership, 2009), http://waterbydesign.com.au/conceptguide/.

10. H.C. Pereira, *Policy and Practice in the Management of Tropical Watersheds* (London: Westview Press, 1989).

CHAPTER 6

6. URBAN ISSUES

6.1 SECTION CONTENT

This chapter describes issues unique to urban areas, including the factors affecting flooding, the impacts of climate, urban flood governance, community engagement, and considerations for urban coastal areas.

Phuket, Thailand, September 5, 2008: Floods on Thanon Ratuthit Songroipi Road in Patong, Phuket. Flooding is very common during the wet season in Phuket as storm drains struggle to cope with the heavy tropical downpours.

6.2 WHAT IS URBAN FLOODING?

More than half the world's population currently lives in urban areas, and this population is expected to increase to 70% by 2050.[1] Most professional flood managers do not distinguish between urban and rural floods; there is no standard definition for what constitutes an urban area. **Urban** areas typically consist of dense populations, a built-up physical landscape including paved streets and electricity, and other economic features, like financial centers. Rural and urban areas exist as part of a larger rural-urban continuum within the watershed, which varies as population, infrastructure and development types shift.

Urban flooding is localized flooding that occurs when the sewage system and/or drainage system lack the capacity to adequately drain precipitation. This type of flooding is often the result of a combination of factors that may accompany **urbanization** (an increase in the proportion of a country that is urban). These factors include an increase in **impervious surfaces** (those that do not allow water to be absorbed, such as rooftops, roads and parking lots); inadequate stormwater storage or drainage capacity; and poorly planned infrastructure, particularly in rapidly urbanizing areas. Riverine floods, coastal floods, pluvial and groundwater floods, and artificial system failures (e.g., dam failure) also affect urban areas (see chapter 3).[2]

6.3 IMPACTS OF URBAN FLOODING

Damages, costs and mortality risks are typically higher in urban floods than in rural floods due to the high concentration of people, infrastructure and other assets. Direct impacts from urban floods may be more geographically widespread and longer lasting. Urban floods disrupt assets of regional or national significance, such as large infrastructure, financial centers and health services. Indirect impacts from urban flooding include disease, reduced nutritional and educational opportunities, and loss of livelihoods.[3]

The number and diversity of people potentially affected by an urban flood amplify the challenge of management and response. Urban floods can occur more quickly than rural floods, and urban development may lead to flooding in areas previously unaffected. Urban populations also include transitory populations, such as workers and visitors, as well as new residents who may be unfamiliar with the timing and location of cyclical flooding. People new to an area may not know how to reach safety and may be unfamiliar with safety precautions. This heightened social vulnerability, in combination with the rapid onset of some types of urban flooding, creates a higher level of flood risk and can lead to significant loss of property – and loss of lives – when flooding does occur.

6.4 WHAT FACTORS AFFECT URBAN AREAS AND FLOODING?

The complex interactions between the following features within an urban environment aggravate flooding:

- physical factors
- climate- and weather-related factors
- governance and management factors

These components operate at various scales – local, regional, state and national – often leading to interrelated causes of flooding. For example, urban floods may result from local factors like inadequate land use planning and impermeable surfaces; regional/upstream factors like deforestation; and national/global factors like sea level rise. This complexity offers a range of opportunities for intervention.

---

1 Abhas K. Jha, Robin Bloch and Jessica Lamond, *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* (Washington, DC: World Bank Publications, 2012), 167, https://www.gfdrr.org/sites/gfdrr/files/urban-floods/urbanfloods.html.

2 Ibid.

3 Ibid.

6.4.1 PHYSICAL FACTORS

6.4.1.1 Land Use Change and Reduced Permeability

Urbanization alters existing land use patterns, frequently resulting in the loss of natural vegetation and open space. These land use changes often cover wetlands; block or redirect rivers or streams; and collect and move water through artificial channels like drains, culverts and tunnels that change the natural drainage patterns. Urbanization may affect neighboring areas (particularly those downstream), thus increasing the risk of flooding elsewhere. All of these issues have implications for flood risk management.

Impervious, or paved, surfaces – such as roads and rooftops – also increase with development. Impervious surfaces dramatically alter the urban **hydrological cycle** and local climate (see figs. 6.1 and 6.2).

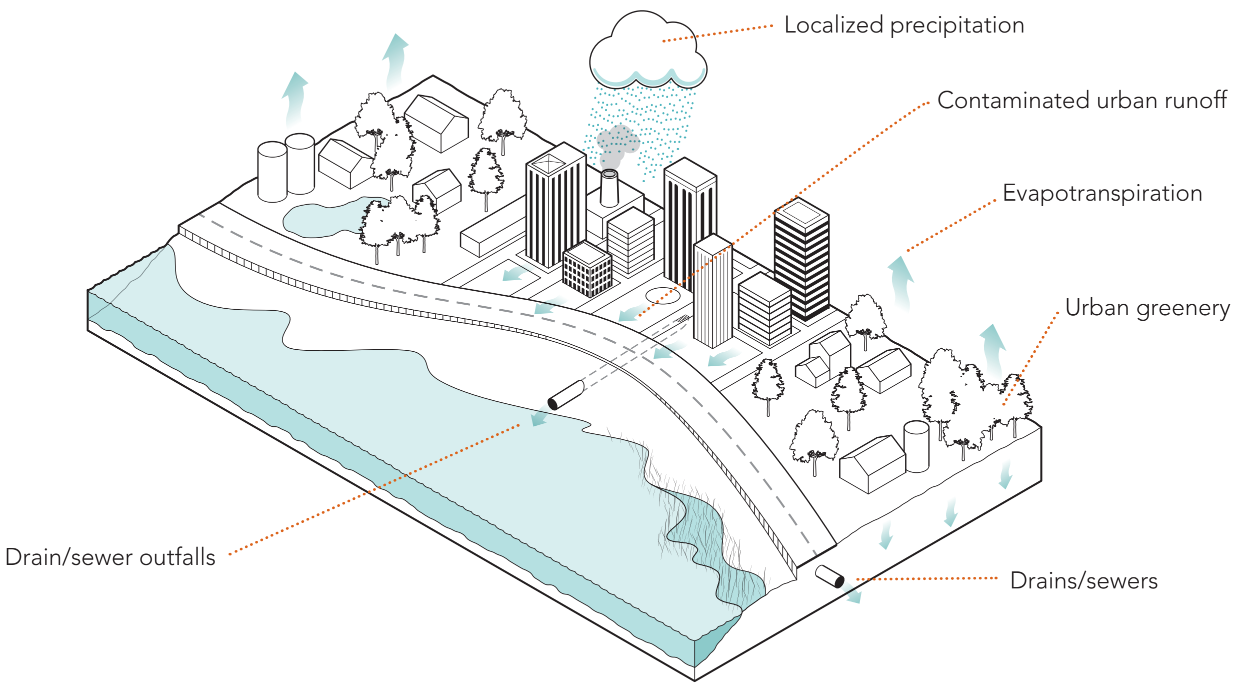


FIGURE 6.1 URBAN HYDROLOGICAL CYCLE EXAMPLE

In urban areas, impervious surfaces increase the amount of precipitation that runs off hard surfaces – and the speed at which it travels – by reducing the opportunity for precipitation to be retained where it falls or intercepted by vegetation.[4] Depending on the expanse of impervious surfaces in the watershed, surface runoff volume can increase between two to 16 times the predevelopment rate, with a corresponding reduction in groundwater recharge.[5] This altered urban **water cycle** can turn normal urban rainfall into localized flooding or flash floods.[6]

Typically, in urban areas, the stormwater management system is made up of hard (gray) infrastructure. **Gray infrastructure** conveys stormwater as quickly as possible out of the urban area and into the nearest body of

---

4 For more discussion on these issues, see the Land Cover, Land Use and Infrastructure section in chapter 3.

5 T. R. Schueler, "The Importance of Imperviousness," *Watershed Protection Techniques* 1, vol. no. 3 (1994): 100-111, http://scc.wa.gov/wp-content/uploads/2015/06/The-Importance-of-Imperviousness_Schueler_2000.pdf.

6 Associated Programme on Flood Management (APFM), *Urban Flood Risk Management*, Technical Document No. 11 (WMO, 2008), accessed November 22, 2014, http://www.apfm.info/publications/tools/Tool_06_Urban_Flood_Risk_Management.pdf.

water. Conventional stormwater management typically includes a collection system made up of graded roads, curbs, gutters and pipes to channel water into combined or separate sewer systems (see chapter 5 for more on **engineered drainage** systems).

Gray infrastructure methods manage a limited volume of stormwater by design. Today, rapid population growth, increased development and more frequent, intense precipitation events easily overwhelm existing urban stormwater management capacity. Without adequate stormwater management capacity, untreated **sewage** and polluted stormwater runoff enter receiving waters, thus reducing water quality and posing environmental and health risks. If collection systems cannot accommodate the increasing volume of stormwater, urban flood risk is increased.

In urban settings, the stormwater management methods outlined in chapter 5, as well as **sustainable urban drainage systems** (SUDs), which perform a similar function, are central to reducing pressure on existing water systems by slowing, retaining and detaining stormwater.

6.4.2 CLIMATE AND WEATHER FACTORS

6.4.2.1 Urban Microclimate and Impervious Surfaces

The increase in impervious surfaces and dense infrastructure that accompanies urbanization creates a local microclimate that is often warmer than surrounding areas.[7] This is known as the **urban heat island (UHI) effect**. The UHI effect is caused by impervious materials used in urban areas and the concurrent reduction in vegetation. Dark materials – like asphalt – used in urban areas typically have low reflectivity, or **albedo**, meaning that the materials absorb heat throughout the day instead of reflecting it.[8] This varies with type and density of materials. The loss of vegetation reduces the cooling effects of evapotranspiration, the shade cover of trees, and ground-level moisture.[9] These conditions combine to create a warmer urban microclimate. Flood Green Guide users should consider the UHI effect as a part of the urban context when they are identifying and selecting flood management methods.

FIGURE 6.2 TEMPERATURE AND RUNOFF IN THE URBAN MICROCLIMATE

7 NASA/Goddard Space Flight Center, "NASA Satellite Confirms Urban Heat Islands Increase Rainfall Around Cities," *Science Daily*, June 19, 2002, https://www.sciencedaily.com/releases/2002/06/020619074019.htm.

8 Ibid.

9 EPA, *Reducing Urban Heat Islands: Compendium of Strategies Urban Heat Island Basics*, https://www.epa.gov/sites/production/files/2014-06/documents/basicscompendium.pdf.

6.4.2.2 Weather and Natural Climate Variability at the Local Scale

Naturally occurring seasonal weather and multiyear climate patterns are also affected by larger-scale processes such as **El Niño** and **La Niña**, which can result in temperatures that are warmer or cooler than normal temperatures and changes in precipitation patterns.[10] These can affect urban flood risk in impacted regions.

In some regions, El Niño and La Niña alter regional temperature and precipitation patterns in intensity and frequency, and can increase the likelihood of storms.[11] The impacts vary by region, causing increased flooding in some areas and drought in others. Natural climate variability has some predictability, but the intensity and duration of weather patterns may shift because of climate change.[12] When assessing urban risks and selecting flood management methods, flood managers should consider current climate variability, the spatial pattern of impervious surfaces, and projected climate change.

The ability of a drainage system to handle runoff from intense rainfall or rapidly melting snow or ice depends on how quickly water flows into the system. The volume of water that a system can handle over a one-hour period might not be the same volume it can handle over a 15-minute period. Intense rainfall or rapid snowmelt can lead to flooding in an area where the same volume of water falling over a longer period will not.

6.4.2.3 Global Climate Change

Climate change, caused by increasing greenhouse gas emissions worldwide, will lead to "increased frequency, intensity, and/or duration of extreme weather events such as heavy rainfall, warm spells and heat events, drought, intense storm surges, and associated sea level rise."[13] The impacts of global climate change in urban areas may vary depending on the conditions and location of the urban area. For example, increases in extreme weather events and precipitation can overwhelm urban drainage systems, causing localized flooding, riverine flooding, and increasing storm surge.[14] Sea level rise from warming oceans and melting glaciers may increase the population at risk from flooding in coastal cities due to a combination of land subsidence and an increase in local sea level height.[15] Sea level rise also contributes to an increase in tidal flooding and intensified storm surge. Research by the New York City Panel on Climate Change demonstrated that it is virtually certain that sea level rise alone will lead to an increased frequency and intensity of coastal flooding as the century progresses.[16]

These components of climate can amplify urban flooding and should be part of a flood risk assessment that identifies the range of multiple risk factors and the best methods for flood risk management.

6.4.3 GOVERNANCE AND MANAGEMENT

6.4.3.1 Inadequate Drainage Planning, Construction and Maintenance

Hard infrastructure for stormwater management – such as gutters, drains, culverts, channels and retention areas – needs constant maintenance, including debris removal and updates to increase capacity and keep up with higher volumes of runoff. If funds are not available, improvements in drainage infrastructure may fall behind the

---

10 NOAA. El Niño & La Niña. Accessed May 20, 2016. Available from https://www.climate.gov/enso.

11 R. Blake et al., "Urban Climate: Processes, Trends, and Projections," in *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*, ed. C. Rosenzweig et al. (Cambridge, UK: Cambridge University Press, 2011), 43–81.

12 Ibid.

13 IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (New York: Cambridge University Press, 2014), 535-612, https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-PartA_FINAL.pdf.

14 Ibid.

15 Blake, "Urban Climate," 43–81.

16 R. Horton, C. Little, V. Gornitz, D. Bader, and M. Oppenheimer, 2015: *New York City Panel on Climate Change 2015 Report: Sea level rise and coastal storms.* Ann. New York Acad. Sci., 1336, 36-44, doi:10.1111/nyas.12593.

increasing rates of stormwater runoff. Even where drainage infrastructure is in place, lack of maintenance – at times combined with inadequate trash removal and lack of waste management – can block drainage systems and lead to flooding.

6.4.3.2 Land Subsidence

Natural factors (e.g., soil types) and human factors (e.g., over-extraction of groundwater, urbanization) cause **land subsidence**, or the compacting and sinking of soil. Delta soils are particularly susceptible because the deltaic soil expands and contracts with water. When water or moisture in the soil is cut off or reduced – by impervious surfaces or from excessive groundwater extraction for drinking water supplies and industrial uses – the soil dries out and begins to compact. The weight of buildings and other infrastructure found in urban areas amplifies soil compaction. Hard engineering methods, such as drainage pumps, levees and dikes, can also cause subsidence.[17] Soil compaction creates low-lying land, thereby increasing the area at risk of flooding and amplifying the impact of sea level rise.

Subsidence also can cause

- changes in river systems and flows
- intrusion of salt water into groundwater sources
- increases in areas at risk of coastal and inland flooding
- damage to existing drainage and infrastructure systems

6.4.3.3 Unplanned Urbanization, Encroachment, and Occupation of Drainage Systems

© Martin Harvey/WWF

This aerial image of an informal settlement in South Africa shows the minimal allocation of space to be used for drainage infrastructure. Lack of infrastructure is often related to failure of planning or inability to enforce municipal plans.

17 Deltares, "Sinking cities: An Integrated Approach towards Solutions," October 2013, https://www.deltares.nl/app/uploads/2015/09/Sinking-cities.pdf.

Many urban areas have grown in an unplanned or semi-planned manner. For example, the population of Lagos, Nigeria, grew from just over 1 million in the 1970s to an estimated population of 21 million in 2016.[18] In many urban areas, municipal governments have been unable to keep up with rapid growth, lack detailed land use plans, or are unable to enforce land use regulations. New construction often encroaches on, blocks or fills in natural drainage systems such as dry streams and wetlands. Unplanned and poorly managed development raises the risk of flooding, particularly in places where formal urban planning and construction management are limited or absent. Urban land that has been set aside for drainage – including large concrete drains, storm channels and flood retention areas – often becomes settlement sites for people who cannot afford to live elsewhere. Informal dwellings in these areas obstruct drainage, leading to a significant risk to life and property in the case of flooding.

6.4.3.4 Upstream and Coastal Land Use Changes

Upstream land use changes that reduce the ability of precipitation to infiltrate the ground – including urbanization, deforestation, conversion of land for agriculture, and infilling of wetlands – can increase flood risk downstream. The flow of stormwater runoff into surface waterways increases when precipitation is unable to infiltrate the ground, thus increasing the risk of flooding downstream. Other land use changes, such as development of coastal wetland areas and loss of mangroves, can increase flood risk in coastal urban communities. For example, wetlands stabilize coastlines, filter pollution, slowly release floodwater and stormwater, and reduce the impact of storm surge.[19] Similarly, mangroves can act as a buffer against the impacts of storm surge. Healthy coastal ecosystems, when well managed, can protect inland communities and reduce the vulnerability of people in coastal areas.

6.5 URBAN FLOOD MANAGEMENT METHODS

To develop an integrated flood management (IFM) approach, urban flood managers should examine a range of scales, from the neighborhood to the watershed, and consider a combination of hard and soft structural methods as well as non-structural methods. Guide users should refer to chapter 2 and the Flood Green Guide Framework before undertaking a project. This chapter will help inform the stage 1 contextual analysis. Urban flood managers may need to coordinate with regional partners in the watershed to address upstream causes of flooding (see chapter 3). Methods vary in cost and maintenance requirements (see chapter 5), and some methods will yield results sooner than others will. For example, improving solid waste management practices – such as collection and disposal, recycling, and clearing debris from drains and waterways – can immediately reduce the impacts of flooding.[20] Constructing retention and detention ponds may take longer; **reforestation** and wetland restoration might not reduce flood risk for years but can offer co-benefits in the short term.

GUIDANCE: The Flood Green Guide recommends managers first apply IFM non-structural methods and then if needed include structural (hard and/or soft) methods as part of an integrated approach.

GUIDANCE: Information provided in this chapter should always be used in conjunction with the Flood Green Guide Framework presented in chapter 2.

18 John Campbell, "This is Africa's New Biggest City: Lagos, Nigeria, Population 21 Million," *The Atlantic*, July 10, 2012, http://www.theatlantic.com/international/archive/2012/07/this-is-africas-new-biggest-city-lagos-nigeria-population-21-million/259611/.

19 EPA, "What are wetland functions?," November 17, 2015, https://www.epa.gov/wetlands/what-are-wetland-functions.

20 Jha, Bloch and Lamond, *Cities and Flooding*, 167.

The design and operation of an urban flood risk management system consists of

- advocating for improved **urban planning** and urban management to limit flood-prone development and reduce the risk of flooding
- increasing public awareness and preparation through the use of flood hazard mapping, preparedness training, warning systems and evacuation plans
- retaining water in designated areas and reducing the volume of runoff during a storm event using structures such as rooftop gardens, swales and detention ponds built as part of the overall drainage systems
- improving drainage in given areas with engineered systems like gutters, drains, culverts and channels as well as natural watercourses such as streams and rivers
- limiting the impact of flooding to locations and facilities by using flood barriers, flood walls and such flood-proofing strategies as buildings elevated above base flood elevation or buildings designed so the first floor can withstand a flood

EXAMPLE: In 2010, the Capital Development Authority (CDA) of Islamabad, Pakistan, launched the first rainwater harvesting program in the country.[21] The Pilot Rain Water Harvesting Project used tanks, ponds and small dams to harvest rainwater at the household, neighborhood and town scales.[22] In this case, rainwater harvesting reduced urban flood risk while providing an additional source of drinking water, which reduced vulnerability to irregular rainfall patterns (a possible result of climate change). In New York City, a 1.4-acre (0.57 hectare) rooftop farm produced over 45 tons of vegetables and managed over 3 million liters of stormwater per year.[23] In addition to reducing flood risk, this rooftop farm provided a source of employment, food security and nutrition, and reduced air pollution.

Non-structural measures include awareness, preparedness and advocacy. Structural measures, such as water retention and drainage systems, can limit the impacts to flood-prone areas and contain damage to facilities. (See chapter 5 for more on non-structural and structural measures.)

Existing urban plans, processes and initiatives can be adapted to integrate flood risk management methods and achieve multiple co-benefits. For example, in urban areas with space and land constraints, multipurpose infrastructure, such as detention basins, may double as parking structures or recreational facilities.

Natural and nature-based flood management methods often help meet multiple objectives, including alternative livelihoods for poverty reduction, climate change adaptation, environmentally responsible development, and improved public health.

---

21 *Daily Times*, "Islamabad First City to Have Rainwater Harvesting Programme," accessed March 5, 2016, http://archives.dailytimes.com.pk/islamabad/13-Apr-2010/islamabad-first-city-to-have-rainwater-harvesting-programme.

22 Brett Walton, "Pakistan Installs Country's First Urban Rainwater Harvesting System," Circle of Blue, last modified April 24, 2010, http://www.circleofblue.org/waternews/2010/world/south-asia/pakistan-installs-countrys-first-urban-rainwater-harvesting-system/.

23 Nevin Cohen and Katinka Wijsman, "Urban Agriculture as Green Infrastructure: The Case of New York City," *Urban Agriculture Magazine*, no. 27, March 2014, http://learning.icma.org/store/streaming/openMaterial.php?id=124491&force_download=1.

Using natural and nature-based methods in urban areas promotes **biodiversity** and ecosystem services such as water and air purification, soil stabilization, noise reduction, heat-island buffers and microclimate regulation.[24] Research shows the introduction of nature into urban areas also reduces stress and crime levels while promoting health and well-being.[25]

EXAMPLE: In 2013, the government of Barcelona, Spain, enacted its Green Infrastructure and Biodiversity Plan 2020 to achieve multiple goals, including environmental objectives to regulate the urban water cycle; social objectives to improve the quality of life in the city; and economic objectives to encourage fiscal growth.

6.6 URBAN FLOOD GOVERNANCE

Urban governance is a critical factor in urban flood risk management. Local governments are primarily responsible for planning, implementing and managing most of the measures that can reduce urban flood risks as well as the direct and indirect impacts of flooding. Urban governance, however, is complex, shaped by interactions among social, political and economic considerations at the local, regional, national and watershed scale. Managing urban floods often requires flood managers to work across departments (e.g., public works, development planning and environment) and across jurisdictions, since watersheds rarely follow administrative boundaries. The success of urban flood management depends on supportive social and institutional conditions as well as effective monitoring and enforcement mechanisms.

Improvements in urban flood risk management require political will and buy-in at the local and national levels as well as community participation. Private sector involvement and acceptance will help address market-based barriers, while social acceptance and community engagement are vital for the long-term success of flood risk management programs.

Governance and urban flood risk management primarily require

- integrating flood risk management into the urban planning process
- coordinating various governmental stakeholders
- strengthening the flood risk management process through regulations, such as planning regulations, municipal bylaws and building codes
- involving nongovernmental and private sector stakeholders in flood-related decision-making
- effectively engaging and consulting with the community at all stages of flood risk management

Financing mechanisms and land use planning are the most effective regulatory systems for managing urbanization, growth and encroachment of the floodplain and other flood-prone areas.

For more discussion on governance, private sector engagement, and financing, see chapter 3.

---

24 Richard Blaustein, "Urban Biodiversity Gains New Converts: Cities around the World Are Conserving Species and Restoring Habitat," *BioScience* 63, no. 2 (February 2013): 72–77, doi: 10.1525/bio.2013.63.2.3.

25 Cecily Maller et al., "Healthy Nature Healthy People: 'Contact with Nature' as an Upstream Health Promotion Intervention for Populations," *Health Promotion International* 21, no. 1 (March 2006): 45–54, doi: 10.1093/heapro/dai032; IUCN, "Barcelona's Quest for a Green Urban Future," last modified December 9, 2013, http://iucn.org/about/union/secretariat/offices/europe/?14172/Barcelonas-quest-for-a-green-urban-future.

6.6.1 INTEGRATING FLOOD RISK MANAGEMENT INTO THE URBAN PLANNING PROCESS

Urban planning shapes the long-term development of a community or region through participatory, inclusive and transparent planning processes that guide community development. **Land use planning** is a part of urban planning and is widely viewed as the process of determining the most efficient uses of land to serve society's economic, social and environmental goals. Land use planning means different things based on the context and country. For the purposes of the guide, land use planning is used interchangeably with spatial/regional/town planning. Land use planning identifies where different types of urban development should take place, along with the associated risks, requirements for use, and constraints or growth boundaries. In urban areas, land use planning often coincides with the development of a master plan (also known as a comprehensive or general plan). For more information about meeting flood risk management objectives with the development of a master plan, see table F1 in appendix F.

Effective land use planning can reduce exposure to floods and flood **impacts** while promoting the ecosystem services of floodplains and coastal areas. Flood risk management, however, is just one consideration among many in land use planning. Planners must make decisions within the context of competing and sometimes mutually exclusive uses for land. Within the flood management context, decisions about land use will often require a balancing act between two competing ideals: making space for development and making space for water. The overall objectives of land use planning for flood risk management should include limiting exposure to flooding (by promoting growth in areas that are less vulnerable) and managing natural resources that can reduce flood risk (e.g., wetlands, forests).

Land use decisions, therefore, should be made after undertaking a participatory planning process with community members and should take into account the results of flood risk assessments (see chapter 4).

6.6.2 COORDINATING VARIOUS GOVERNMENTAL STAKEHOLDERS

Urban flood risk management crosses multiple sectors and disciplines and is the responsibility of an array of departments, agencies and organizations – often spanning jurisdictions. Effective flood risk management requires a process of collaboration and governance to ensure the support of government and nongovernmental organizations, involvement and support of the private sector, and community engagement.

6.6.3 STRENGTHENING THE FLOOD RISK MANAGEMENT PROCESS THROUGH REGULATIONS

Planning regulations, municipal bylaws, building codes and other regulations can help manage flood risk. **Zoning** is a systematic way of regulating land use allocations and population densities across an area of interest. Zoning regulations should support and enforce the guidance provided in the land use master plan for that area. Land use plans and zoning regulations supported by monitoring and enforcement mechanisms are one of the more effective ways to limit exposure to flooding and reduce risk. Increasingly, urban governments are adopting zoning to address flood risk and disaster management. For more information on integrating flood management into zoning, see table F2 in appendix F; for more information on building regulations, see chapter 5.

6.6.4 INVOLVING NONGOVERNMENTAL AND PRIVATE SECTOR STAKEHOLDERS

Integrating flood risk management into existing urban governance frameworks requires enlisting all aspects of the affected community, including residents, local government, nongovernmental organizations and the private sector. Local governments should work to incentivize **disaster risk reduction** measures with private developers and landowners in flood-prone areas. Public-private partnerships (PPPs) can help local governments fund flood risk management efforts, increase flexibility in the regulatory process, access innovative technology or new expertise, and create jobs related to flood and stormwater management. For more information on involving the private sector, see chapter 3.

6.6.5 EFFECTIVELY ENGAGING AND CONSULTING WITH THE COMMUNITY

Urban flood management benefits from community engagement throughout the planning, design, implementation and monitoring phases of the Flood Green Guide Framework. Community engagement fosters the political will and buy-in necessary to implement and sustain flood management projects. Projects benefit from local knowledge of flood risk and gain increased context and cultural sensitivity. For more information about community engagement, see chapter 3.

ADDITIONAL INFORMATION:

According to the IPCC, 60% of the world's 39 metropolises with a population of over 5 million are located within 100 km of the coast; among these areas are 12 of the world's 16 cities with populations greater than 10 million.[26]

6.7 URBAN COASTAL AREAS AND SPECIAL CONSIDERATIONS

According to the IPCC, 60% of the world's 39 metropolises with a population of over 5 million are located within 100 km of the coast; among these areas are 12 of the world's 16 cities with populations greater than 10 million.[27] Urban areas are often located along coastlines and in the lower courses of watersheds in delta floodplains – like Jakarta, Indonesia; Guayaquil, Ecuador; and Lagos, Nigeria. The advantages that originally attracted people to these areas and spurred development (e.g., access to trade) become vulnerabilities in an uncertain climate with rising sea levels. Coastal urban areas are subject to multiple flood risk drivers and are uniquely vulnerable to flooding because urbanization can lead to land subsidence, erosion, and reduced natural barriers to coastal storms. Urban development often encroaches on coastal ecosystems, removing or degrading mangroves, wetlands and dunes, thereby increasing the risk of flooding. Functioning coastal ecosystems can reduce the intensity of **storm surge**, slow the movement of water inland, and stabilize the shoreline. For more information on coastal flood management methods, see chapter 5.

Special considerations for urban coastal areas include the following:

- **Sea level rise:** Coastal flood management efforts should account for sea level rise, which increases the volume of water and, therefore, the area affected by storm surge and tidal flooding. Sea level rise can increase the risk of saltwater intrusion into surface and groundwater, leading to contaminated drinking water and impacts to livelihoods.

- **Land use regulation (zoning):** Establishing building setbacks and no-build zones, promoting natural areas, and restricting land use activities can reduce the number of people and the amount of infrastructure exposed to flood risk when undertaken in a socially just and equitable way. Land use regulation can be particularly effective in reducing exposure to coastal flooding. Critical facility development, such as building hospitals and utilities, should be restricted in coastal flood zones and evacuation routes. Evacuation routes should ideally be located outside coastal flood zones so they can be accessed during flood events.

- **Land subsidence:** Subsidence significantly affects many urban coastal and delta areas. In many areas, land subsidence now exceeds absolute sea level

26 IPCC, "Increasing Human Utilisation of the Coastal Zone," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (New York: Cambridge University Press, 2007), https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-2-2.html.

27 Ibid.

rise up to a factor of 10.[28] Lower land elevations increase coastal flood risk, and in combination with sea level rise, subsidence can lead to saltwater intrusion, which can reduce fresh water and contribute to upstream flooding.

Urban coastal flood management methods, discussed in chapter 5, should account for the unique environment along the coast in addition to the other contributing factors of urban flooding discussed throughout this chapter.

6.8 ADDITIONAL RESOURCES

1. World Bank, *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*, 2012, https://www.gfdrr.org/sites/gfdrr/files/publication/World_Bank_Cities_and_Flooding_Guidebook.pdf.

2. Associated Programme on Flood Management (APFM), *Urban Flood Management in a Changing Climate*, 2012, http://www.apfm.info/publications/tools/APFM_Tool_14.pdf.

3. ESCAP/WMO Typhoon Committee, *Guidelines on Urban Flood Risk Management*, 2013, http://www.typhooncommittee.org/46th/Docs/item%2010%20Publications/UFRM_FINAL.pdf.

4. World Bank and Global Facility for Disaster Reduction and Recovery (GFDRR), *Safer Homes, Stronger Communities: A Handbook for Reconstructing after Natural Disasters*, 2010, http://www.preventionweb.net/files/12229_gfdrr.pdf.

5. UN-Habitat, *Inclusive and Sustainable Urban Planning: A Guide for Municipalities*, 2007, http://unhabitat.org/wp-content/uploads/2014/07/A-guide-for-Municipalities-Inclusive-and-Sustainable-Urban-Development-Planning-Volume-1.pdf.

6. UN-Habitat, *Planning for Climate Change: A Strategic, Values-based Approach for Urban Planners*, 2014. Available at: http://unhabitat.org/books/planning-for-climate-change-a-strategic-values-based-approach-for-urban-planners-cities-and-climate-change-initiative/.

7. Practical Action, *Participatory Urban Planning Toolkit Based on the Kitale Experience, 2008*. Available at http://practicalaction.org/participatory-planning-2.

28 G. Erkens et al., "Sinking Coastal Cities," *Proceedings of the International Association of Hydrological Sciences* 372 (November 12, 2015): 189–98, doi: 10.5194/piahs-372-189-2015.

APPENDICES

APPENDICES

APPENDIX A: FLOOD HAZARD TYPOLOGY

For the purpose of the Flood Green Guide, the following typology was created based on a review of a number of sources.

TABLE A1. FLOOD HAZARD TYPOLOGY

Flood: A general and temporary condition of partial or complete inundation of normally dry land areas from overflow of inland or tidal waters or from the unusual and rapid accumulation of surface runoff from any source.
Source: FEMA, "Floods and Floodplains."

HAZARD	DEFINITION	SUMMARY OF PROCESS AND DAMAGE
Riverine (fluvial) flooding *Sources*: FEMA, "Floods and Floodplains"; APFM, "Management of Flash Floods."	Flooding occurs when water flow exceeds the capacity of natural or constructed channels and water spills into adjacent low-lying areas. It is often caused by prolonged seasonal precipitation of low to high intensity or seasonal snow and glacial melt. Additional causes may involve failure of dams, levees, dikes or other protective structures, and blockage of drains, diversions and bypasses. The formation and failure of ice jams can lead to this type of flooding. The increase in water volume within a river channel and the rising of water over the top of the channel onto the adjacent floodplain.	• Characterized by slow water level rise beyond the natural channel that reaches peak flow within hours to days and then slowly recedes (within several hours to days) and mostly coincides with high base flow levels. • Riverine flooding dynamics vary with terrain. Land may stay covered with shallow, slow-moving floodwater for days or even weeks in relatively flat areas. In hilly and mountainous areas, floods may come minutes after a heavy rain. • Impacted areas can include river plains and valleys, extending from the local to the regional level, and affecting large areas. • Leads to unplanned flooding of areas normally considered safe from floods. • Damage also can occur due to the difficulty in removing water from a flooded area back to the main channel due to a lack of pumps, openings in banks/levees, and a high level of water in the main channel.
Flash flooding *Source:* APFM, "Management of Flash Floods."	A local flood with a fast onset and short duration with great volume. It typically follows within a few (usually less than six) hours of heavy or excessive rainfall or rapid snowmelt. The sudden release of water from a dam or levee failure or the breakup of an ice jam can also cause flash flooding. Other causes can include low infiltration or limited retention of flowing water, or blockage of drains, diversions and bypasses.	• A hydrometeorological phenomenon characterized by rapid water level rise above natural channels that can reach peak flow within minutes up to a few hours and then recede rapidly (within minutes to a few hours). • Floodwater often carries high sediment and debris loads because of significant erosive power. • Particularly common in mountainous areas and desert regions, where impacted areas can include river plains, valleys and alluvial fans.[1] They are a potential threat in any area where the terrain is steep, surface runoff rates are high, streamflow occurs in constrained channels, and severe convective rainfall prevails. • Mostly occur at a local level, and generally small to medium areas are affected.

1 An alluvial fan is "the fan-shaped deposits of water-transported material (alluvium). They typically form at the base of topographic features where there is a marked break in slope. Consequently, alluvial fans tend to be coarse-grained, especially at their mouths. At their edges, however, they can be relatively fine-grained," according to Marli Miller's "Alluvial Fans," http://pages.uoregon.edu/millerm/fan.html.

Lake level flooding *Source:* FEMA, "Floods and Floodplains."	The fluctuation of a lake's water level on a short-term (e.g., seasonal) or a long-term (e.g., annual) basis caused by periods of heavy rainfall and annual snowmelt. Additional causes involve changes in outflow channels caused by landslides or intentional raising of lake levels.	• "Long-term lake level fluctuations are a less-recognized phenomenon that can cause high water and subsequent flooding problems lasting for years or even decades." • Associated with increasing retention capacity of reservoirs (e.g., behind a hydroelectric dam). • Lakeshores can flood in ways similar to ocean coasts. For example, along the Great Lakes, severe storms can produce waves and cause shoreline erosion.
Coastal flooding *Sources:* FEMA, "Floods and Floodplains"; Millennium Ecosystem Assessment.	"The increase in water surface elevation above normal tide levels due primarily to low barometric pressure and the piling up of waters in coastal areas as a result of wind action over a long stretch of open water."	• Waves and debris in the sea surge hitting structures can cause damage, and the flow of seawater to and from land can cause erosion of seawall foundations and other structures. • Coastal flooding over sandy areas (e.g., barrier islands) can move sand and create new islands or channels. • Damage from coastal flooding can occur when water flows over land areas or through natural outlets and lagoons back to the sea.
Storm surge *Source:* NOAA National Hurricane Center, "Storm Surge Overview."	"Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge is produced by water being pushed toward the shore by the force of the winds moving cyclonically around the storm. The impact on surge of the low pressure associated with intense storms is minimal in comparison to the water being forced toward the shore by the wind. This rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 20 feet (6 meters) or more in some cases."	• The force of the surge and battering waves increase the impact on land because the surge makes it possible for waves to push inland. The waves may increase damage to buildings directly along the coast. Extended pounding by waves can demolish a structure not specifically designed to withstand such forces. • Tidal currents combine with waves to erode beaches and coastal highways. Buildings that survive hurricane winds can be damaged if their foundations are undermined and weakened by erosion. • Marinas and boats in confined harbors can sustain severe damage from storm tides, waves and currents. • In estuaries and bayous, saltwater intrusion endangers public health, kills vegetation, and can send animals, such as snakes and alligators, fleeing from flooding.
Tsunami flooding *Source:* NOAA, "Tsunami."	"A series of ocean waves generated by sudden displacements in the seafloor, landslides, or volcanic activity. The tsunami wave may come gently ashore or may increase in height to become a fast-moving wall of turbulent water several meters high."	• Impacts and damages are similar to storm surges and other coastal flooding. • The area to be flooded by a tsunami can be hard to predict in advance. Once a tsunami warning has been issued, there may be limited time for evacuation. • Alerts may not be accurate due to local undersea conditions.

Urban flooding *Source:* FLOODsite, "Flooding in Urban Areas."	"Flooding when the city sewage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling."	• Urban floods disrupt daily life in the city. Roads can be blocked, preventing people from going to work or school, and economic damages are high. • These floods can result in deaths when water levels increase quickly (e.g., when water flows down steep streets or rises to ground level through underground drainage systems), or when pedestrians or drivers attempt to go through deep or swiftly moving water. • Urban flooding can also encompass all other types of flooding that occur in urban areas, such as riverine and coastal flooding.
Areal flooding *Source:* NOAA National Weather Service, "NWS Flood Products."	"Flooding that develops more gradually, usually from prolonged and persistent moderate to heavy rainfall."	• "Results in a gradual ponding or buildup of water in low-lying, flood-prone areas, as well as small creeks and streams." • "Flooding normally occurs more than six hours after the rainfall begins, and may cover a large area. However, even though this type of flooding develops more slowly than flash flooding, it can still be a threat to life and property."
High groundwater *Source:* UK Groundwater Forum.	"Water rising up from the underlying rocks or from water flowing from abnormal springs." Can occur after long periods of sustained high rainfall or due to reduced groundwater pumping (e.g., for water supplies, irrigation or dewatering), or infiltration of the ground by water from unlined or poorly maintained irrigation systems.	• "Higher rainfall means more water will infiltrate into the ground and cause the water table to rise above normal levels.… In low-lying areas … the water table can rise up to the surface causing groundwater flooding." • Generally results in ground-level or below-ground-level (basement) flooding; can cause damage to foundations and absorption of water into walls that are not hydrologically isolated from foundations. • Can result in foundation and wall failure and increased humidity in living spaces (possibly associated with respiratory health problems).

Mudflood, mudflow (or debris flow) *Source:* FEMA, "Floods and Floodplains."	Mudflood: "A flood in which the water carries heavy loads of sediment (as much as 50% by volume), including coarse debris." Mudflow: "A specific subset of landslides where the dominant transporting mechanism is that of a flow having sufficient viscosity to support large boulders within a matrix of smaller sized particles. Mudflows may be confined to drainage channels or may occur unconfined on hill slopes."	• Mudfloods typically occur in drainage channels and on alluvial fans adjacent to mountains, but they also can occur on floodplains. • The most common mudflow resulting from slope failure in forested lands occurs about five to 10 years after a major forest fire in which established timber is killed. During the following years, new growth is established. However, roots from the previous growth have deteriorated, and the new roots are not strong enough to hold the soil from moving, thus starting a mudflow. • Both mudflows and mudfloods start with moving water or a stationary mass of saturated soil. Mudfloods usually originate as sheet flow or as water flowing in drainage channels, rivers or streams, and pick up sediment and debris as they flow. Mudflows often originate as a mixture of stationary soil and water. When the mixture gets wet enough, it begins to move as a mass, either as a result of gravity or when triggered by an earthquake or sudden flow of debris-laden water. • Mudflows may also begin as clear-water flows but incorporate sediments and other debris from the stream channel or banks and "bulk up" to flows much larger than the clear-water flow before eventually dropping the debris and attenuating. Mudflows may travel many miles from their source. • "Mudflows and mudfloods may cause more severe damage than clear water flooding due to the force of the debris-filled water and the combination of debris and sediment. The force of the water often destroys pilings and other protective works, as well as structures in its path (or when structures remain intact, sediment must often be physically removed with shovels or hoses). Mud and debris may also fill drainage channels and sediment basins, causing floodwater to suddenly inundate areas outside of the floodplain." • Mudflows and mudfloods are often the result of rain falling on terrain that has been denuded by fires and, therefore, cannot retain runoff. Where ground cover has been removed, even small rains can cause mudflows and mudfloods. Steep lands with an identifiable subsoil clay layer could break loose and start a mudflow when the clay layer becomes saturated. • Mudfloods and mudflows are also known as debris flows, or landslides triggered by rainfall.
Rain on ice flooding *Source:* Wright, "Chapter 2 Types of Floods."	Rainfall on ice that leads to flows across the ice and flooding in low areas.	• Often occurs in late winter before melting of snow and ice on fields. • Can be associated with warm-weather spring storms. • Can be exacerbated when normal drainages are covered with snow and ice, and water cannot drain through normal channels. • A particular danger for buildings, as floodwaters may not be able to drain until ice melts, leading to prolonged standing water.

APPENDIX B: THE SIX DOMAINS OF GENDER ANALYSIS

The information here is adapted from USAID's "Tips for Conducting a Gender Analysis at the Activity or Project Level."

Conducting gender analysis should be a part of project design and implementation. Typically the *Six Domains of Gender Analysis* are applied. Below are examples of specific questions to ask in the context of designing a flood risk management project.

ACCESS

This domain refers to a person's ability to use the necessary resources to be a fully active and productive participant (socially, economically and politically) in society. It includes access to resources, income, services, employment, information and benefits. Sample questions for a hypothetical flood risk management program might include

- Do men and women have equal access to resources – including money, access to credit, ownership of property (including land) – that can be used as collateral to obtain credit required to start a project?
- Do men and women have equal access to the formal or informal communications networks that share flood risk management information, including social (networking) settings?
- Do men and women have equal access to technologies and services that support flood risk management, including training and other opportunities to develop skills?
- Will men and women have equal participation in the project or activity? Would unequal access interfere with the successful achievement of project goals?

KNOWLEDGE, BELIEFS AND PERCEPTION

This domain refers to the types of knowledge that men and women possess; the beliefs that shape gender identities and behavior; and the different perceptions that guide people's understanding of their lives, depending on their gender identity. Sample knowledge, beliefs and perception questions might include

- Do gender stereotypes in the geographic area of the proposed project/activity help or hinder flood risk management opportunities? For example, do such stereotypes depict flood risk management as something that men do more than women?
- Do self-perceptions or levels of self-confidence help or hinder men and women in the area of flood risk management?
- Do men and women have unequal education or knowledge in areas that are important for successful flood risk management? If yes, in what areas?
- Will gender awareness training be required to ensure that husbands, families and communities support female flood risk managers?

PRACTICES AND PARTICIPATION

This domain refers to people's behaviors and actions in life – what they actually do – and how this varies by gender roles and responsibilities. The questions include not only current patterns of action, but also differences in the ways men and women may engage in activities. Types of action may include attendance at meetings and training courses, and accepting or seeking out services. Participation can be both active and passive. Sample practice and participation questions for a flood risk management program include

- Are the communication channels used to spread awareness of and encourage participation in the project equally available to, and used by, men and women?
- Will the overall project be designed in a way to facilitate active participation by both men and women?
- Are men and women likely to have equal access to, and equal participation in, available training sessions in conjunction with this project?

TIME AND SPACE

This domain recognizes gender differences in the availability and allocation of time and decisions about locations. It considers the division of both productive and reproductive labor; the identification of how time is spent during the day (and week, month, or year, and in different seasons); and determines how men and women each contribute to the welfare of the family, community and society. The objective of this domain is to determine how men and women spend their time and what implications their time commitments have for their availability for program activities. Sample time and location questions for a flood risk management program include

- What are the responsibilities of men and women regarding childcare and housework? What are the cultural norms regarding the division of labor between men and women in the areas of childcare and housework?
- If women have greater responsibilities in these areas, do they have enough time to also engage in flood risk management?
- Will participating in this project increase a woman's workload to an unsustainable level?
- Would it be possible for women to participate in the project if support services (for example, childcare) were available to them?
- Would a woman's home responsibilities prevent her from participating in a project at certain times of day or on certain days of the week?
- Do men or women typically work or spend the majority of their time in locations that would make it difficult for them to participate in the project?
- Are men or women more likely to participate in the informal economy, and how would that impact their participation in the project?

LEGAL RIGHTS AND STATUS

This domain involves assessing how people are regarded and treated by customary legal codes, formal legal codes and judicial systems. The domain encompasses legal documentation, such as identification cards, voter registration and property titles. Additionally, the domain includes the right to inheritance, employment, atonement of wrongs and legal representation. Sample legal rights and status questions for a flood risk management program include

- Are women and men treated equally in legislation related to flood risk management?
- Do any legal impediments prevent men and women from having an equal opportunity to participate in the project and/or experience equal outcomes?
- In the legal or regulatory framework, do any special benefits or restrictions explicitly or indirectly target women or men?

POWER AND DECISION-MAKING

This domain pertains to the ability of people to decide, influence, control and enforce personal and governmental power. It refers to one's capacity to make decisions freely, and to exercise power over one's body, within an individual's household, community, municipality and state. This domain also details the capacity of adults to make household and individual economic decisions, including about the use of household and individual economic resources and income, as well as choosing their employment. Additionally, this domain describes the decisions to vote, run for office, and enter into legal contracts.

Sample power and decision-making questions for a flood risk management program include

- Do women hold the power to make economic decisions?
- Do women have control over and benefit from the funds and assets they may accrue as a result of participating in a project?
- Do women actively participate in formal decision-making structures/bodies that address flood risk management?
- Do women and men hold an equal number of decision-making positions in these entities?

While collecting this information, the user should remember that certain subcategories of women or men (for example, youth, those living in poverty, people with disabilities, members of minority or ethnic groups, those who live in rural areas, pensioners, individuals living in certain geographic areas of a country) can face unique barriers or obstacles that could potentially prevent them from participating in the project and/or experiencing the same outcomes as other men and women.

While conducting a gender analysis, look for these potential differences among subgroups, and consider whether altering the project design is necessary.

What should be done after asking these questions?

If the project is still in the design phase, gender analysis findings should be incorporated into the design. If, however, the process is well underway, consider amending the project design. As part of this evaluation process, consider the following questions:

- Have any key gender issues been identified that will impact the ability of the project to achieve its goals or prevent women and men from benefiting equally?
- If yes, then how can the project be amended to ensure that men and women benefit equally?
- Do the identified gender issues require reconceptualizing and editing of overarching objectives and activity or project goals?
- Does the gender analysis suggest that without any proactive intervention, participation in the project will be gender imbalanced? If not, how can the project be designed or amended to increase participation rates for the less-represented sex?
- Are the needs of men and women in relation to this project different enough that a separate project component focusing on women (or a subgroup of women) or men (or a subgroup of men) is necessary?
- What types of data should be collected to track the gender-related project impacts?
- Have any potential unintended consequences been identified? If yes, how should the project or activity counteract the unintended consequences?
- Are there any entry points or opportunities for empowering especially vulnerable groups of women or men through this project?

APPENDIX C: BEAUFORT WIND SCALE[1]

FORCE	WIND (KNOTS)	WMO CLASSIFICATION	APPEARANCE OF WIND EFFECTS	
			ON THE WATER	ON LAND
0	Less than 1	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	1-3	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	4-6	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	11-16	Moderate Breeze	Small waves 1-4 ft becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	Fresh Breeze	Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	22-27	Strong Breeze	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	28-33	Near Gale	Sea heaps up, waves 13-19 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	34-40	Gale	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
9	41-47	Strong Gale	High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
10	48-55	Storm	Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	56-63	Violent Storm	Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced	
12	64+	Hurricane	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	

1 Scale recreated from National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center, "Beaufort Wind Scale." http://www.spc.noaa.gov/faq/tornado/beaufort.html.

APPENDIX D: RESOURCE AND COST-PLANNING GUIDANCE FOR METHODS

DAMS/DIVERSIONS AX1 AX2

PLANNING AND DESIGN INPUTS

1. Community meetings and consultation
2. Pre-feasibility study
3. Detailed hydrological and geological surveys
4. Environmental impact study[1]
5. Conceptual design and selection of dam/barrage, spillway, inlet, outlet, gate(s) types and any other additional features (hydropower, irrigation)
6. Initial cost estimations and feasibility study
7. Detailed engineering designs
8. Detailed bills of quantities and contract documents
9. Project plan and schedules
10. Safety plans, site plans, traffic/navigation alteration plans, and water regulation plans during construction
11. Plans for ongoing public awareness and participation
12. Post-construction site restoration plan

REGULATORY REQUIREMENTS

1. EIA or IEE will be essential under law
2. Should comply with national/provincial economic and development policies and planning
3. Necessary approvals from national and provincial governments and all relevant agencies for the project
4. Proper and equitable land acquisition procedure
5. Permission and community consensus for access roads, quarries, temporary buildings, blasting, interruption of water services, traffic/navigation alterations
6. Approval from indigenous seniors (if applicable)
7. Obtaining proper insurance policies

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Large quantities of conventional construction material
2. Heavy construction machinery and cranes
3. Stone crushers, blasting equipment, batching plants
4. Control devices (gates, electrical components)
5. Safety and communication equipment
6. Provisions for the workforce (shelter, food etc.)

ESSENTIAL EXTERNAL EXPERTISE

1. Team of specialized engineers
2. Project manager and project planner
3. Geologist and hydrologist
4. Cost expert and construction contracts expert
5. Sociologist and community mobilizers
6. Project environmental adviser
7. EIA team
8. Safety expert and safety officers

COST BREAKDOWN TEMPLATE — $$$

Planning costs

1. Cost of community consultations
2. Conducting pre-feasibility and report
3. Conducting EIA and report
4. Conducting geological, hydrological surveys
5. Conducting feasibility study and report
6. Fees for permits and approvals
7. Payments to experts for preparation of designs, project plans, estimates and contract documents
8. Costs related to contract procedure and insurance

Subtotal ____

Construction and implementation costs

1. Regular payments to external experts and construction administration staff
2. Cost of site preparation, access roads, establishing quarries and mobilizing machinery
3. Cost of construction material
4. Labor costs
5. Honoraria for volunteers
6. Costs of community awareness

Subtotal ____

Operation and maintenance costs

1. Payments for staff operating and maintaining the headworks
2. Energy costs for operation
3. Costs of routine repair and upgrading

Subtotal ____

Monitoring and other costs

1. Payments to dedicated monitoring team and volunteers
2. Payments to external experts for regular monitoring and evaluation meetings
3. Cost of advanced/electronic monitoring systems (if applicable)
4. Staff training and costs of community monitoring

Subtotal ____

TOTAL COST ____

1 The Flood Green Guide recommends conducting a voluntary environmental impact study for every method, regardless of legal requirements for IEE or EIA (which are generally much more elaborate).

CONSTRUCTED WETLANDS AX3

PLANNING AND DESIGN INPUTS	COST BREAKDOWN TEMPLATE	$$$
1. Community meetings and consultation 2. Hydrological investigation and hydraulic design 3. Selection of wetland type and plants 4. Environmental impact study 5. Initial cost estimations 6. Detailed engineering and ecological designs 7. Detailed bills of quantities and contract documents (if contracted to an external party) 8. Project plan and schedules	**Planning costs** 1. Cost of community consultations 2. Conducting hydrological/hydraulic study 3. Conducting EIA and report (if applicable) 4. Conducting feasibility study and report 5. Payments to experts for preparation of designs, project plans, estimates and contract documents 6. Costs related to contract procedure and insurance (if applicable) **Subtotal**	___
REGULATORY REQUIREMENTS 1. EIA or IEE may be required under law 2. Necessary approvals from relevant government agencies (irrigation, local government, drainage boards) 3. Permission and community consensus for site clearing and access roads 4. Obtaining insurance (for large-scale projects)	**Construction and implementation costs** 1. Payments to construction administration staff (large-scale projects) 2. Cost of site preparation, access roads 3. Cost of hiring and mobilizing machinery 4. Cost of construction material 5. Labor costs 6. Honoraria for volunteers 7. Costs of community awareness **Subtotal**	___
ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED 1. Conventional construction material 2. Material for substrate, liners, geotextiles 3. Seeds and plants 4. Pipes, valves, and gates 5. Safety equipment	**Operation and maintenance costs** 1. Payments to laborers for regular pruning of vegetation 2. Costs of routine repair, cleaning and upgrading **Subtotal**	___
ESSENTIAL EXTERNAL EXPERTISE 1. Environmental engineer 2. Civil engineer and project manager 3. Wetland ecologist (for large-scale/specialized projects) 4. Cost expert and construction contracts expert (for large-scale projects) 5. Community mobilizers 6. EIA team (if applicable) 7. Safety expert and safety officers (for large-scale projects)	**Monitoring and other costs** 1. Payments to external experts for periodic monitoring visits 2. Staff training and costs of community monitoring **Subtotal**	___
	TOTAL COST	___

LEVEES/FLOODWAYS/GROYNES AND REVETMENTS AX4 AX6 AX9

PLANNING AND DESIGN INPUTS

1. Community meetings and consultation
2. Pre-feasibility study (for large-scale projects)
3. Detailed hydrological and geological surveys
4. Environmental impact study
5. Initial cost estimations and feasibility study
6. Detailed engineering designs
7. Detailed bills of quantities and contract documents
8. Project plan and schedules
9. Safety plans, site plans, traffic/navigation alteration plans, and water regulation plans during construction
10. Plans for ongoing public awareness and participation
11. Post-construction site restoration plan

REGULATORY REQUIREMENTS

1. EIA or IEE will be essential under law
2. Necessary approvals from national and provincial governments and all relevant agencies for the project
3. Permission and community consensus for access roads, quarries and blasting (if required), temporary buildings, interruption of water services, traffic/navigation alterations
4. Approval from indigenous seniors (if applicable)
5. Obtaining proper insurance policies
6. Equitable land acquisition procedure (if applicable)

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Large quantities of conventional construction material
2. Heavy construction machinery and cranes
3. Control devices (e.g., lock gates)
4. Safety and communication equipment
5. Provisions for the workforce (shelter, food, etc.)
6. Seeds and plants for bank vegetating (if applicable)
7. Advance electronic monitoring systems (if applicable)

ESSENTIAL EXTERNAL EXPERTISE

1. Team of specialized engineers
2. Project manager and project planner
3. Geologist and hydrologist
4. Cost expert and construction contracts expert
5. Community mobilizers
6. Project environmental adviser (for large-scale projects)
7. EIA team
8. Safety expert and safety officers
9. Sociologist/conflict resolution expert (if involuntary land acquisition is involved)

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Cost of community consultations	
2. Conducting pre-feasibility study (if required)	
3. Conducting EIA and report	
4. Conducting geological, hydrological studies	
5. Conducting feasibility study and report	
6. Fees for permits and approvals	
7. Payments to experts for preparation of designs, project plans, estimates and contract documents	
8. Costs related to contract procedure and insurance	
Subtotal	____
Construction and implementation costs	
1. Regular payments to external experts and construction administration staff	
2. Cost of site preparation, access roads, establishing quarries (if required)	
3. Cost of hiring and mobilizing machinery	
4. Cost of construction material	
5. Labor costs	
6. Honoraria for volunteers	
7. Costs of community awareness	
8. Costs related to site restoration	
Subtotal	____
Operation and maintenance costs	
1. Payments for lock-gate operators	
2. Energy costs for operation	
3. Costs of routine repair and upgrading	
Subtotal	____
Monitoring and other costs	
1. Payments to external experts for regular monitoring and evaluation meetings	
2. Cost of advanced/electronic monitoring systems (if applicable)	
3. Staff training and costs of community monitoring	
Subtotal	____
TOTAL COST	____

CANAL WIDENING AND DEEPENING AX5

PLANNING AND DESIGN INPUTS

1. Community meetings and consultation
2. Hydrological investigation and hydraulic design
3. Environmental impact study
4. Initial cost estimations
5. Detailed engineering designs
6. Detailed bills of quantities and contract documents
7. Project plan and schedules
8. Safety plans, traffic/navigation alteration plans during construction

REGULATORY REQUIREMENTS

1. EIA or IEE may be required depending on the scale
2. Necessary approvals from relevant government agencies (irrigation, local government, drainage boards)
3. Equitable land acquisition procedure (if applicable)
4. Permission and community consensus for access roads, demolition of structures, traffic/navigation alterations
5. Obtaining proper insurance policies

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Soil, conventional construction material, geotextiles or liners (if applicable), gabions (if applicable)
2. Light construction machinery and dredgers
3. Safety and communication equipment
4. Plants and seeds for bank vegetating (if applicable)

ESSENTIAL EXTERNAL EXPERTISE

1. Civil engineer and project manager
2. Hydraulics design engineer
3. Hydrologist (if required)
4. Cost expert and construction contracts expert
5. Community mobilizers
6. Sociologist/conflict resolution expert (if involuntary land acquisition is involved)
7. EIA team (if required)
8. Safety expert and safety officers

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Cost of community consultations	
2. Conducting EIA and report	
3. Conducting hydrological study and report	
4. Fees for permits and approvals	
5. Payments to experts for preparation of designs, project plans, estimates and contract documents	
6. Costs related to contract procedure and insurance	
Subtotal	____
Construction and implementation costs	
1. Regular payments to external experts and construction administration staff	
2. Cost of site preparation, access roads	
3. Cost of hiring and mobilizing machinery	
4. Cost of construction material	
5. Labor costs	
6. Honoraria for volunteers	
Subtotal	____
Operation and maintenance costs	
1. Costs of routine repair and cleaning	
Subtotal	____
Monitoring and other costs	
1. Payments to external experts for periodic monitoring visits	
2. Staff training and costs of community monitoring	
Subtotal	____
TOTAL COST	____

PUMPING AX7

PLANNING AND DESIGN INPUTS	COST BREAKDOWN TEMPLATE	$$$
1. Community meetings and consultation 2. Hydrological investigation and hydraulic design 3. Selection of pump sizes and types 4. Environmental impact study 5. Initial cost estimations and feasibility study 6. Detailed engineering designs 7. Detailed bills of quantities and contract documents 8. Project plan and schedules 9. Safety plans	**Planning costs** 1. Cost of community consultations 2. Conducting EIA and report (if required) 3. Conducting feasibility study and report 4. Fees for permits and approvals 5. Payments to experts for preparation of designs, project plans, estimates and contract documents 6. Costs related to contract procedure and insurance **Subtotal**	____
REGULATORY REQUIREMENTS 1. EIA or IEE may be required depending on the scale 2. Necessary approvals from relevant government agencies (irrigation, local government, drainage boards) 3. Permission and community consensus for site clearing and access roads 4. Obtaining proper insurance policies	**Construction and implementation costs** 1. Regular payments to external experts and construction administration staff 2. Cost of site preparation, access roads 3. Cost of hiring and mobilizing machinery 4. Cost of construction material 5. Cost of pumps, pipes, valves and accessories, electrical equipment 6. Labor costs **Subtotal**	____
ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED 1. Conventional construction material, lining and waterproofing material 2. Construction machinery 3. Pumps, valves and accessories, pipes, electrical controls 4. Advanced remote control and monitoring systems (if applicable)	**Operation and maintenance costs** 1. Energy cost 2. Costs of pump maintenance, repair and overhauling 3. Routine maintenance costs of intakes and pipelines **Subtotal**	____
ESSENTIAL EXTERNAL EXPERTISE 1. Civil engineer(s) and project manager 2. Hydraulics design engineer 3. Hydrologist (if required) 4. Mechanical engineer, electrical engineer 5. Cost expert and construction contracts expert 6. Community organizers 7. EIA team (if required) 8. Safety expert and safety officers	**Monitoring and other costs** 1. Payments to external experts for regular monitoring visits 2. Staff training 3. Cost of advanced/electronic monitoring systems (if applicable) **Subtotal** **TOTAL COST**	____ ____

ENGINEERED DRAINAGE SYSTEMS AX8

PLANNING AND DESIGN INPUTS	COST BREAKDOWN TEMPLATE	$$$
1. Community meetings and consultation 2. Hydrological investigation and hydraulic design 3. Environmental impact study 4. Initial cost estimations 5. Feasibility study (for large-scale projects) 6. Detailed engineering designs 7. Detailed bills of quantities and contract documents 8. Project plan and schedules 9. Safety plans	**Planning costs** 1. Cost of community consultations 2. Conducting EIA and report (if required) 3. Conducting feasibility study and report (if required) 4. Fees for permits and approvals 5. Payments to experts for preparation of designs, project plans, estimates and contract documents 6. Costs related to contract procedure and insurance	
REGULATORY REQUIREMENTS 1. For very large-scale project, EIA/IEE might be required 2. Necessary approvals from relevant government agencies (irrigation, local government, drainage boards) 3. Permission and community consensus for drainage alterations 4. Obtaining proper insurance policies	**Subtotal**	____
	Construction and implementation costs 1. Regular payments to external experts and construction administration staff 2. Cost of site preparation (if applicable) 3. Cost of hiring and mobilizing machinery 4. Cost of construction material 5. Labor costs	
ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED 1. Conventional construction material 2. Light construction machinery 3. Tunneling or micro-tunneling material/equipment 4. Pipes, gates, manholes, manhole covers, drain covers, geotextiles	**Subtotal**	____
	Operation and maintenance costs 1. Payments to dedicated maintenance staff 2. Regular cleaning costs 3. Routine maintenance and repair costs	
ESSENTIAL EXTERNAL EXPERTISE 1. Civil engineer(s) and project manager 2. Hydraulics design engineer 3. Hydrologist (if required) 4. Cost expert and construction contracts expert 5. Community organizers 6. EIA team (if required) 7. Safety expert and safety officers	**Subtotal**	____
	Monitoring and other costs 1. Payments to external experts for periodic monitoring visits 2. Staff training and costs of community monitoring	
	Subtotal	____
	TOTAL COST	____

FLOOD WARNING AND EVACUATION INFRASTRUCTURE/MULTIPURPOSE INFRASTRUCTURE AX10 AX11

Costs and inputs will vary substantially according to the type of infrastructure.

UPPER WATERSHED RESTORATION AND SOIL CONSERVATION METHODS AY1 AY2

PLANNING AND DESIGN INPUTS

1. Community meetings and consultation
2. Field surveys to assess slopes and vegetation and soil cover
3. Environmental impact study
4. Design of physical features such as terraces, trenches and benches
5. Selection of suitable plant types and planning the planting sequences
6. Calculation of material requirements and machinery needed for land preparation and construction of physical features
7. Preparation of cost estimates and program of implementation

REGULATORY REQUIREMENTS

1. Inform the local government authority, local agricultural officer and environmental officer, and obtain necessary approvals
2. Environmental Impact Assessment (EIA or IEE) may be needed under law

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Seeds, seedlings, compost and mulch for planting
2. Earth, rock and timber for constructing physical features (e.g., terraces)
3. Fencing material or wire mesh to construct enclosure to protect plants
4. In projects that cover extensive areas, strategic use of machinery, such as a backhoe loader or mechanical compactor, will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. In projects that involve >50 ha, or if the intended plants are not native to the area, consult a conservation ecologist.
2. If extensive changes to physical features are required, consult a civil engineer.
3. In major projects, seek advice from a horticulturist on planting methods, maintenance and running a plant nursery.
4. If the project is mainly community-driven, use the services of a community organizer.

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Cost of community consultations	
2. Payments for experts and logistics for initial field survey	
3. EIA and feasibility reports (if required)	
4. Fees for permits and approvals (if applicable)	
5. Payments to experts for preparation of designs, plant schedules and estimates	
Subtotal	____
Construction and implementation costs	
1. Material for physical features (cement, sand, rubble, timber, soil)	
2. Seeds, seedlings, mulch, compost and fertilizer	
3. Hiring earth-moving machinery (if required)	
4. Payments for experts to supervise the work	
5. Labor costs for skilled workers and foremen	
6. Honoraria and food for volunteers	
7. Fee for community mobilization or organization (if required)	
Subtotal	____
Operation and maintenance costs	
1. Repair of physical features	
2. Routine pruning and mulch application	
Subtotal	____
Monitoring and other costs	
1. Regular monitoring visits	
2. Awareness and training for staff, volunteers and community	
Subtotal	____
TOTAL COST	____

WETLAND RESTORATION AND RIPARIAN VEGETATION RESTORATION AY3 AY8

PLANNING INPUTS

1. Community meetings and consultation
2. Field surveys to assess the wetland type and scope, hydrology and vegetation
3. Environmental study
4. Planning of physical alterations (opening waterways, removing structures, dredging)
5. Selection of suitable plant types and sequences for replanting
6. Calculation of material requirements and machinery needed for alterations
7. Preparation of cost estimates and schedule of implementation

REGULATORY REQUIREMENTS

1. Inform local government authority, environmental officer, irrigation engineer and coastal conservation authority (if applicable). Obtain necessary approvals
2. EIA or IEE may be needed under law. If the wetlands are used by local communities, obtain consent from user groups (farmer organizations, fisher cooperatives)

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Seeds, seedlings, compost and mulch for planting
2. Earth, sand and other material for limited artificial nourishment for planting
3. Fencing material, mesh and floaters to construct enclosures to protect plants
4. Construction material to build access facilities and walkways
5. In projects that cover extensive area, strategic use of machinery like a backhoe loader or a small dredger will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. The program should be planned by a conservation ecologist/wetland ecologist, especially when it comes to selecting correct plant types for restoration
2. In major projects, seek advice from a horticulturist on planting methods, maintenance and running a plant nursery
3. If any alteration of waterways or excavation/filling, a hydrologist and a civil engineer should be consulted
4. If the project is mainly community-driven, get the services of a community organizer

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Cost of community consultations	
2. Payments to experts and logistics for initial field survey	
3. EIA, feasibility and hydrological report (if required)	
4. Fees for permits and approvals (if applicable)	
5. Payments to experts for preparation of designs, hydrological studies, plant schedules and estimates	
Subtotal	____
Construction and implementation costs	
1. Cost of material and hiring machinery for physical alterations (if required)	
2. Cost of seeds, seedlings for revegetation	
3. Payments to experts who supervise the work	
4. Labor costs for skilled workers and foremen	
5. Honoraria and food for volunteers	
6. Fee for community mobilization or organization (if required)	
Subtotal	____
Operation and maintenance costs	
1. Routine maintenance work (if required)	
Subtotal	____
Monitoring and other costs	
1. Regular monitoring visits	
2. Awareness and training for staff, volunteers and community	
Subtotal	____
TOTAL COST	____

CONSTRUCTED WETLANDS AX3

PLANNING INPUTS

1. Initial hydrology studies and field surveys
2. Preparation of feasibility report, environmental study and initial design (hydraulic design and landscape plan)
3. Community consultations
4. Detailed design of landscape and hydraulic structures
5. Selection of vegetation species and planting schedule
6. Calculation of material requirements and machinery needed for alterations
7. Preparation of cost estimates and schedule for implementation

REGULATORY REQUIREMENTS

1. Inform local government authority, environmental officer, irrigation engineer and coastal conservation authority (if applicable). Obtain necessary approvals
2. Check conformity with local authority's drainage plan
3. EIA or IEE may be needed under law if the restoration project is beyond a certain extent (e.g., >5 ha)

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Earth, sand and other material for building bunds, embankments and substrate for planting
2. Construction materials, hydraulic control structures, access facilities, walkways and railings, and fences
3. Pipes and sluices for control structures and electrical fixtures for lighting
4. Strategic use of earth-moving machinery such as a backhoe loader, bulldozer, motor grader or compactor will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. The constructed wetland should be designed by a wetland scientist/environmental engineer/landscape architect
2. For constructed wetlands >1 ha, a registered civil engineer should be in charge of planning and implementing construction
3. If alteration of existing waterways is involved, a hydrologist should be consulted

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Payments to experts and logistics for initial field survey and hydrological study	
2. Feasibility study, EIA and hydrological report (if required)	
3. Payments to experts for preparation of designs, hydrological studies, plant schedules and estimates	
4. Cost of community consultations	
5. Fees for permits and approvals (if applicable)	
Subtotal	____
Construction and implementation costs	
1. Material and machinery hiring for physical alterations (if required)	
2. Seeds, seedlings for revegetation	
3. Payments to experts who supervise the work	
4. Labor costs for skilled workers and foremen	
5. Honoraria and food for volunteers	
Subtotal	____
Operation and maintenance costs	
1. Routine maintenance work	
2. Running pumps and other facilities (if applicable)	
Subtotal	____
Monitoring and other costs	
1. Regular inspections	
2. Training professional staff and building community awareness (where applicable)	
Subtotal	____
TOTAL COST	____

SWALES AND INFILTRATION DEVICES AY4

PLANNING INPUTS

1. The devices can be installed in individual households as community projects or in public facilities (public/office buildings, parks)
2. Hydrology studies, environmental studies and field surveys
3. Community consultations
4. Initial calculations and sizing of the swales and infiltration devices
5. Detailed structural design of infiltration devices
6. Landscape design and selection of suitable vegetation species for the swales
7. Calculation of material requirements and machinery needed for construction
8. Preparation of cost estimates and program of implementation

REGULATORY REQUIREMENTS

1. Inform the local government authority and environmental officer. Obtain necessary approvals
2. Check conformity with local authority's drainage plan
3. For swales along highways, get approval from the relevant authority
4. Large projects may need EIA/IEE by law

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Construction material for infiltration devices
2. Earth, sand and other material for preparing swales
3. Seeds, seedlings, compost and mulch for planting
4. Pipes, gutters and other fixtures
5. If the project involves a number of infiltration devices or extensive roadside swales (>1 km), strategic use of machinery such as a backhoe loader, compactor or movable concrete mixer will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. Any infiltration device installed in a public place should be designed by a registered civil engineer
2. If a number of infiltration devices or swales that run along roads >1 km are constructed simultaneously, consult a civil engineer for construction planning
3. In major projects where a number of swales are installed, get advice from a horticulturist on planting methods, maintenance and running a plant nursery
4. In community-driven projects, recruit a community organizer

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Payments to experts and logistics for initial field survey and hydrology study	
2. Feasibility study, EIA and hydrological report (if required)	
3. Payments to experts for preparation of designs, hydrological studies, plant schedules and estimates	
4. Cost of community consultations	
5. Fees for permits and approvals (if applicable)	
Subtotal	____
Construction and implementation costs	
1. Cost of material and machinery hiring for physical alterations (if required)	
2. Cost of seeds and seedlings for revegetation	
3. Payments to experts who supervise the work	
4. Labor costs for skilled workers and foremen	
5. Honoraria and food for volunteers	
6. Fee for community mobilization or organization (if required)	
Subtotal	____
Operation and maintenance costs	
1. Routine maintenance work	
Subtotal	____
Monitoring and other costs	
1. Regular inspections	
2. Awareness and training for staff, volunteers and community	
Subtotal	____
TOTAL COST	____

RAINWATER HARVESTING AY5

PLANNING INPUTS

1. Rainwater harvesting can be installed in individual households as community projects or in public facilities (public/office buildings, parks)
2. Initial hydrological calculations
3. Community meetings and consultation (in case of a community project)
4. Sizing and design of rain gardens
5. Selection of plants and substrates (soils) for rain gardens
6. Sizing and structural design of rainwater harvesting tanks
7. Calculation of material requirements and machinery needed for construction
8. Preparation of cost estimate, program of implementation and construction schedules

REGULATORY REQUIREMENTS

1. Inform the local government authority; obtain necessary approval for construction
2. Check conformity with local authority's drainage plan

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Earth, sand and other material for preparing the rain gardens
2. Seeds, seedlings, compost and mulch for planting
3. Construction material, rainwater harvesting tanks or other structures
4. Pipes, gutters, and other fixtures
5. If the project involves a number of structures or extensive rain gardens (>1 ha), strategic use of machinery, such as a backhoe loader, compactor, or movable concrete mixer, will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. Any above- or underground rainwater tank (>2 cubic meters) should be designed by a registered civil engineer
2. If more than 10 rainwater tanks and/or rain gardens are implemented simultaneously, consult a civil engineer for construction planning
3. In a community-driven project, recruit a community organizer
4. In major rain garden projects (>1 ha extent or >20 installations), get advice from a horticulturist on planting methods, maintenance and running a plant nursery

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Payments for an expert for hydrological calculations	
2. Feasibility and hydrological reports (if required)	
3. Payments to experts for preparation of designs, structural designs, plant schedules and estimates	
4. Cost of community consultations (if applicable)	
5. Fees for permits and approvals (if applicable)	
Subtotal	____
Construction and implementation costs	
1. Mobilization costs and ground preparations	
2. Material and machinery hiring for construction	
3. Seeds and seedlings for rain gardens	
4. Payments to engineers and experts who supervise the work	
5. Labor costs for skilled workers and foremen	
6. Honoraria and food for volunteers (in community projects)	
Subtotal	____
Operation and maintenance costs	
1. Routine maintenance of rain gardens	
2. Cleaning infiltration devices/ rainwater tanks	
Subtotal	
Monitoring and other costs	
1. Training and awareness programs for communities	
Subtotal	____
TOTAL COST	____

DETENTION BASINS AND RETENTION PONDS AY6

PLANNING INPUTS

1. Initial field study and survey
2. For pond projects >1 ha or watershed areas >1 sq. km, hydrology study, feasibility report, environmental study and initial design (hydraulic design and landscape plan)
3. Community consultations
4. Detailed design of hydraulic control devices (inlets, sluices) and bunds
5. Calculation of material requirements and machinery needed for alterations
6. Preparation of cost estimates and program of implementation

REGULATORY REQUIREMENTS

1. Inform the local government authority, environmental officer and irrigation engineer; obtain necessary approvals
2. Check conformity with local authority's drainage plan
3. If a pond's impoundment is large (>5 ha), EIA or IEE may be needed under law

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Earth or rock for building bunds and embankments
2. Construction material to build hydraulic control structures, access facilities, walkways and railings, and fences
3. Pipes and sluices for control structures
4. Strategic use of earth-moving machinery, such as a backhoe loader, bulldozer, motor grader or compactor, will expedite the job

ESSENTIAL EXTERNAL EXPERTISE

1. Any bund or embankment that serves as an impoundment should be designed and implemented by a registered civil engineer
2. Any hydraulic control structure in a public place should be designed by a registered civil engineer
3. If any alteration of existing waterways is involved, a hydrologist should be consulted
4. In community-driven projects, recruit a community organizer

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Payments to experts and logistics for initial field survey and hydrology study	
2. Feasibility and hydrological report (if required)	
3. Payments to experts for preparation of designs, hydrological studies, planting schedules and estimates	
4. Cost of community consultations	
5. Fees for permits and approvals (if applicable)	
Subtotal	____
Construction and implementation costs	
1. Cost of material and machinery hiring for physical alterations (if required)	
2. Cost of seeds and seedlings for revegetation	
3. Payments to experts who supervise the work	
4. Labor costs for skilled workers and foremen	
5. Honoraria and food for volunteers	
6. Fee for community mobilization or organization (if required)	
Subtotal	____
Operation and maintenance costs	
1. Routine maintenance work and periodic dredging	
Subtotal	____
Monitoring and other costs	
1. Regular inspection	
2. Training for staff, volunteers and community	
Subtotal	____
TOTAL COST	____

NATURAL DRAINAGE PATH RESTORATION AND REMOVAL OF BARRIERS AY7 AY9

PLANNING INPUTS

1. Community meetings/consultation
2. Field surveys to identify natural drainage paths and/or to assess the types/extent of barrier clearance required
3. Environmental study
4. Demarcating the natural drainage paths with community participation
5. Planning of physical alterations (clearing, weeding, removal of large woody debris, removal of unauthorized structures)
6. Calculation of workforce/material requirements and machinery needed for alterations
7. Preparation of cost estimates and program of implementation

REGULATORY REQUIREMENTS

1. Inform the local government authority, environmental officer, irrigation engineer and coastal conservation authority (if applicable); obtain necessary approvals
2. If burrier removal includes removing large natural features (rocks, sandbars), conduct an environmental impact study even if it is not required by local regulations
3. Obtain the consent of all user groups (farmer organizations, fisher cooperatives) and private property owners before accessing drainage paths even for surveys

ESSENTIAL MATERIAL INPUTS AND MACHINERY REQUIRED

1. Earth, sand and other material rehabilitation of natural drainage paths
2. Fencing material if drainage paths have to be physically demarcated
3. Strategic use of machinery such as a backhoe loader, breakers, or hand compactors will expedite the clearance work, especially when large structures are involved
4. Trucks or carts to transport the cleared/removed material

ESSENTIAL EXTERNAL EXPERTISE

1. Community knowledge should be used to identify natural drainage paths
2. Recruit a community organizer to ensure fullest community engagement
3. Where drainage paths are unclear or barrier removal work will result in substantial hydraulic modifications, a hydrologist should be consulted
4. If demolition of large structures or excavations are involved, a civil engineer should be consulted

COST BREAKDOWN TEMPLATE	$$$
Planning costs	
1. Cost of community consultations	
2. Payments to experts and logistics for initial field survey	
3. Feasibility and hydrological reports (if required)	
4. Fees for permits and approvals (if applicable)	
5. Payments to experts for preparation of hydrological and structural studies and estimates (if required)	
Subtotal	____
Construction and implementation costs	
1. Material and machinery hiring for physical alterations (if required)	
2. Payments to experts who supervise the work (if required)	
3. Labor costs for skilled workers and construction supervisors	
4. Honoraria and food for volunteers	
5. Fee for community mobilization or organization (if required)	
6. Hiring truck or carts for material removal	
Subtotal	____
Operation and maintenance costs	
1. Periodic cleaning and maintenance	
Subtotal	____
Monitoring and other costs	
1. Periodic inspections	
2. Community awareness sessions and volunteer training	
Subtotal	____
TOTAL COST	____

APPENDIX E: MONITORING AND EVALUATION REQUIREMENTS FOR DIFFERENT METHODS

TABLE E1. MONITORING AND EVALUATION REQUIREMENTS FOR DIFFERENT METHODS

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
STABILITY OF PHYSICAL FEATURES/STRUCTURES/DEVICES					
Structures in place in the intended location	Community & Officials	Regular	AX7 Pumping AX8 Engineered drainage systems AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Visible damages to the structures/ devices or malfunctions (e.g., crack in dam, malfunctioning automatic siren)	Community & Officials/Experts	Regular/Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Structural strength and integrity tests (e.g., stability tests in levees)	Experts	Long-term	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY6 Detention basins and retention ponds	---

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
COST AND MAINTENANCE OF PHYSICAL (STRUCTURAL AND ECOLOGICAL) FEATURES					
Adequate personnel (staff/ volunteers/ owners) and expertise to operate and maintain the physical features	Officials/Experts	Intermediate/Long-term	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Physical features are maintained; no maintenance issues or bottlenecks	Officials/Experts	Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Current operation and maintenance costs of the features are in line. (If excessive, what are the reasons?)	Officials/Experts	Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY8 Riparian vegetation restoration	---

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
PROGRAM MANAGEMENT					
Adequate staff to administrate the non-structural programs	Community & Officials	Intermediate	---	---	B1 Soil and watershed protection legislation B2 Land use planning (regional/ community) B3 Flood- and waterproofing (building regulations) B4 Regular maintenance of headworks B5 Flood monitoring and warning framework B6 Crop change and alternative land use
Adequate staff to carry out regular social mobilization or awareness activities	Community & Officials	Intermediate	---	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY5 Rainwater harvesting AY7 Natural drainage path restoration AY8 Riparian vegetation restoration	B5 Flood monitoring and warning framework B6 Crop change and alternative land use
Adequate knowledge base for staff or training in place	Community & Officials	Intermediate	---	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY5 Rainwater harvesting AY7 Natural drainage path restoration AY8 Riparian vegetation restoration	B5 Flood monitoring and warning framework B6 Crop change and alternative land use

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
Current administrative costs of the programs are in line. (If excessive, what are the reasons?)	Community & Officials	Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs AY11 Coastal and reef restoration	B1 Soil and watershed protection legislation B2 Land use planning (regional/ community) B3 Flood- and waterproofing (building regulations) B4 Regular maintenance of headworks B5 Flood monitoring and warning framework B6 Crop change and alternative land use
ECOLOGICAL SUSTAINABILITY					
Are there any unanticipated environmental issues associated with the structures/ devices/ ecological modifications?	Community & Officials/Experts	Regular/Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs AY11 Coastal and reef restoration	---

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
Have the ecological features (wetlands, riparian zones) deviated from the intended habitat types and structures?	Officials/Experts	Intermediate/Long-term	AX3 Constructed wetlands	AY1 Upper watershed restoration AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY8 Riparian vegetation restoration	---
Evidence of species loss, eutrophication or pollution	Community & Officials/Experts	Intermediate/Long-term	AX3 Constructed wetlands	AY1 Upper watershed restoration AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY8 Riparian vegetation restoration	---
Evidence of invasive species proliferation	Officials/Experts	Intermediate	AX3 Constructed wetlands	AY1 Upper watershed restoration AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY8 Riparian vegetation restoration	---
Are there any anticipated environmental threats to ecological features in the program?	Officials & Community/ Experts	Regular/Intermediate	AX3 Constructed wetlands	AY1 Upper watershed restoration AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY8 Riparian vegetation restoration	---

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
SOCIAL ACCEPTABILITY					
Community embraces the project with a sense of ownership	Community & Officials	Intermediate/Long-term	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs AY11 Coastal and reef restoration	B1 Soil and watershed protection legislation B2 Land use planning (regional/ community) B3 Flood- and waterproofing (building regulations) B4 Regular maintenance of headworks B5 Flood monitoring and warning framework B6 Crop change and alternative land use
Threats to the physical features (e.g., vandalism, terrorism). How to mitigate?	Community & Officials	Regular/Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Threats to the ecological features (e.g., animal grazing, timber felling). How to mitigate?	Community & Officials	Regular/Intermediate	AX3 Constructed wetlands	AY1 Upper watershed restoration AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY8 Riparian vegetation restoration	---

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
Are there unanticipated safety and health issues associated with the structures/ devices/ ecological features?	Community & Officials /Experts	Regular/Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds	---
Community feedback on general program administration	Community & Officials	Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs AY11 Coastal and reef restoration	B1 Soil and watershed protection legislation B2 Land use planning (regional/ community) B3 Flood- and waterproofing (building regulations) B4 Regular maintenance of headworks B5 Flood monitoring and warning framework B6 Crop change and alternative land use

ITEM	TYPE	FREQUENCY	METHODS		
			STRUCTURAL HARD	STRUCTURAL SOFT	NON-STRUCTURAL
Opportunities for expanding community participation in the programs. What should be changed?	Community & Officials	Intermediate	AX1 Dams and reservoirs AX2 Diversions AX3 Constructed wetlands AX4 Levees AX5 Canal widening and deepening AX6 Floodways AX7 Pumping AX8 Engineered drainage systems AX9 Groynes and revetments AX10 Multipurpose infrastructure AX11 Warning/evacuation infrastructure	AY1 Upper watershed restoration AY2 Soil conservation methods AY3 Wetland restoration AY4 Swales and infiltration devices AY5 Rainwater harvesting AY6 Detention basins and retention ponds AY7 Natural drainage path restoration AY8 Riparian vegetation restoration AY9 Removal of barriers AY10 Green roofs/walls and blue roofs AY11 Coastal and reef restoration	B1 Soil and watershed protection legislation B2 Land use planning (regional/ community) B3 Flood- and waterproofing (building regulations) B4 Regular maintenance of headworks B5 Flood monitoring and warning framework B6 Crop change and alternative land use

APPENDIX F: COMMON MASTER PLAN ELEMENTS AND ZONING REGULATIONS USED FOR FLOOD RISK MANAGEMENT

The table below highlights master plan elements that are commonly used to promote urban flood risk management.

TABLE F1. MASTER PLAN ELEMENTS RELATED TO FLOOD RISK MANAGEMENT

MASTER PLAN ELEMENT	DESCRIPTION	POTENTIAL USE FOR FLOOD RISK MANAGEMENT
Land use	Address land uses for all development types, including residential, commercial, institutional, governmental	• Identify flood-prone and hazardous areas • Discourage development in hazardous areas • Promote compact, dense development patterns combined with open spaces • Provide adequate space for future growth in less vulnerable areas
Environmental management	Address protection/ restoration of sensitive environmental areas like wetlands, and air and water quality	• Promote natural drainage path and riparian restoration and protection • Encourage reforestation and protection of forest areas • Encourage wetland protection and restoration • Suggest soil conservation measures and sustainable agricultural practices • Promote the linkage of natural and nature-based methods to air- and water-quality improvement; a reduction in the UHI effect; biodiversity; and habitat creation
Open space	Include recreation opportunities such as parks and natural areas	• Promote open spaces and recreation areas in flood-prone or hazardous areas • Promote multipurpose infrastructure techniques that use recreational areas for water storage • Promote the use of vegetated open spaces as a tool for water quality improvement and reduction of the UHI effect
Infrastructure	Include critical service networks such as water supply, wastewater, solid waste and stormwater management	• Limit infrastructure services in flood-prone or hazardous areas, which discourages development • Promote the use of natural and nature-based flood management techniques; for example, rain gardens, swales, constructed wetlands, green/blue roofs • Promote recycling programs to reduce solid waste • Provide for adequate solid waste facilities and collection services to prevent debris from blocking waterways or drainage systems • Suggest water conservation measures, such as rainwater harvesting, to reduce peak flow

Transportation	Include road and public transportation services and networks	• Limit access to flood-prone or hazardous areas • Promote development in less vulnerable areas by limiting roads within flood-prone areas • Provide for evacuation routes and emergency response • Promote the use of permeable pavement where appropriate • Encourage integration of natural and nature-based methods in road projects (e.g., swales)
Sources: World Bank, *Safer Homes, Stronger Communities*; APA Safety Audit; APA Hazard Mitigation.		

The table below illustrates a few common zoning and land use regulations that can be applied in flood risk management.

TABLE F2. APPLICATIONS OF LAND USE ZONING FOR FLOOD RISK MANAGEMENT

ZONING TYPE	DESCRIPTION	POTENTIAL USE FOR FLOOD RISK MANAGEMENT
Floodplain zoning	• Restricts development near floodways and flood fringe areas to create a natural buffer • Designates land uses and density of development (e.g., restricts housing development and allows parks) • Limits heavy industrial land uses, which reduces risk of industrial waste and pollutants entering water bodies during floods • Limits exposure of lifesaving facilities (e.g., hospitals and fire stations) and infrastructure (evacuation routes) to floods	Traditionally used for flood risk management
Coastal zoning	Restricts development adjacent to coastlines; see floodplain zoning	Traditionally used for coastal flood risk management
Overlay zone: hazardous area or conservation	Overlays more general zoning regulations to apply additional restrictions to development types, land uses and building regulations within specific areas to meet objectives such as DRR, conservation or historic preservation	• Increase zoning requirements in areas around the immediate floodway or coastal area to further reduce flood risk and support other flood management goals • Support building regulations (e.g., flood-proofing) and promote household or site-specific requirements such as managing stormwater runoff • Promote preservation and restoration of natural resources

Floating zones	Establishes zoning regulations for areas that meet specific conditions or characteristics without linking the regulations to a geographic area	• Allow predetermined zoning decisions to apply only in flood-affected or disaster-affected areas • Reduce development density and limit development types in areas after they are impacted by floods • Require the use of natural and nature-based flood risk management methods
Subdivision regulations	Regulates land parcels that are sub-divided within a planned development to restrict development or require specific conditions to be met at the site level	• Require conditions at the site level, such as setbacks or buffers, to increase vegetated open space • Promote compact development on higher ground within a development site
Non-conforming use regulations	Applies regulations to buildings that were constructed prior to current zoning regulations and do not comply with current standards	Limit rebuilding of structures that are non-conforming in areas affected by floods or other disasters
Sources: World Bank, *Safer Homes, Stronger Communities*; APA Safety Audit; APA Hazard Mitigation.		

GLOSSARY

GLOSSARY

The following is a list of the key terms and phrases used throughout the Flood Green Guide. In some cases, the definitions have been quoted directly from the original source. If no source is given, this indicates that the chapter author developed a common definition for use in the guide. For a full listing of sources used in the glossary, see the bibliography.

TERM	DEFINITION
Adaptation *Source:* USAID, *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change.*	The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, adaptation is a reaction to an actual change in climate since ecosystems cannot anticipate or plan for climate change. Adaptation actions seek to enhance resilience and reduce climate vulnerability in the near and long term by decreasing exposure or sensitivity, or by increasing adaptive capacity.
Adaptive capacity *Source:* USAID, *Climate-Resilient Development.*	The combination of the strengths, attributes and resources available to an individual, community, society or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities. The factors that can increase adaptive capacity include financial resources, access to technology, information, skills, infrastructure, effective institutions and equity.
Albedo *Source:* EPA, *Glossary of Climate Change Terms.*	The amount of solar radiation reflected from an object or surface, often expressed as a percentage.
Areal flooding *Source:* NOAA National Weather Service, *NWS Flood Products.*	Flooding that develops gradually, usually from prolonged and persistent moderate to heavy rainfall. This results in a gradual ponding or buildup of water in low-lying, flood-prone areas, and as small creeks and streams.
Barrage *Source:* WMO and UNESCO, *International Glossary of Hydrology.*	Structure across a stream, equipped with a series of gates or other mechanisms that control the water-surface level upstream to regulate the flow or to divert water supplies into another watercourse.
Base flow *Source:* WMO and UNESCO, *International Glossary.*	Discharge that enters a stream channel mainly from groundwater, but also from lakes and glaciers, during long periods when no precipitation or snowmelt occurs.
Biodiversity *Source:* Sayers et al., *Flood Risk Management: A Strategic Approach.*	A measure of the health of ecosystems, which can readily be destroyed or enhanced by management choices. Biodiversity is most commonly used to describe the totality of genes, species and ecosystems of a region – which in this context may refer to an area ranging from a single river reach through to a river basin or even a network of basins. Biodiversity provides a unified description of the traditional three levels at which biological variety is defined: species diversity, ecosystem diversity and genetic diversity. All of these are important considerations in IFM.
Blue roofs *Source:* NYC Environmental Protection, *Blue Roof and Green Roof.*	Blue roofs are flat, non-vegetated roofs, designed to temporarily store and slowly drain rainwater through the use of weirs on roof drains.

Capacity *Source:* Oxfam, *Participatory Capacity and Vulnerability Analysis.*	The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed-upon goals. Adaptive capacity relates to the potential of the above to minimize negative impacts and maximize any benefits from changes in the climate.
Catchment	See watershed.
Climate *Source:* IPCC, *5th Assessment Report, WG 1 Glossary.*	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.
Climate change *Source:* IPCC, *5th Assessment Report, WG 1 Glossary.*	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.
Climate projections *Source:* USAID, *Climate-Resilient Development.*	Potential future climate conditions (e.g., higher sea levels, warmer temperatures, wetter or drier rainy seasons). These are typically generated from climate models. Climate projections may be accompanied by assumptions about change in socioeconomic conditions (e.g., income, technology, greenhouse gas emissions).
Climate variability *Source:* IPCC, *5th Assessment Report, WG 1 Glossary.*	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events.
Coastal flooding *Source:* Wright, *Floods and Floodplains.*	Flooding can be caused by hurricanes, cyclones, other large storm systems, tsunamis and rising sea levels. It is often the result of a combination of rising coastal waters on riverine flooding.
Co-benefit *Source:* EPA, *Climate Change Terms.*	The benefits of policies that are implemented for various reasons at the same time, including climate change mitigation, acknowledging that most policies designed to address greenhouse gas mitigation also have other, often at least equally important, rationales (e.g., related to objectives of development, sustainability and equity).
Culverts *Source:* Jha, Bloch and Lamond, *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century.*	Closed conduit for the free passage of surface drainage water under a highway, railroad, canal or other structure.
Deforestation *Source:* FAO, *Definitions of Forest.*	Deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold.
Design flood *Source:* USACE Coastal and Hydraulics Laboratory, *Glossary.*	The maximum amount of water for which a flood control project will offer protection. Selection is based on engineering, economic and environmental considerations.
Detention basin	Depressions in the landscape that temporarily hold stormwater, which is then released slowly through a controlled outflow.

Disaster *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	Serious disruption of the functioning of a society, causing widespread human, material or environmental losses that exceed the ability of the affected society to cope using only its own resources. Disasters are often classified according to their speed of onset (sudden or slow) and their cause (natural or manufactured). Disasters occur when a natural or manufactured hazard meets and adversely impacts vulnerable people, their communities and/or their environment.
Disaster risk reduction (DRR) *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	The practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.
Downstream *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	That part of a channel nearer to the sea than the reference point; traveling with the normal direction of flow.
Drainage pattern (or network) *Source:* USDA, *Glossary of Landform and Geologic terms.*	The configuration or arrangement, in plan view, of stream courses in an area, including gullies or first-order channelized flow areas, higher-order tributaries, and main streams. Drainage pattern is related to local geologic materials and structure, geomorphological features and geomorphic history of an area. Major drainage pattern types include dendritic, trellis, artificial, etc. Also called drainage network.
Ecosystem *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	Dynamic complexes of plants, animals, other living communities, and the nonliving environment interacting as functional units. Humans are an integral part of ecosystems.
Ecosystem services *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	The benefits that people and communities obtain from ecosystems. This definition is drawn from the Millennium Ecosystem Assessment. The benefits that ecosystems can provide include “regulating services,” such as regulation of floods, drought, land degradation and disease; “provisioning services,” such as provision of food and water; “supporting services,” such as help with soil formation and nutrient cycling; and “cultural services,” such as recreational, spiritual, religious, and other nonmaterial benefits. The foundation for all ecosystem services – including those that reduce disaster risks – is integrated management of land, water and living resources. This integrated management should promote conservation and sustainable use.
El Niño-Southern Oscillation *Source:* EPA, *Climate Change Terms.*	El Niño, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño-Southern Oscillation. During an El Niño event, the prevailing trade winds weaken, and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.
Engineered drainage	All manufactured infrastructure built to effectively collect and convey runoff away from a given area.
Environment *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	The complex of physical, chemical and biotic factors (such as climate, soil and living things) that acts upon individual organisms and communities, including humans, and ultimately determines their form and survival. It is also the aggregate of social and cultural conditions that influence the life of an individual or community. The environment includes natural resources and ecosystem services that comprise essential life-supporting functions for humans, including clean water, food, materials for shelter, and livelihood generation.

Environmental flows *Source:* Hirji and Davis, *Environmental Flows in Water Resources Policies, Plans, and Projects: Findings and Recommendations.*	The quality, quantity and timing of water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems that provide goods and services to people.
Estuarine or tidal wetlands	Reed beds, salt marsh, mangrove or mudflats at the river mouth or landside of a lagoon; can provide protection from tidal floods.
Evaporation *Source:* WMO and UNESCO, *International Glossary.*	Process by which water changes from liquid to vapor at a temperature below boiling point.
Evapotranspiration *Source:* EPA, *Climate Change Terms.*	The combined process of evaporation from the Earth's surface and transpiration from vegetation.
Exposure	What might be affected or damaged (i.e., people, property, habitats, networks) by a hazard of a specific magnitude recurring within a specific frequency. Exposure is often assessed by identifying the extent to which lives and physical assets would be affected by a flood of a specific magnitude.
Filter strip *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Gently sloping area of vegetated land, delaying and reducing stormwater peaks and trapping pollutants and silts.
Flash flooding *Source:* WMO and UNESCO, *International Glossary.*	Flood of short duration with a relatively high peak discharge. Normally occurs due to heavy or intense rainfall over a period of minutes to hours. The result is that creeks and streams quickly rise out of their banks.
Flood peak (or flood crest) *Source:* USACE, *Glossary.*	The highest value of discharge or flow achieved by a flood. Flood crest is equivalent to peak stage.
Flood risk	Flood risk is conceptualized as risk due to the presence of a flood hazard, along with an area's vulnerability to sustain damage from such an event, and the capacity to respond. In other words, flood hazard, exposure to flood damage, and vulnerability to flood damage, modified by the capacities to resist this damage.
Flood risk assessment	The process of defining the threat flooding poses to lives, livelihoods, society and other aspects of everyday life.
Floodplain *Source:* Sayers et al., *Flood Risk Management: A Strategic Approach.*	The generally flat areas adjacent to a watercourse or the sea where water flows in time of flood, or would flow but for the presence of structures and other flood controls.
Flood-proofing *Source:* FEMA, *Floodproofing: Definitions/Descriptions.*	Any combination of structural and non-structural additions, changes or adjustments to structures that reduce or eliminate flood damage to real estate or improved real property, water and sanitary facilities, and structures and their contents.
Floodway *Source:* WMO and UNESCO, *International Glossary.*	A channel, or an enclave or reservoir, to carry excess water and to receive overflow when the waterway reaches its capacity.
Frequency	How often a hazard of a certain magnitude occurs, often expressed in the number of times an event occurs during a specific period of years.

Gabion *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Container made of wire, plastic mesh (or similar material), filled with stones and used to form retaining wall or provide protection against scour.
Gender *Source:* USAID, *Guide to Gender Integration and Analysis: Additional Help for ADS Chapters.*	Gender is a social construct that refers to relations between and among the sexes, based on their relative roles. It encompasses the economic, political and sociocultural attributes, constraints and opportunities associated with being male or female. As a social construct, gender varies across cultures, and is dynamic and open to change over time. Because of the variation in gender across cultures and over time, gender roles should not be assumed but investigated. Note that "gender" is not interchangeable with "women" or "sex."
Gender analysis (also referred to as gender-sensitive, gender-based or gender-aware analysis) *Source:* UNDP, Gender, Climate Change and Community-Based Adaptation: A Guidebook for Designing and Implementing Gender-Sensitive Community-based Adaptation Programmes and Projects.	This is analysis that (a) makes visible any disparities between genders and (b) analyzes these disparities according to established sociological (or other) theories about gender relations. Gender-sensitive analysis reminds us that gender-related differences are not always obvious.
Geographic information systems (GIS) *Source:* NOAA/NWS, *Glossary.*	A computerized data management system used to capture, store, manage, retrieve, analyze and display spatial information.
Geomorphology *Source:* USACE, *Glossary.*	That branch of physical geography that deals with the form of Earth, the general configuration of its surface, and the distribution of the land, water, etc.
Gray infrastructure *Source:* American Rivers, *Green Infrastructure Training.*	Manufactured, engineered components of a system. In the context of stormwater management, gray infrastructure can include gutters, storm sewers, tunnels, culverts, detention basins, pipes and mechanical devices used collectively in a system to capture and convey runoff. Also known as hard or traditional infrastructure or engineering.
Green infrastructure *Source:* EPA, *Terms and Acronyms.*	An adaptable term used to describe an array of products, technologies and practices that use natural systems, or engineered systems that mimic natural processes, to enhance overall environmental quality and provide utility services. As a general principle, green infrastructure techniques use soils and vegetation to infiltrate, evapotranspirate and/or recycle stormwater runoff. For purposes of the Flood Green Guide, the term green infrastructure is used interchangeably with the terms natural or nature-based or soft methods for flood risk management.
Green roofs *Source:* EPA, *Reducing Urban Heat Islands: Compendium of Strategies.*	Vegetative layer grown on top of roofs. Green roofs consist of vegetation, a growing media (which can vary in depth), drainage materials, and a waterproof membrane on top of a traditional roof system.
Green walls *Source:* Loh, *Living Walls: A Way to Green the Built Environment.*	Green walls, or vertical gardens, are typically constructed using modular containers to hold a growing media, the growing media itself, and vegetation.
Groundwater *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment and rocks. Groundwater originates from rain and from melting snow and ice and is the source of water for aquifers, springs and wells. The upper surface of groundwater is the water table.

Groyne *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Wall or embankment built out from the coast, or a riverbank, to inhibit erosion of the shore or riverbank (and in some cases to encourage accretion). The structures usually have a simple linear shape and are constructed in right angles (90 degrees) to the bank.
Hard engineering	See gray infrastructure.
Hazard (flood) *Source:* Sayers et al., *Flood Risk Management: A Strategic Approach.*	The potential for inundation that threatens life, health, property and/or natural floodplain resources and functions. The flood hazard is composed of three elements: severity (depth, velocity, duration and extent of flooding), probability of occurrence and speed of onset.
Headworks	Physical structures such as dams, canals, drainage systems and pumping systems at the head of a waterway.
High groundwater *Source:* UK Groundwater Forum.	Water rising up from the underlying rocks or from water flowing from abnormal springs. Can occur after long periods of sustained high rainfall or due to reduced groundwater pumping (e.g., for water supplies, irrigation or dewatering) or infiltration of the ground by water from unlined or poorly maintained irrigation systems.
Hydrological cycle *Source:* WMO and UNESCO, International Glossary.	Succession of stages through which water passes from the atmosphere to Earth and returns to the atmosphere. The cycle begins with evaporation from the land or sea or inland water, followed by condensation to form clouds, precipitation (rain, snow or hail), interception, infiltration, percolation, runoff, accumulation in the soil or in bodies of water, and re-evaporation. Also known as the water cycle.
Hydrology *Source:* WMO and UNESCO, *International Glossary.*	Science that deals with the waters above and below the land surfaces of Earth; their occurrence, circulation and distribution both in time and space; their biological, chemical and physical properties; and their interaction with their environment, including their relation to living beings.
Impact *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	Any effect caused by a proposed activity on the environment, including effects on human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments, or other physical structures, or the interaction among those factors. It also includes effects on cultural heritage or socioeconomic conditions resulting from alterations to those factors.
Impervious surface *Source:* USACE, *Glossary.*	Surfaces, such as roads, parking lots and roofs, whose properties prevent the infiltration of water and increase the amount of stormwater runoff in a watershed.
Informant	Human source of information, including local residents and community groups, local government officials and specialists working for the government, NGOs, representatives of the private sector, or in academia.
Integrated flood management (IFM) *Source:* APFM, *Integrated Flood Management Concept Paper.*	A process promoting integrated land and water resources development in a watershed, within the context of integrated water resources management, with a view to maximizing the efficient use of floodplains and to minimizing loss of life and property. Integrated flood management should encourage the participation of users, planners and policy-makers at all levels. The approach should be open, transparent, inclusive and communicative; should require the decentralization of decision-making; and should include public consultation and the involvement of stakeholders in planning and implementation.
Integrated water resources management (IWRM) *Source:* APFM, *Integrated Flood Management Concept Paper.*	As defined by the Global Water Partnership, IWRM is "a process which promotes the coordinated management and development of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." This approach recognizes that a single intervention has implications for the system as a whole, and that the integration of development and flood management can yield multiple benefits from a single intervention.

La Niña	See El Niño-Southern Oscillation.
Lag time (or basin lag) *Source:* WMO and UNESCO, *International Glossary.*	In an interconnected stream–aquifer system, the time difference between the peak runoff and the highest groundwater level at a given cross section.
Lake flooding (or lake level flooding) *Source:* Wright, *Floods and Floodplains.*	Flooding caused by excessive inflow from the lake's tributaries; tsunamis triggered by landslides; and changes in regional groundwater conditions.
Land subsidence *Source:* USGS, *Land Subsidence*.	Land subsidence occurs when large amounts of groundwater have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts because the water is partly responsible for holding the ground up. When the water is withdrawn, the rock falls in on itself. Land subsidence is most often caused by human activities, mainly the removal of subsurface water.
Land use planning (or physical/spatial planning) *Source:* UNISDR, *Terminology.*	The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including the consideration of long-term economic, social and environmental objectives; the implications for different communities and interest groups; and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses. For purposes of this guide, land use planning is used interchangeably with spatial and physical planning.
Levee *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	An embankment raised to prevent a river from overflowing.
Livelihood *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	A livelihood comprises the capabilities, assets (including both material and social resources), and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, and when it can maintain or enhance its capabilities and assets both now and in the future, without undermining the natural resource base.
Magnitude	For flood-related hazards, the magnitude is often expressed as the volume of water per time period (e.g., cubic meters per second) or in total volume (e.g., cubic meters of water flooding an area).
Marsh	Common in floodplain areas near the lower reaches of a river; low grassy vegetation and peaty soil that can hold very large amounts of water.
Mitigate/mitigation *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	The use of reasonable care and diligence in an effort to minimize or avoid injury; to take protective action to avoid additional injury or loss.
Mudflood *Source:* Wright, *Floods and Floodplains.*	A flood in which the water carries heavy sediment. Also referred to as mudflows, debris flows, or sometimes as landslides triggered by rainfall.
Natural and nature-based methods *Source:* USACE, *Coastal Risk Reduction and Resilience.*	The use of environmental systems to accomplish multiple purposes, including stormwater management, flood risk management, water conservation and improved water quality. For the purposes of this guide, the terms "green infrastructure" or "soft engineering methods" are used interchangeably. Also see green infrastructure.
Non-structural flood mitigation *Source:* WMO and UNESCO, *International Glossary.*	Systems for reducing the effects of floods using non-structural means, such as regulations, land use planning, advanced warning systems and flood insurance.

Overflow *Source:* Sayers et al., *Flood Risk Management: A Strategic Approach.*	Flow over a structure, such as a flood embankment or seawall, by a progressive increase in water level.
Overtopping *Source:* Sayers et al., *Flood Risk Management: A Strategic Approach.*	Periodic flow over a structure, such as a flood embankment or seawall, through wave action.
Permeability *Source:* USACE, *Glossary.*	Properties of bulk material (sand, crushed rock, pavement) that permit movement of water through its pores.
Physical or spatial planning	See land use planning.
Polder *Source:* WMO and UNESCO, *International Glossary.*	Mostly low-lying area, artificially protected from surrounding water, and within which the water table can be controlled. Similar to wetlands, but they are created by building dikes around subsided land.
Precipitation *Source:* WMO and UNESCO, *International Glossary.*	The products of water vapor condensation – rain, hail or snow.
Probability *Source:* WMO, *DRR Definitions.*	Likelihood of an event happening. Probability is statistically higher for low-intensity hazards. Probability reflects the future frequency of occurrence of a hazard event and cannot be drawn using historical statistics alone. For hydrometeorological hazards, probability assessments need to reflect trends related to ongoing evolutions (e.g., climate change, deforestation, etc.).
Rain gardens	A landscape technique that uses small garden plots to increase infiltration, evapotranspiration and rainwater storage.
Rain on ice flooding	Flooding caused by rainfall on ice, leading to flows across the ice and flooding in low areas.
Rainwater harvesting *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Accumulating and storing rainwater for reuse before it reaches the aquifer.
Rational method *Source:* Thompson, *The Rational Method.*	The rational method is a simple technique for estimating a design discharge from a small watershed. It was developed by Kuichling (1889) for small drainage basins in urban areas.
Reforestation *Source:* FAO, *Definitions of Forest.*	Reforestation is the reestablishment of forest formations after a temporary condition with less than 10% canopy cover due to human-induced or natural perturbations.
Remote sensing *Source:* Lillesand et al., *Remote Sensing and Image Interpretation.*	The science and art of obtaining information about an object, area or phenomenon by analyzing data acquired by a device that is not in contact with the object, area or phenomenon under investigation.
Resilience	The ability of a social-ecological system to absorb and recover from shocks and disturbances, maintain functionality and services by adapting to chronic stressors, and transform when necessary.

Response (also called disaster relief) *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety, and meet the basic subsistence needs of the people affected.
Return period (also known as recurrence interval) *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Long-term average interval of time between years in which hydrological events occur that equal, or exceed, a given magnitude.
Revegetation *Source:* USDA NRCS, *Terminology and Definitions Associated With Revegetation.*	General expression used for the process of planting bare areas (raw mineral soils) with perennial plants or, less often, with annual plants. It encompasses three levels in order of increasing complexity: rehabilitation, reclamation, and restoration.
Revetments	Revetments are structures built as a cover or apron to protect a stream/lake bank with loose material. They are generally constructed by packing boulders, other heavy material, gabion walls or concrete lining that cannot be carried by the force of water along the waterway.
Riparian *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Land bordering a watercourse. Habitats that exist adjacent or along the streams are riparian ecosystems.
Risk *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	The probability of harmful consequences or expected losses resulting from a given hazard to a given element at danger or peril over a specified time period.
River basin	See watershed.
Riverine flooding *Source:* Wright, *Floods and Floodplains.*	Flooding that occurs when water in a river or drainage channel cannot be constrained within its natural or artificial boundaries and results in inundation of the floodplain. Riverine flooding can develop from heavy or extended periods of rainfall and rapid snowmelt.
Sewage *Source:* UN-Water, *Wastewater Management: A UN Water Analytical Brief.*	Consists of blackwater (excreta, urine and fecal sludge or night soil) and gray water (kitchen and bathing wastewater). The mix and composition will depend on the water supply and sanitation facilities available, water-use practices and social norms. Also known as domestic wastewater.
Soft engineering	See natural and nature-based methods.
Soil conservation *Source:* WMO and UNESCO, *International Glossary.*	Soil conservation is the protection of soil from erosion and other types of deterioration, so as to maintain soil fertility and productivity. It generally includes watershed management and water use.
Spill over *Source:* WMO and UNESCO, *International Glossary.*	Flow from a reservoir over or through a spillway.
Spillway *Source:* WMO and UNESCO, *International Glossary.*	Structure, usually in dams, over which excess floodwater flows.
Storm surge *Source:* NOAA National Hurricane Center, *Glossary of NHC Terms.*	An abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge is usually estimated by subtracting the normal or astronomical high tide from the observed storm tide.

Stormwater runoff *Source:* NOAA/NWS, *Glossary.*	Precipitation that does not infiltrate the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems. Also known as stormwater discharge.
Stream flow *Source:* USACE, *Glossary.*	The amount of water passing a given point in a river in a given period of time, usually expressed in cubic feet per second (cfs) or million gallons per day (mgd).
Structural flood mitigation *Source:* WMO and UNESCO, *International Glossary.*	Reduction of the effects of a flood using physical solutions, such as reservoirs, levees, dredging and diversions.
Surface runoff *Source:* NOAA/NWS, *Glossary.*	In hydrologic terms, the runoff that travels overland to the stream channel. Rain that falls on the stream channel is often included with this quantity. Also known as overland flow.
Sustainable urban drainage systems (SUDS) *Source:* Scottish Environment Protection Agency, *Diffuse pollution in the urban environment (SUDS).*	A sequence of water management practices and facilities designed to drain surface water in a manner that will provide a more sustainable approach than what has been the conventional practice of routing runoff through a pipe to a watercourse. SUDS is similar to green infrastructure.
Swale *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Grass-lined channel or low-lying depression or ditch that allows the slow infiltration, storage and conveyance of stormwater.
Transpiration *Source:* WMO and UNESCO, *International Glossary.*	Process by which water from vegetation is transferred into the atmosphere in the form of vapor.
Tsunami flooding *Source:* NOAA, *Tsunami.*	A series of ocean waves generated by sudden displacements in the seafloor, landslides, or volcanic activity. The tsunami wave may come gently ashore or may increase in height to become a fast-moving wall of turbulent water several meters high.
Upstream *Source:* Jha, Bloch and Lamond, Cities and Flooding.	That part of a channel nearer the source of the watercourse than the reference point; traveling opposite the normal direction of flow.
Urban *Source:* UNICEF, *The State of the World's Children 2012: Children in an Urban World.*	The definition of urban varies from country to country and, with periodic reclassification, can also vary within one country over time, making direct comparisons difficult. An urban area can be defined by one or more of the following: administrative criteria or political boundaries (e.g., area within the jurisdiction of a municipality or town committee); a threshold population size (where the minimum for an urban settlement is typically about 2,000 people, although this varies globally between 200 and 50,000); population density; economic function (e.g., where a significant majority of the population is not primarily engaged in agriculture, or where there is surplus employment); or the presence of urban characteristics (e.g., paved streets, electric lighting, sewerage).
Urban flooding *Source:* FLOODsite, *Flooding in Urban Areas.*	Flooding due to a combination of increasing impervious surfaces, inadequate stormwater storage or drainage capacity, and poorly planned infrastructure, particularly in rapidly urbanizing areas. Urban flooding can also encompass all other types of flooding that occur in urban areas, such as riverine and coastal flooding.
Urban heat island effect (UHI) *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Urban areas are significantly warmer than the surrounding rural areas; temperatures can vary across a city depending on the nature of the land cover, such that urban parks and lakes are cooler than adjacent areas covered by buildings.

Urban planning *Source:* UN-Habitat, *Issue Paper on Urban and Spatial Planning and Design.*	A decision-making process aimed at realizing economic, social, cultural and environmental goals through the development of spatial visions, strategies and plans, and the application of a set of policy principles, tools, institutional and participatory mechanisms and regulatory procedures.
Urbanization *Source:* OECD, *Glossary of Environment Statistics.*	The increase in the proportion of a country that is urban. Positive rates of urbanization result when the urban population grows at a faster rate than the total population.
Vulnerability *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	Human vulnerability is the relative lack of capacity of a person or community to anticipate, cope with, resist, and recover from the impact of a hazard. Structural or physical vulnerability is the extent to which a structure or service is likely to be damaged or disrupted by a hazard event. Community vulnerability exists when the elements at risk are in the path or area of the hazard and are susceptible to damage by it. The losses caused by a hazard, such as a flood, will be proportionally much greater for more vulnerable populations, e.g., those living in poverty, with weak structures, and without adequate coping strategies.
Wastewater *Source:* UN-Water, *Wastewater Management: A UN Water Analytical Brief.*	A combination of one or more of the following: domestic effluent consisting of blackwater (excreta, urine and fecal sludge) and gray water (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater, and other urban runoff; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter.
Water balance (or hydrological balance) *Source:* WMO and UNESCO, *International Glossary.*	Evaluation of the inputs, outputs and changes in storage in a water body over a period of time.
Water cycle	See hydrological cycle.
Watershed (or river basin, or catchment) *Source:* WWF and ARC, *Green Recovery and Reconstruction.*	An area of land that drains downslope to the lowest point. The water moves through a network of drainage pathways, both underground and on the surface. Generally, these pathways converge into streams and rivers that become progressively larger as the water moves downstream, eventually reaching a water basin (e.g., lake, estuary, ocean).
Watershed approach	See integrated flood management.
Weather *Source:* USAID, *Climate-Resilient Development.*	The state of the atmosphere in a given place at a given time; refers to the actual temperature, wind speed and direction; the amount and form of precipitation (e.g., rain, snow, hail); and cloudiness. Examples include wind speeds this morning, rainfall this spring and temperatures in May. A compilation of weather data over 30 years is typically used to determine climate (e.g., the average temperature and precipitation).
Weir *Source:* WMO and UNESCO, *International Glossary.*	Overflow structure that may be used for controlling upstream water level or for measuring discharge, or for both.
Wetland *Source:* Mitsch and Gosselink, *Wetlands.*	A wetland is an ecosystem in which the soil is permanently or intermittently saturated (or inundated) with water and that has vegetation that tolerates high moisture levels, has shallow water or flooded soils intermittently, has organisms adapted to this environment, and has soil indicators of flooding, such as hydric soils.
Zoning *Source:* Jha, Bloch and Lamond, *Cities and Flooding.*	Land use zoning is a systematic way of regulating the types of development and human activities that can take place within an administrative area.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adelekan, Ibidun O. "Flood Risk Management in the Coastal City of Lagos, Nigeria." *Journal of Flood Risk Management*. July 2015. doi: 10.1111/jfr3.12179.

Ahrens, C. Donald. *Meteorology Today: An Introduction to Weather, Climate, and the Environment*. 9th ed. Belmont, CA: Brooks/Cole Cengage Learning, 2009.

American Rivers. "Green Infrastructure Training." Accessed January 26, 2016. http://www.americanrivers.org/green-infrastructure-training/stormwater-management/gray-infrastructure/.

Asian Development Bank (ADB). *Guidelines for Preparing a Design and Monitoring Framework*. 2nd ed. Bangkok: ADB, 2007. Accessed March 28, 2016. http://www.adb.org/sites/default/files/institutional-document/32509/files/guidelines-preparing-dmf.pdf.

———. *The Economics of Climate Change in Southeast Asia: A Regional Review*. Mandaluyong City, Philippines: ADB, 2009. Accessed May 5, 2016. http://www.adb.org/sites/default/files/publication/29657/economics-climate-change-se-asia.pdf.

———. *Strengthening Participation for Development Results: An Asian Development Bank Guide to Participation*. Mandaluyong City, Philippines: ADB, 2012. Accessed March 28, 2016. http://www.adb.org/sites/default/files/institutional-document/33349/files/strengthening-participation-development-results.pdf.

Asian Disaster Preparedness Center (ADPC) and United Nations Development Programme (UNDP). *A Primer Integrated Flood Risk Management in Asia*. Bangkok: ADPC, 2005. Accessed March 21, 2016. http://www.preventionweb.net/files/2776_adpcprimerapr05.pdf.

Associated Programme on Flood Management (APFM). *Conducting Flood Loss Assessments*. Integrated Flood Management Tools Series, no. 2. Geneva: World Meteorological Organization (WMO), 2007. Accessed March 21, 2016. http://www.apfm.info/publications/tools/APFM_Tool_02.pdf.

———. *Flood Management in a Changing Climate*. Integrated Flood Management Tools Series, no. 14. Geneva: WMO, 2009. Accessed March 21, 2016. http://www.apfm.info/publications/tools/Tool_09_FM_in_a_changing_climate.pdf.

———. *Flood Mapping*. Integrated Flood Management Tools Series, no. 20. Geneva: WMO, 2013. Accessed March 21, 2016. http://www.apfm.info/publications/tools/APFM_Tool_20.pdf.

———. *Integrated Flood Management Concept Paper*. Integrated Flood Management Tools Series, no. 1047. Geneva: WMO, 2009. Accessed March 21, 2016. http://www.apfm.info/publications/concept_paper_e.pdf.

———. *Management of Flash Floods*. Integrated Flood Management Tools Series, no. 16. Geneva: WMO, 2012. Accessed March 21, 2016. http://www.apfm.info/publications/tools/APFM_Tool_16.pdf.

———. *Management of Sediment-Related Risks*. Integrated Flood Management Tools Series, no. 12. Geneva: WMO, 2011. Accessed March 21, 2016. http://www.apfm.info/publications/tools/APFM_Tool_12.pdf.

———. *Urban Flood Risk Management*. Flood Management Tools Series, no. 11. Geneva: WMO, 2008. Accessed March 21, 2016. http://www.apfm.info/publications/tools/Tool_06_Urban_Flood_Risk_Management.pdf.

Basham, A. L. *The Wonder That Was India*. 3rd ed. New Delhi: Pan McMillen, 2014.

Blake, R., A. Grimm, T. Ichinose, R. Horton, S. Gaffin, S. Jiong, D. Bader, L. D. Cecil. "Urban Climate: Processes, Trends, and Projections." In *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*. Edited by C. Rosenzweig, W. D. Solecki, S. A. Hammer and S. Mehrotra, 43-81. Cambridge, UK: Cambridge University Press, 2011.

Blaustein, Richard. "Urban Biodiversity Gains New Converts: Cities around the World Are Conserving Species and Restoring Habitat." *BioScience* 63, no. 2 (2013): 72–77. doi: 10.1525/bio.2013.63.2.3.

Boles, E., A. Anderson, R. Cawich, V. Figueroa, J. Franco, D. Grijalva, D. Mai, K. Mendez, A. Peralta, L. Requena, M. Rodriguez and E. Sanchez. *Rapid Assessment of Effects and Issues Related to Development in the Placencia Area, Dry Season 2011*. NRMP 4552 Integrated Coastal Zone Management Course Project. August 24, 2011. Accessed May 4, 2016. http://www.pcsdbelize.org/placencia-assessment.pdf.

Bonell, M. and L. A. Bruijnzeel, eds. *Forests, Water, and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management*. Cambridge, UK: Cambridge University Press, 2004.

Bood, Nadia and M. Fish. *Promoting Mangrove Conservation and Restoration as a Means of Effluent Reduction, Shoreline Stabilization and Flood Control along the Placencia Peninsula and Lagoon Area: A Case Study*. World Wildlife Fund. August 2012. Accessed May 9, 2016. http://community.eldis.org/.59c095ef/Climate Change Triple-wins in Belize coastal zone_Placencia Casestudy_draft.pdf.

Braw, Elisabeth. "Rotterdam: Designing a Flood-Proof City to Withstand Climate Change." *Guardian*. November 18, 2013. Accessed May 10, 2016. http://www.theguardian.com/sustainable-business/rotterdam-flood-proof-climate-change.

Brewer, Douglas J. *Ancient Egypt: Foundations of a Civilization*. New York: Routledge, 2014.

Bruijnzeel, L. A. "Hydrological Functions of Tropical Forests: Not Seeing the Soil for the Trees?" *Agriculture, Ecosystems and Environment* 104, no. 1 (September 2004): 185–228. doi: 10.1016/j.agee.2004.01.015.

———. "Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review." UNESCO/Vrije Universiteit, 1990. Accessed March 21, 2016. http://unesdoc.unesco.org/images/0009/000974/097405eo.pdf.

Buffle, P., T. Nguyen and M. F. Thomsen. *Community-Based Mangrove Reforestation and Management in Da Loc, Vietnam*. Ecosystems and Livelihoods Adaptation Network (ELAN). 2011. Accessed May 5, 2016. http://www.preventionweb.net/files/25381_vietnam.pdf.

Campbell, John. "This is Africa's New Biggest City: Lagos, Nigeria, Population 21 Million." *Atlantic*. July 10, 2012. Accessed March 21, 2016. http://www.theatlantic.com/international/archive/2012/07/this-is-africas-new-biggest-city-lagos-nigeria-population-21-million/259611/.

Caparelli, Maria Estela, Ludmilla Palazzo and Rhazi Kone. "In Brazil, Adolescents Use UNICEF's New Digital Mapping Technology to Reduce Disaster Risks in the Favelas." UNICEF. May 20, 2015. Accessed June 23, 2015. http://www.unicef.org/statistics/brazil_62043.html.

CARE. "Mangroves and Coastal Community Resilience." *First Meeting of Climate Change Adaptation Demonstration Projects in the Lower Mekong Basin*. Ho Chi Minh City, Vietnam: CARE, 2012.

———. "Mangroves to Protect from Climate Change." Accessed May 5, 2016. http://www.careclimatechange.org/files/adaptation/Vietnam_Mangroves_Thanh_Hoa.pdf.

Carey, Bruce. "A Study Guide on the Empirical Version of the Rational Method to Estimate Peak Discharge Runoff." July 2014. Accessed March 21, 2016. http://landcare.org.au/wp-content/uploads/2013/01/Empirical-version-of-the-Rational-method-to-estimate-peak-discharge-Runoff.pdf.

Carpenter, S., B. Walker, J. M. Anderies and N. Abel. "From Metaphor to Measurement: Resilience of What to What?" *Ecosystems*, 4 (2001): 765-781. doi: 10.1007/s10021-001-0045-9.

Chesapeake Bay Program. "Restoring Wetlands on Agricultural Lands." Accessed May 12, 2016. http://www.chesapeakebay.net/indicators/indicator/restoring_wetlands.

Coastal Zone Management Authority and Institute (CZMAI). *Belize Integrated Coastal Zone Management Plan*. Belize City: CZMAI, 2015.

———. *State of the Coast Report 2000*. Belize City: CZMAI, 2001. Accessed May 4, 2016. http://www.coastalzonebelize.org/wp-content/uploads/2010/04/state_ofthe_coast_report_2000.pdf.

Coca-Cola Journey Pakistan. "Integrated Development in Ayubia National Park." Accessed May 4, 2016. http://www.coca-colajourney.com.pk/stories/integrated-development-in-ayubia-national-park.

Cohen, Nevin and Katinka Wijsman. "Urban Agriculture as Green Infrastructure: The Case of New York City." *Urban Agriculture Magazine*. March 2014. Accessed March 21, 2016. http://www.ruaf.org/sites/default/files/p16-19.pdf.

Correa, Elena, ed. *Preventive Resettlement of Populations at Risk of Disaster: Experiences from Latin America*. Washington, DC: World Bank, 2011. Accessed May 5, 2016. http://www.gfdrr.org/sites/gfdrr/files/publication/preventive_resettlement_LAC_experiencesDS150.pdf.

Daily Times. "Islamabad First City to Have Rainwater Harvesting Programme." Accessed March 5, 2016. http://archives.dailytimes.com.pk/islamabad/13-Apr-2010/islamabad-first-city-to-have-rainwater-harvesting-programme.

Datu, Kerwin. "A Flood-Free Lagos: The Regional Imperative." Heinrich Böll Stiftung Nigeria. July 29, 2014. Accessed May 5, 2016. https://ng.boell.org/2014/07/29/flood-free-lagos-regional-imperative.

David, Carlos P. C., D. M. V. Padua, M. M. Vargas, J. I. Caceres, M. C. T. M. Vicente, D. B. Tolentino, C. C. Abon, J. Ramores, R. A. Wamil. "Community and DRR Technology Interface: The 'Reduction of Flood Risk in the Bicol River Basin II' Project." Building Disaster Resilient Communities: Stories and Lessons from the Philippines. Accessed May 5, 2016. http://community.eldis.org/?233@@.59e99723!enclosure=.59e99844&ad=1.

de Brito, M. M., A. Passuello, E. M. A. Giazzon, C. Korzenowski, S. F. de Araújo, A. L. Alves, C. Pauletti and L. C. P. da Silva Filho. "A Participatory and Integrated Flood Risk Management Experience: Belo Horizonte, Brazil." Sixth International Conference of Flood Management. Sao Paulo, Brazil, September 2014.

Deltares. "Sinking Cities: An Integrated Approach towards Solutions." October 2013. Accessed March 21, 2016. https://www.deltares.nl/app/uploads/2015/09/Sinking-cities.pdf.

Department for Environment, Food and Rural Affairs (Defra) and the Slowing the Flow Partnership. *Defra FCERM Multi-objective Flood Management Demonstration Project*. Project RMP5455: Slowing the Flow at Pickering. London: Defra, 2015. Accessed May 4, 2016. http://www.forestry.gov.uk/pdf/FR_STF_Pickering_P2_May2015.pdf/$FILE/FR_STF_Pickering_P2_May2015.pdf.

Duy, Truong Tuan, Frits J. H. Dirks, Ger de Lange, Ruben J. Dahm, Ho Long Phi. "Land Subsidence: The Flooding Threat in Coastal Cities from Within; A Case Study in Ho Chi Minh City." E-proceedings of the 36th IAHR World Congress. June 28-July 3, 2015. Accessed May 5, 2016. http://89.31.100.18/~iahrpapers/84710.pdf.

Ecoshape. "Overview Building with Nature Program." 2014. Accessed May 10, 2016. http://www.ecoshape.nl/overview-bwn.html.

Environmental Protection Agency (EPA). "Chapter 1: Urban Heat Island Basics." *Reducing Urban Heat Islands: Compendium of Strategies*. October 2008. Accessed March 21, 2016. https://www.epa.gov/heat-islands/heat-island-compendium.

———. "Glossary of Climate Change Terms." Accessed March 21, 2016. https://www3.epa.gov/climatechange/glossary.html.

———. "Terms and Acronyms." Accessed January 2016. http://iaspub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do.

———. "What are Wetland Functions?" Last updated November 17, 2015. Accessed March 21, 2016. https://www.epa.gov/wetlands/what-are-wetland-functions.

Erkens, G., T. Bucx, R. Dam, G. de Lange and J. Lambert. "Sinking Coastal Cities." *Proceedings of the International Association of Hydrological Sciences*, 372 (November 12, 2015): 189–98. doi: 10.5194/piahs-372-189-2015.

European Agency for Reconstruction (EAR). *Evaluation Guidelines*. Brussels: EAR, 2005. Accessed March 28, 2016. http://ec.europa.eu/enlargement/archives/ear/publications/main/documents/RevisedEvaluationGuidelines.pdf.

Executive Order No. 13677. 79 FR 58229. September 23, 2014. Accessed March 21, 2016. https://www.federalregister.gov/articles/2014/09/26/2014-23228/climate-resilient-international-development.

Executive Order No. 13690. 80 FR 6425. January 30, 2015. Accessed March 21, 2016. https://www.federalregister.gov/articles/2015/02/04/2015-02379/establishing-a-federal-flood-risk-management-standard-and-a-process-for-further-soliciting-and.

Federal Emergency Management Agency (FEMA), "Floodproofing: Definitions/Descriptions." Accessed April 26, 2015. http://www.fema.gov/floodproofing.

FLOODsite. "Flooding in Urban Areas." 2008. Accessed March 21, 2016. http://www.floodsite.net/juniorfloodsite/html/en/student/thingstoknow/hydrology/urbanfloods.html.

Food and Agriculture Organization (FAO). "Definitions on Forest Change Processes." Forestry Department. Accessed January 26, 2016. http://www.fao.org/docrep/006/ad665e/ad665e04.htm.

Ghimire, Chandra Prasad, Mike Bonell, L. Adrian Bruijnzeel, Neil A. Coles and Maciek W. Lubczynski. "Reforesting Severely Degraded Grassland in the Lesser Himalaya of Nepal: Effects on Soil Hydraulic Conductivity and Overland Flow Production." *Journal of Geophysical Research: Earth Surface* 118, no. 4 (2013): 2528–45. doi: 10.1002/2013JF002888.

Godschalk, David R. "Safe Growth Audits." *Zoning Practice*, no. 10. Chicago: American Planning Association, 2009. Accessed March 28, 2016. http://snohomishcountywa.gov/ArchiveCenter/ViewFile/Item/3939.

Gray, Donald H. and Robbin B. Sotir. *Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control*. New York: John Wiley and Sons, 1996.

Hirji, Rafik and Richard Davis. *Environmental Flows in Water Resources Policies, Plans, and Projects: Findings and Recommendations*. Washington, DC: World Bank, 2009. Accessed March 22, 2016. http://siteresources.worldbank.org/INTWAT/Resources/Env_Flows_Water_v1.pdf.

International Fund for Agricultural Development (IFAD). *Good Practices in Participatory Mapping: A Review Prepared for the International Fund for Agricultural Development (IFAD)*. 2009. Accessed May 12, 2016. http://www.ifad.org/pub/map/pm_web.pdf.

International Panel on Climate Change (IPCC). "Annex III: Glossary." In *Climate Change 2013: The Physical Science Basics*. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. New York: Cambridge University Press, 2013. Accessed March 31, 2016. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_AnnexIII_FINAL.pdf.

———. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. New York: Cambridge University Press, 2014. Accessed March 22, 2016. https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-PartA_FINAL.pdf.

———. "Increasing Human Utilisation of the Coastal Zone." In *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Working Group II to the Fourth Assessment Report of the IPCC. New York: Cambridge University Press, 2007. Accessed March 22, 2016. https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch6s6-2-2.html.

———. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press, 2012.

International Tropical Timber Organization (ITTO). *Manual for Project Monitoring, Review, Reporting and Evaluation*. 3rd ed. ITTO, 2009. Accessed March 28, 2016. http://www.itto.int/projectimplementation/manuals/.

International Union for Conservation of Nature (IUCN). "Barcelona's Quest for a Green Urban Future." Last modified December 9, 2013. Accessed March 22, 2016. http://iucn.org/about/union/secretariat/offices/europe/?14172/Barcelonas-quest-for-a-green-urban-future.

Irfanullah, Haseeb Md., Md. Abul Kalam Azad, Md. Kamruzzaman and Md. Ahsanul Wahed. "Floating Gardening in Bangladesh: A Means to Rebuild Lives after Devastating Flood." *Indian Journal of Traditional Knowledge* 10, no. 1 (January 2011): 31-38.

Japan International Corporation Agency (JICA). *JICA Guideline for Project Evaluation*. JICA, 2004. Accessed March 28, 2016. http://www.jica.go.jp/english/our_work/evaluation/tech_and_grant/guides/pdf/guideline01-01.pdf.

Jha, Abhas K., Robin Bloch and Jessica Lamond. *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century*. Washington, DC: World Bank Publications, 2012. Accessed March 17, 2016. http://www.gfdrr.org/sites/gfdrr/files/publication/World_Bank_Cities_and_Flooding_Guidebook.pdf.

Jha, Abhas K., Jennifer Duyne Barenstein, Priscilla M. Phelps, Daniel Pittet and Stephen Sena. *Safer Homes, Stronger Communities: A Handbook for Reconstructing after Natural Disasters*. Washington, DC: World Bank, 2010. Accessed March 28, 2016. https://www.gfdrr.org/sites/gfdrr/files/publication/SaferHomesStrongerCommunitites.pdf.

Jones-Bos, Renée. "New Paradigm - Living with Water." Closing keynote speech at American Planning Association National Planning Conference. Los Angeles, April 14-17, 2012. Accessed May 10, 2016. http://www.the-netherlands.org/key-topics/water-management/more-information/water-management-apa-conference-2012.html.

Kazmierczak, A., and J. Carter. "Adaptations to Climate Change Using Green and Blue Infrastructure: A Database of Case Studies." The University of Manchester, June 2010. Accessed May 12, 2016. https://www.escholar.manchester.ac.uk/uk-ac-man-scw:128518.

Keeton, Rachel. "A Half-Millennium-Old Dike in Holland Gets a State-of-the-Art Upgrade." *Next City*. September 2, 2014. Accessed May 10, 2016. https://nextcity.org/daily/entry/new-hondsbossche-dunes-netherlands-upgrade.

Keller, Gordon and James Sherar. *Low-Volume Roads Engineering: Best Management Practices Field Guide*. Washington, DC: USAID, 2003. http://pdf.usaid.gov/pdf_docs/Pnadb595.pdf.

Lane, S. N., N. Odoni, C. Landstrom, S. J. Whatmore, N. Ward and S. Bradley. "Doing Flood Risk Differently: An Experiment in Radical Scientific Method." *Transactions of the Institute of British Geographers 36* (October 2010): 15–36. doi: 10.1111/j.1475-5661.2010.00410.x.

Lankford, B., C. Sokile, D. Yawson and H. Lévite. *The River Basin Game: A Water Dialogue Tool*. Working Paper 75. Colombo, Sri Lanka: International Water Management Institute, 2004. Accessed August 5, 2015. http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR75.pdf.

Lankford, Bruce. *Resource Efficiency Complexity and the Commons: The Paracommons and Paradoxes of Natural Resource Losses, Wastes and Wastages*. Abingdon, UK: Earthscan Publications, 2013.

Lankford, Bruce and Drennan Watson. "Metaphor in Natural Resource Gaming: Insights from the River Basin Game." *Simulation and Gaming* 38, no. 3 (2007): 421-443. doi: 10.1177/1046878107300671.

Lewis, Lisa. *Soil Bioengineering an Alternative for Roadside Management: A Practical Guide.* US Department of Agriculture (USDA). September 2000. Accessed May 12, 2016. http://www.wsdot.wa.gov/publications/fulltext/Roadside/SoilBioEng.pdf.

Lillesand, Thomas M., Ralph W. Kiefer and Jonathan W. Chipman. *Remote Sensing and Image Interpretation*. 7th ed. Hoboken, NJ: John Wiley and Sons, 2015.

Loh, Susan. "Living Walls: A Way to Green the Built Environment." *BEDP Environment Design Guide*. August 2008. Accessed April 19, 2016. http://math.unife.it/lm.ecologia/Insegnamenti/management-degli-ecosistemi/materiale-didattico/Loh 2008 living walls.pdf.

Lohani, B. N., J. W. Evans, R. R. Everitt, H. Ludwig, R. A. Carpenter and S. Tu. *Environmental Impact Assessment for Developing Countries in Asia: Volume 1 - Overview*. Asian Development Bank, 1997. Accessed March 28, 2016. http://adb.org/sites/default/files/pub/1997/eia-developing-countries-asia.pdf.

Mackin, Rebecca. "Weathering the Storm: Horticulture Management in Brooklyn Bridge Park in the Aftermath of Hurricane Sandy." Ecological Landscape Alliance. January 15, 2013. Accessed May 12, 2016. http://www.ecolandscaping.org/01/stormwater-management/weathering-the-storm-horticulture-management-in-brooklyn-bridge-park-in-the-aftermath-of-hurricane-sandy/.

Magombevi, M. S., D. Rollin, B. Lankford. "The River Basin Game as a Tool for Collective Water Management at Community Level in South Africa." *Physics and Chemistry of the Earth* Parts A/B/C 33, no. 8-13 (2008): 873-880.

Maller, Cecily, Mardie Townsend, Anita Pryor, Peter Brown and Lawrence St. Leger. "Healthy Nature Healthy People: 'Contact with Nature' as an Upstream Health Promotion Intervention for Populations." *Health Promotion International* 21, no 1 (March 2006): 45–54. Accessed March 22, 2016. doi: 10.1093/heapro/dai032.

McVeigh, Tracy. "The Dutch Solution to Floods: Live with Water, Don't Fight It." *Guardian*. February 15, 2014. Accessed May 10, 2016. http://www.theguardian.com/environment/2014/feb/16/flooding-netherlands.

Millennium Ecosystem Assessment. "Flood and Storm Control." In *Ecosystems and Human Well-Being: Policy Responses*. Washington, DC: Island Press, 2005.

Mitsch, William J. and James G. Gosselink. *Wetlands*. 4th ed. Hoboken, NJ: John Wiley and Sons, 2007.

NASA. "NASA Satellite Confirms Urban Heat Islands Increase Rainfall around Cities." June 19, 2002. Accessed March 22, 2016. http://svs.gsfc.nasa.gov/stories/urban_rain_20020618/index.html.

National Oceanic and Atmospheric Administration (NOAA). "The Tsunami Story." Accessed April 6, 2015. http://www.tsunami.noaa.gov/tsunami_story.html.

Nelson, Stephen A. "River Systems and Causes of Flooding." Tulane University. EENS 3050 Natural Disasters. July 13, 2012. Accessed March 22, 2016. http://www.tulane.edu/~sanelson/Natural_Disasters/riversystems.htm.

———. "Streams and Drainage Systems." Tulane University. EENS 111 Physical Geology. Accessed January 6, 2016. http://www.tulane.edu/~sanelson/eens1110/streams.htm.

New York City Department of City Planning. *Coastal Climate Resilience: Urban Waterfront Adaptive Strategies*. June 2013. Accessed May 12, 2016. http://www.sustainablenyct.org/news/UWAS_Draft_lowres.pdf.

NOAA National Hurricane Center. "Glossary of NHC Terms." Accessed January 27, 2016. http://www.nhc.noaa.gov/aboutgloss.shtml#s.

———. "Storm Surge Overview." Accessed January 6, 2016. http://www.nhc.noaa.gov/surge/.

NOAA National Severe Storms Laboratory. "Flood Forecasting." Accessed January 6, 2016. http://www.nssl.noaa.gov/education/svrwx101/floods/forecasting/.

NOAA National Weather Service (NWS). "Glossary." Last modified June 25, 2009. Accessed March 28, 2016. http://w1.weather.gov/glossary/index.php?letter=s.

NOAA NWS Weather Forecast Office. "NWS Flood Products: What Do They Mean? Flash Flood Warning, Areal Flood Warning, River Flood Warning or Urban and Small Stream Flood Advisory." Accessed January 6, 2016. http://www.srh.noaa.gov/bmx/?n=outreach_flw.

NOAA Photo Library and Oblak. "Beaufort Wind Scale." http://weather.about.com/od/imagegallery/ig/Weather-Map-Symbols/Beaufort-Wind-Scale.htm.

NYC Environmental Protection. "Blue Roof and Green Roof." Accessed December 30, 2015. http://www.nyc.gov/html/dep/html/stormwater/green_pilot_project_ps118.shtml.

Organisation for Economic Co-operation and Development (OECD). "Glossary of Statistical Terms." Accessed April 19, 2016. https://stats.oecd.org/glossary/detail.asp?ID=2819.

Partnership for the Delaware Estuary. "Living Shorelines." Accessed May 12, 2016. http://delawareestuary.org/Living_Shorelines.

Paul, B. K. "Perception of and Agricultural Adjustment to Floods in Jamuna Floodplain, Bangladesh." *Human Ecology* 12, no. 1 (March 1984). http://www.jstor.org/stable/4602721.

Pawelczyk, Katarzyna. "Voices of Youth Takes Digital Mapping Project to the Next Level." UNICEF. October 30, 2013. Accessed July 23, 2015. http://www.unicef.org/adolescence/index_70781.html.

Pidwirny, Michael and Scott Jones. "Chapter 7: Introduction to the Atmosphere." In *Fundamentals of Physical Geography*. 2nd ed. E-book, 2010. Accessed March 23, 2016. http://www.physicalgeography.net/fundamentals/7v.html.

Practical Action. "Floating Gardens in Bangladesh." 2006. Accessed May 5, 2016. http://answers.practicalaction.org/our-resources/item/floating-gardens-in-bangladesh.

Public and Private Infrastructure Investment Management Center (PIMAC). *General Guidelines for Preliminary Feasibility Studies*. Seoul: Korea Development Institute, 2008. Accessed March 28, 2016. http://pimac.kdi.re.kr/eng/mission/pdf/General_Guidelines_for_PFS.pdf.

Rajabu, K. R. M. "Use and Impacts of the River Basin Game in Implementing Integrated Water Resources Management in Mkoji Sub-catchment in Tanzania." *Agricultural Water Management* 94, no. 1-3 (2007): 63-72.

Rapid Emergency Assessment and Coordination Team (REACT) Tajikistan. *REACT Flood Appeal for East, Khatlon, Tajikistan*. May 19, 2010. Accessed May 5, 2016. http://reliefweb.int/sites/reliefweb.int/files/resources/615233 77C67D9DBC4925772C0023737D-Full_Report.pdf.

Rasid, Harun and Bimal Kanti Paul. "Flood Problems in Bangladesh: Is There an Indigenous Solution?" *Environmental Management* 11, no. 2 (1987): 155-173.

Ricketts, Sam and Jennifer L. Jurado. "How Can the Federal Government Help Prepare Local Communities for Natural Disasters?" Environmental and Energy Study Institute (EESI). Washington, DC. April 1, 2015. http://www.eesi.org/briefings/view/040115resilience.

Riley, Ann L. *Restoring Streams in Cities: A Guide for Planners, Policy Makers and Citizens*. Washington, DC: Island Press, 1998.

Roeth, Helen. *The Development of a Public Partnership Framework and Action Plan for Disaster Risk Reduction (DRR) in Asia*. Bangkok, Thailand: UNISDR, 2009. Accessed March 23, 2016. https://www.unisdr.org/we/inform/publications/12080.

Rowling, Megan. "From Parks to Jobs, Disaster Prevention Gets a Makeover." Reuters. March 4, 2015. Accessed May 8, 2016. http://www.reuters.com/article/2015/03/04/us-disaster-risk-urbanresilience-idUSKBN0M00DS20150304Global.

Sayers, P., L. Yuanyuan, G. Galloway, E. Penning-Rowsell, S. Fuxin, W. King, C. Yiwei and T. Le Quesne. *Flood Risk Management: A Strategic Approach*. Paris: UNESCO, 2013. Accessed May 24, 2016. http://www.adb.org/sites/default/files/publication/30246/flood-risk-management.pdf.Schueler, T. R. "The Importance of Imperviousness." *Watershed Protection Techniques* 1, no. 3 (1994): 100-111. Accessed March 23, 2016. http://scc.wa.gov/wp-content/uploads/2015/06/The-Importance-of-Imperviousness_Schueler_2000.pdf.

Schwab, James C., ed. *Planning for Post-Disaster Recovery: Next Generation*. Chicago: American Planning Association, 2014. Accessed March 28, 2016. http://www.fema.gov/media-library-data/1425503479190-22edb2 46b925ba41104b7d38eddc207f/APA_PAS_576.pdf.

Scottish Environment Protection Agency. "Diffuse Pollution in the Urban Environment (SUDS)." Accessed January 26, 2016. http://www.sepa.org.uk/regulations/water/diffuse-pollution/diffuse-pollution-in-the-urban-environment/.

Sen, L., R. Suzuki and M. F. Thomsen. "Adapting to Natural Disasters and Contributing to Climate Change Mitigation: Mangrove Community Forestry in Viet Nam." In *Sharing Lessons on Mangrove Restoration: Proceedings and a Call for Action from an MFF Regional Colloquium*. Gland, Switzerland: IUCN, 2012.

Setchell, Charles A. "Kinshasa, DRC: An Early Success Story in Urban DRR." Washington, DC: USAID, 2004. Accessed May 8, 2016. http://pdf.usaid.gov/pdf_docs/PA00J7D9.pdf.

———. "Multi-Sector Disaster Risk Reduction as a Sustainable Development Template: The Bamako Flood Hazard Mitigation Project." *Monday Developments* 26, no. 4 (2008): pp. 18-19.

Shaikh, Saleem and Sughra Tunio. "Anti-erosion Effort Stops Pakistani Farmers Abandoning Mountain Fields." Thomas Reuters Foundation. August 15, 2014. Accessed May 4, 2016. http://news.trust.org//item/20140814152515-7hnau/?source=jtOtherNews1.

Shanahan, M. "A Tale of Typhoons, Trees and Tiny Creatures that Stood Between a Community and Climate Resilience." International Institute for Environment and Development. April 17, 2012. Accessed May 5, 2016. http://www.iied.org/tale-typhoons-trees-tiny-creatures-stood-between-community-climate-resilience.

Shelter Case Studies. "A.2 Colombia – 2011 – Floods." Accessed May 5, 2016. http://www.sheltercasestudies.org/shelterprojects2013-2014/SP13-14_A02-Colombia-2011.pdf.

Stein, B. A., P. Glick, N. Edelson and A. Staudt, eds. *Climate-Smart Conservation: Putting Adaptation Principles into Practice*. Washington, DC: National Wildlife Federation (NWF), 2014. Accessed March 28, 2016. http://www.nwf.org/pdf/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.pdf.

Suarez, Pablo, Friederike E. L. Otto, Nidhi Kalra, Carina Bachofen, Eric Gordon and Wisford Mudenda. *Loss and Damage in a Changing Climate: Games for Learning and Dialogue that Link HFA and UNFCCC*. Working Paper Series No. 8. The Hague: Red Cross/Red Crescent Climate Centre, 2015. Accessed May 4, 2016. http://www.climatecentre.org/downloads/files/Case%20studies/AW_RCCC_WP8_Suarez%20and%20al%20v3.pdf.

Thanh Nien News. "Vietnam Metro to Tackle Floods with Ponds, Lakes." April 15, 2014. Accessed May 5, 2016. http://www.thanhniennews.com/society/vietnam-metro-to-tackle-floods-with-ponds-lakes-25249.html.

Thompson, David B. "The Rational Method." Texas Tech University, 2006. Accessed March 28, 2016. http://drdbthompson.net/writings/rational.pdf.

Tompkins, Emma L. and W. Neil Adger. "Defining Response Capacity to Enhance Climate Change Policy." *Environmental Science and Policy* 8, no. 6 (December 2005): 562-571.

Tunnel. "Long-term Flood Prevention in Chaophaya Basin, Thailand." *Tunnel*, no. 3. March 2013. Accessed July 23, 2015. http://www.tunnel-online.info/en/artikel/tunnel_2012-03_Long_Term_Flood_Prevention_in_Chaophaya_Basin_Thailand_1419390.html.

Turenscape. "The Floating Gardens – Yongning River Park." Accessed July 24, 2015. http://www.turenscape.com/english/projects/project.php?id=323.

Turnbull, Marilise and Edward Turvill. *Participatory Capacity and Vulnerability Analysis: A Practitioner's Guide*. Oxford, UK: Oxfam GB, 2012. Accessed March 23, 2016. http://policy-practice.oxfam.org.uk/publications/participatory-capacity-and-vulnerability-analysis-a-practitioners-guide-232411.

UK Groundwater Forum. "What Is Groundwater Flooding?" Accessed April 6, 2015. http://www.groundwateruk.org/FAQ_groundwater_flooding.aspx.

United Nations Development Programme (UNDP). *Gender, Climate Change and Community-Based Adaptation*. New York: UNDP, 2010. Accessed March 23, 2016. http://genderandenvironment.org/resource/gender-climate-change-and-community-based-adaptation/.

———. *Gender and Climate Change: Impact and Adaptation*. UNDP Asia-Pacific Gender Community of Practice Annual Learning Workshop. Negombo, Sri Lanka, 2009. Accessed March 23, 2016. http://www.snap-undp.org/elibrary/Publications/GenderAndClimateChange.pdf.

UNDP Special Unit for South-South Cooperation. "Kuala Lumpur, Malaysia: Case Study (Mixed Use Tunnel)." November 2012. Accessed July 23, 2015. http://www.esc-pau.fr/ppp/documents/featured_projects/malaysia_kuala_lumpur.pdf.

UN-Habitat. *Issue Paper on Urban and Spatial Planning and Design*. May 2015. Accessed March 28, 2016. http://unhabitat.org/wp-content/uploads/2015/04/Habitat-III-Issue-Paper-8_Urban-and-Spatial-Planning-and-Design-2.0.pdf.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). "What is Good Governance?" March 28, 2016. http://www.unescap.org/sites/default/files/good-governance.pdf.

United Nations Educational, Scientific and Cultural Organization (UNESCO). "Senegal River Basin (Guinea, Mali, Mauritania, Senegal)." UNESCO World Water Assessment Programme. Accessed July 29, 2015. http://webworld.unesco.org/water/wwap/case_studies/senegal_river/.

UN International Children's Emergency Fund (UNICEF). *The State of the World's Children 2012: Children in an Urban World*. New York: UNICEF, 2012. Accessed March 28, 2016. http://www.unicef.org/sowc2012/pdfs/SOWC%202012-Main%20Report_EN_13Mar2012.pdf.

UN International Strategy for Disaster Reduction (UNISDR). "Gender." Accessed March 23, 2016. http://www.unisdr.org/we/advocate/gender.

———. *Progress and Challenges in Disaster Risk Reduction: A Contribution towards the Development of Policy Indicators for the Post-2015 Framework on Disaster Risk Reduction*. Geneva: UNISDR, 2014. Accessed March 23, 2016. http://www.unisdr.org/files/40967_40967progressandchallengesindisaste.pdf.

———. "Terminology on DRR." August 30, 2007. Accessed March 23, 2016. http://www.unisdr.org/we/inform/terminology#letter-e.

UN Office of Outer Space Affairs (UNOOSA). "International Charter Space and Major Disasters." UN-SPIDER Knowledge Portal. Accessed February 2016. http://www.un-spider.org/space-application/emergency-mechanisms/international-charter-space-and-major-disasters.

UN-Water. *Wastewater Management: A UN-Water Analytical Brief*. Accessed January 26, 2016. http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/UN-Water_Analytical_Brief_Wastewater_Management.pdf.

UN Women. *Gender Mainstreaming in Development Programming*. New York: UN Women, 2014. Accessed March 28, 2016. http://www.unwomen.org/~/media/headquarters/attachments/sections/how%20we%20work/unsystemcoordination/gendermainstreaming-issuesbrief-en%20pdf.pdf.

US Agency for International Development (USAID). *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change*. Washington, DC: USAID, 2014. Accessed March 28, 2016. http://pdf.usaid.gov/pdf_docs/PBAAA245.pdf.

———. *Guide to Gender Integration and Analysis: Additional Help for ADS Chapters 201 and 203*. Washington, DC: USAID, 2010. Accessed March 28, 2016. https://www.usaid.gov/sites/default/files/documents/1865/201sab.pdf.

———. *Tips for Conducting a Gender Analysis at the Activity or Project Level: Additional Help for ADS Chapter 201*. March 17, 2011. Accessed March 28, 2016. https://www.usaid.gov/sites/default/files/documents/1865/201sae.pdf.

US Army Corps of Engineers (USACE). *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. Washington, DC: Directorate of Civil Works, 2013. http://www.corpsclimate.us/docs/USACE_Coastal_Risk_Reduction_final_CWTS_2013-3.pdf.

———. "Glossary." Coastal and Hydraulics Laboratory. Accessed January 26, 2016. http://chl.erdc.usace.army.mil/glossary.

US Coast Guard. "General Information on GPS." Accessed January 26, 2016. http://www.navcen.uscg.gov/?pageName=gpsmain.

US Department of Agriculture (USDA). "Glossary of Landform and Geologic Terms." Accessed January 26, 2015. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054230.

US Geological Survey (USGS). "Flood Definitions." Kansas Water Science Center. Accessed January 6, 2016. http://ks.water.usgs.gov/flood-definitions.

———. "What is a Watershed?." Last modified December 9, 2016. https://water.usgs.gov/edu/watershed.html.

———. "Land Subsidence." Last modified August 20, 2015. http://water.usgs.gov/edu/earthgwlandsubside.html.

Vietnam News Agency. "Community Role in Mangrove Forest Management." January 29, 2015. Accessed August 3, 2015. http://en.vietnamplus.vn/Home/Community-role-in-mangrove-forest-management/20141/45670.vnplus.

Walter, Stephen. "'Upriver': A Game of Flood Preparedness in the Zambezi Valley." Red Cross/Red Crescent Centre. October 9, 2013. Accessed May 4, 2016. http://www.climatecentre.org/news/468/upriver-a-game-of-flood-preparedness-in-the-zambezi-valley.

Walton, Brett. "Pakistan Installs Country's First Urban Rainwater Harvesting System." Circle of Blue. April 24, 2010. Accessed March 28, 2016. http://www.circleofblue.org/waternews/2010/world/south-asia/pakistan-installs-countrys-first-urban-rainwater-harvesting-system/.

World Meteorological Organization (WMO). "DRR Definitions." Disaster Risk Reduction Programme. Accessed March 28, 2016. https://www.wmo.int/pages/prog/drr/resourceDrrDefinitions_en.html.

WMO and UNESCO. *International Glossary of Hydrology*. WMO, no. 385. Geneva: WMO, 2012. Accessed March 28, 2016. http://www.wmo.int/pages/prog/hwrp/publications/international_glossary/385_IGH_2012.pdfhttp://www.wmo.int/pages/prog/hwrp/publications/international_glossary/385_IGH_2012.pdf.

World Wildlife Fund (WWF) and American National Red Cross (ARC). "Module 1 Content Paper." *Green Recovery and Reconstruction: Training Toolkit for Humanitarian Aid*. Accessed January 26, 2016. http://envirodm.org/green-recovery.

WWF. *Mangrove Conservation and Preserves as Climate Change Adaptation in Belize, Central America: A Case Study*. June 30, 2011. Accessed May 5, 2016. http://awsassets.panda.org/downloads/placencia_mangrove_reserves_case_study_final.pdf.

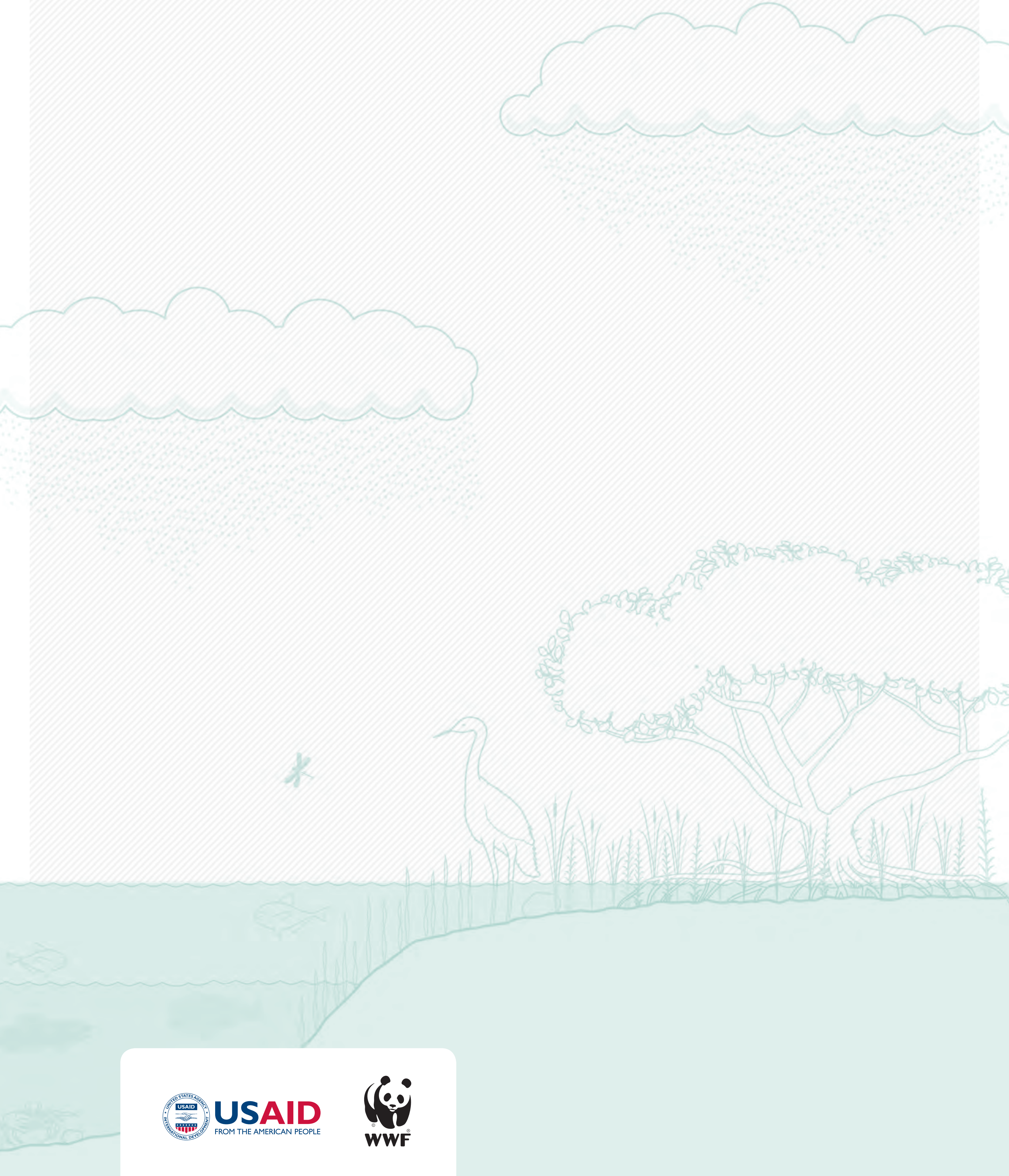
WWF-Pakistan. "Improving Sub-Watershed Management and Environmental Awareness in the Ayubia National Park." Accessed May 4, 2016. http://wwf.panda.org/who_we_are/wwf_offices/pakistan/index.cfm?uProjectID=PK0115.

WWF-Philippines. *The Abuan Integrated Watershed Program FY2015 Work and Financial Plan*. Washington, DC: USAID, 2014. Accessed May 6, 2016. http://pdf.usaid.gov/pdf_docs/pbaab082.pdf.

Wright, James. "Chapter 1: Floods and Floodplains." *Floodplain Management: Principles and Current Practices*. FEMA Emergency Management Institute. 2007. https://www.training.fema.gov/hiedu/aemrc/courses/coursetreat/fm.aspx.

———. "Chapter 2: Types of Floods and Floodplains." *Floodplain Management: Principles and Current Practices*. FEMA Emergency Management Institute. 2007. http://training.fema.gov/hiedu/docs/fmc/chapter%202%20-%20types%20of%20floods%20and%20floodplains.pdf.

Zhiyu, Liu, Cheng Xiaotao, Chen Zuhua, Wan Haotao, Zhou Li, Edwin S. T. Lai, Masashi Kunitsugu, Yang-Su Kim, Tae Sung Cheong, Gunhui Chung, Susan R. Espinueva. *Guidelines on Urban Flood Risk Management (UFRM)*. Technical Report of TC Cross-Cutting Project on Urban Flood Risk Management (UFTM) in the Typhoon Committee Area. Macao, China: ESCAP/WMO Typhoon Committee, 2013. Accessed March 28, 2016. http://www.typhooncommittee.org/46th/Docs/item 10 Publications/UFRM_FINAL.pdf.



USAID
FROM THE AMERICAN PEOPLE

WWF