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Flood Risk Management

A Strategic Approach

Part of a series on strategic water management

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EXECUTIVE SUMMARY

The concepts of flood risk management (FRM) have been widely embraced over the past decade. In many instances this conceptual acceptance has resulted in changes to decision-making practice, highlighting risk management as potentially more complex, but more efficient and effective in delivering multiple goals, than a traditional engineering standards-based approach.

In particular, the emergence of strategic FRM is enabling a longer-term, catchment-wide perspective to emerge. The decision process is based on an explicit trade-off of the whole life-cycle risks reduced, opportunities promoted and the resources required. In doing so, the advantages of adopting a portfolio of integrated multisector responses (including structural and nonstructural measures as well as policy instruments), have moved centre stage.

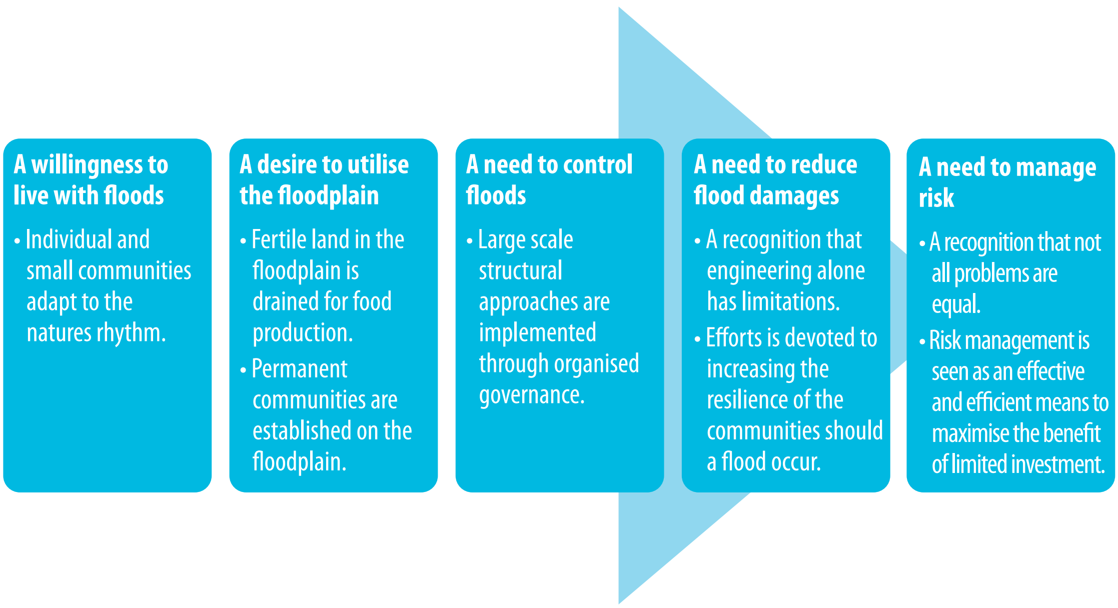
A brief history of flood risk management

The earliest civilizations recognized the need to live alongside floods; locating critical infrastructure on the highest land (as seen through the churches and cathedrals of England), providing flood warnings to those who were at risk of being flooded (common practice in ancient Egypt), and making flood-sensitive land use planning choices (as practised by the Romans).

The requirement for protection and a belief in people's ability to control floods started increasingly to dominate attempts to deal with flooding. During the early part of the twentieth century the concepts of modern FRM began to emerge, and in particular, those recognizing flood management not only as an engineering pursuit but also as a social endeavour. Throughout the 1960s to 1980s, the principal means of mitigating the impacts of floods remained physical flood control (via the construction of levees, dykes, diversion channels, dams and related structures). As populations grew and flood plains were developed, flood losses continued to increase, and the need to do things differently became more apparent. A new approach was needed, one that utilized the concept of risk in decision-making in practice and not just in theory.

This progression is summarized in Figure 1.

Figure 1: The evolution of flood risk management practice



Despite this, traditional flood control approaches continue to persist today in many policies, and perhaps most importantly in decisions taken, decisions that ultimately we may come to regret. But practice is changing slowly. Adopting a strategic approach to FRM is central in aiding this transition. Although there is no single roadmap to follow, and there are few comprehensive examples, many of the elements of good practice and the supporting tools and techniques do now exist.

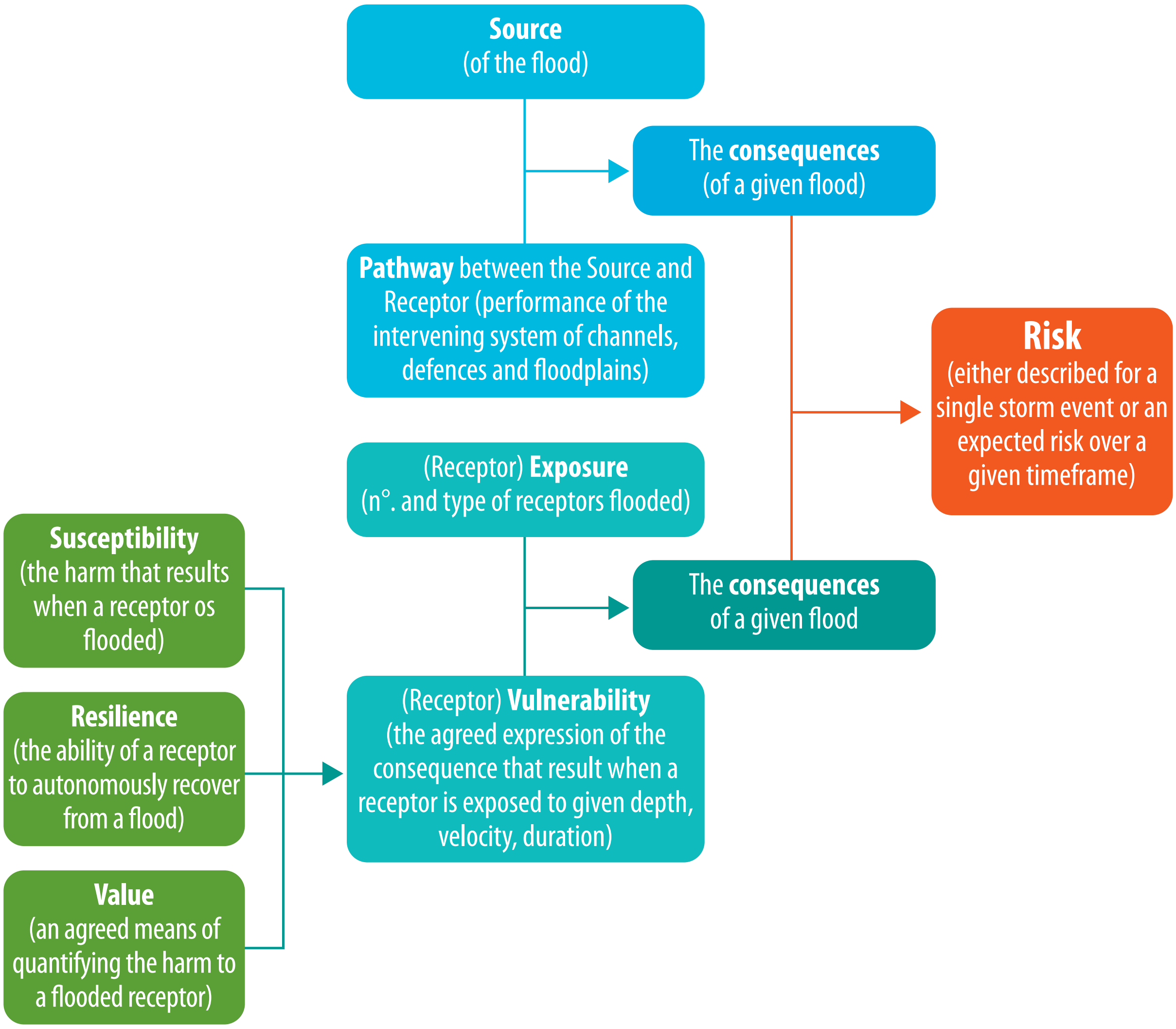
Dimensions of risk

A number of important concepts underlie our understanding of risk and bridge the gap between assessing the risk and making risk-informed decisions. One of the most important of these concepts is the multiple, and sometimes subtle, dimensions of risk itself (Figure 2).

All of these dimensions are subject to change, through either autonomous pressures or purposeful intervention. Traditionally the focus has been on reducing the probability of flooding through extensive structural defence systems such as those found in the Rotterdam in the Netherlands, New Orleans in the United States and around the Huai River, China. Increasingly, there is the recognition that nonstructural actions offer a vital contribution to risk management. Many, however, nonstructural options exist, including actions to, first, reduce the exposure of people, the economy and ecosystems to flooding (through, for example, effective planning control in flood-prone areas, as in the city of Cape Town, South Africa); and second, reduce the vulnerability of those exposed to flooding (through, for example, the use of safe havens, better warning and evacuation planning, modern flash flood forecasts and flood-specific building codes and insurance arrangements).

Recent actions in Bangladesh, and in alpine regions of Europe and China, bear out the effectiveness of such approaches.

Figure 2: The components of risk



Strategic flood risk management

Flood risk management has multiple goals relating to multiple time and space scales (Figure 3). Achieving these relies on the development and implementation of appropriate portfolios of measure (where the advantages of one compensates for the disadvantages of another), a process that is complicated by the changing nature of the flooding system (through climate, geomorphologic and socio-economic influences). Accepting that the future is unknown impacts on the way in which plans are made and decisions implemented. Flood risk management therefore embeds a continuous process of adaptation that is distinct from the 'implement and maintain' philosophy of a traditional flood defence approach.

Taking a longer term, whole-system view places a much higher demand upon those affected by flooding and those responsible for its mitigation. It involves collaborative action across governments, the public sector, businesses, voluntary organizations and individuals. This places an increasing emphasis on effective communication of the residual risks and actions to be taken.

These characteristics form the building blocks of good FRM (Figure 4), and represent an approach that concurrently seeks to make space for water while supporting appropriate economic use of the floodplain.

Figure 3: The primary goals of strategic flood risk management

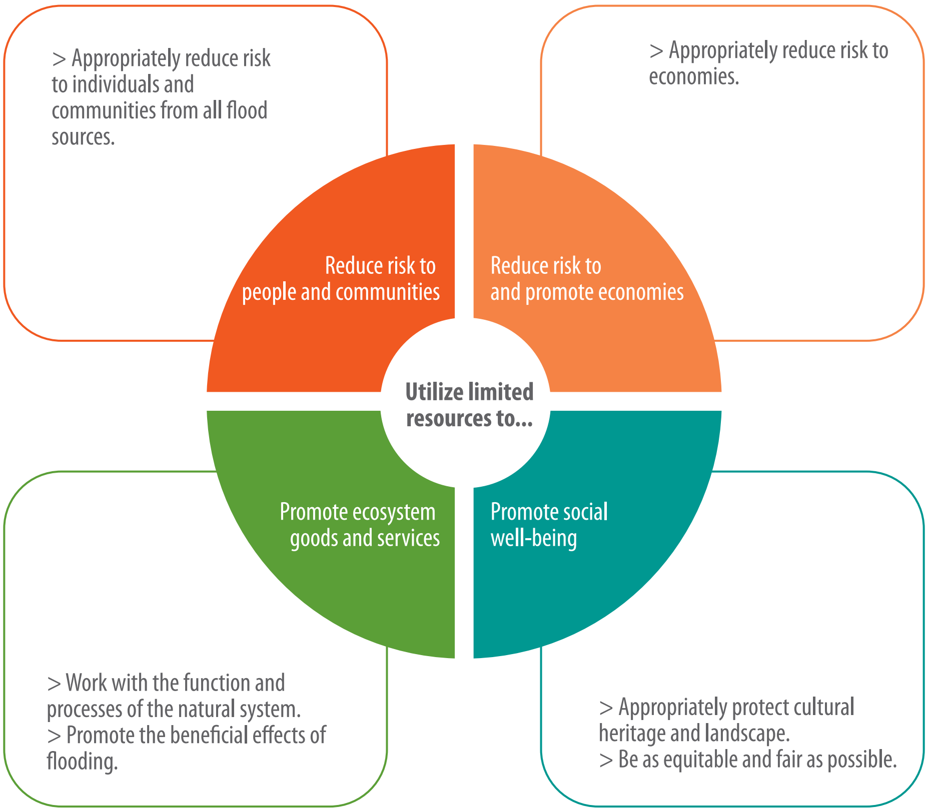
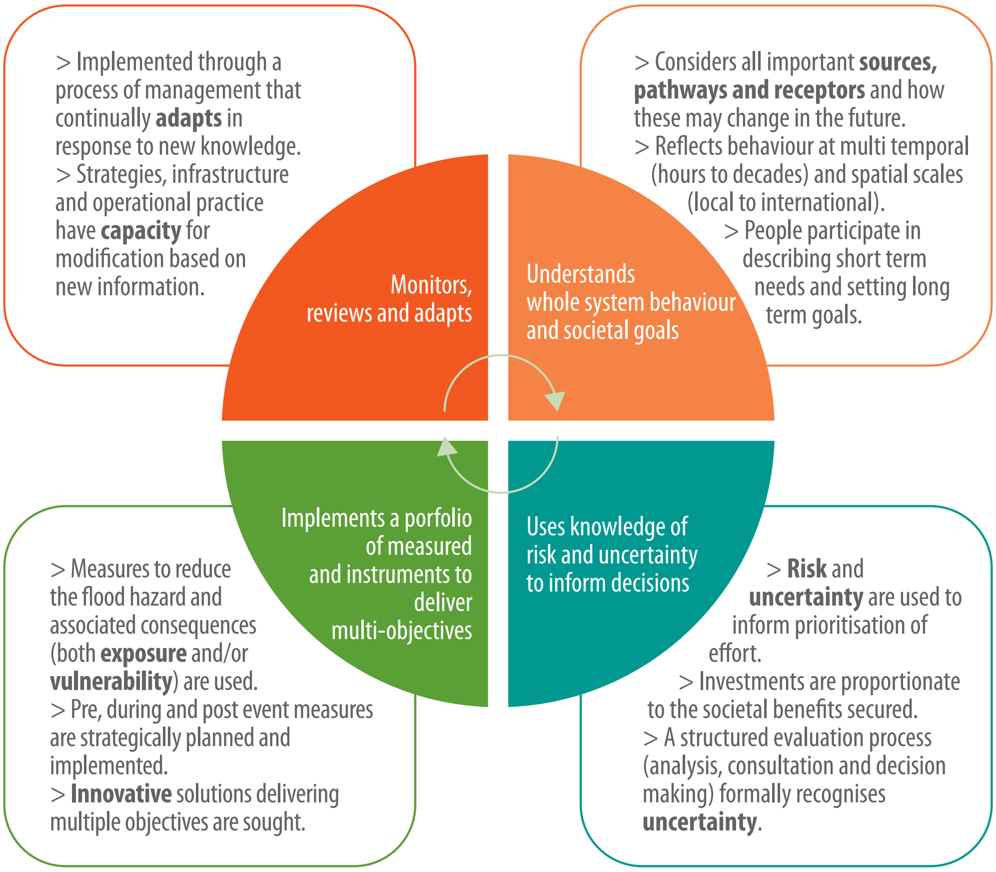


Figure 4: The characteristics of good flood risk management



Supporting sustainability

Supporting sustainability involves much more than simply maintaining the long-term integrity of flood control structures. It also includes promoting the long-term health of the associated ecosystems, societies and economies. The manner in which these higher-level goals are translated into specific objectives shapes the nature of the FRM that is delivered. For example, delivering efficiency and fairness, and building resilience and adaptive capacity, are core goals of flood control.

DELIVERING EFFICIENCY AND FAIRNESS

Flooding is not fair: the inherent natural differences of the landscape, plus the legacy of differential interventions, are the causes of some areas being flooded much more frequently than others. Every intervention in FRM tends to prioritize one group or location over another, creating further inequality and 'unfairness'. Maximizing the utility of an investment, whilst ensuring that it is distributed through an equitable process that also protects the most vulnerable members of society, raises a number of practical problems. Providing protection to one community but not another is unfair; providing a higher level of protection to one than to another is unfair. However providing a common level of protection to all is impossible, and even if achievable would be inefficient. The desire to manage flood risk more fairly promotes the use of nationally consistent nonstructural strategies that are available to all (for example better forecasting, improved building codes and grant\compensation schemes). Such an approach offers a greater contribution to equality and vulnerability-based social justice principles than the status quo of providing engineered solutions to the few.

BUILDING RESILIENCE AND ADAPTIVE CAPACITY

Delivering resilience involves much more than simply reducing the chance of damage through the provision of 'strong' structures, and adaptive management involves much more than simply the 'wait and see' approach. Both are purposeful approaches that actively manage uncertainty – minimizing damage when storm events exceed notional design values and enabling strategies to change with minimum regret as the future reality unfolds (Table 1).

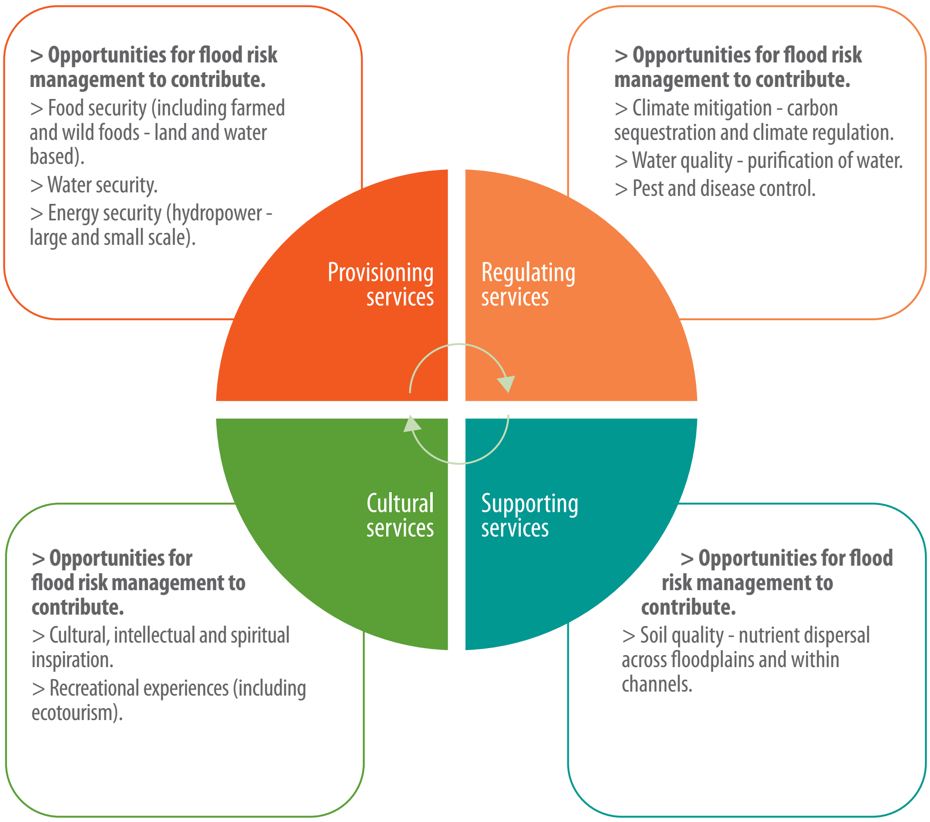
Table 1: The recognition of uncertainty has a profound impact on strategy development; forcing the traditional linear design model to be replaced with adaptive strategies

Stages of strategy development	Traditional (certain) model of strategy development and decision-making	Adaptive (uncertain) model of strategy development and decision-making
Deciding what to do	Predefined system of goals, objectives and desired outcomes. Defined set of activities and resource demands.	Emerging pattern of goals, objectives and desired outcomes. Flexible configuration of resources and priorities.
Deciding how to do it	Sequential process of planning, programming and implementation. Top-down strategy development. Reliance on single solutions to deliver defined standards.	Continuous alignment of plans, programmes and implementation activities with the changing world. Continuous reconciliation of the bottom-up initiatives and top-down strategies. Use of sustainable approaches that are easily adaptable.
Understanding the external and internal influences	Stable system of decision-making. Predictable (deterministic) future change – climate, demographics, deterioration, preferences etc.	Changing decision processes and priorities. Unknown future change – climate, demographics, deterioration, preferences etc.

Safeguarding and promoting ecosystem services

If implemented well, FRM can have a positive influence on ecosystems and the provisioning, regulating and cultural services they provide. Flood detention areas in China and the United States, for example, provide occasional flood storage and enhance habitat development. If little consideration is given to ecosystems, the impact can be devastating (for example the historical defences along the Danube caused severe environmental disruption and led to significant restoration needs). 'Soft path' measures (such as land use changes, wetland storage and floodplain reconnection) and selective 'hard path' measures (such as bypass channels and controlled storage) both offer opportunities to simultaneously deliver effective and efficient flood risk reduction and promote ecosystem services; a synergy all too often over looked (Figure 5).

Figure 5: The four characteristics of a healthy ecosystem and mutual opportunities with flood risk management



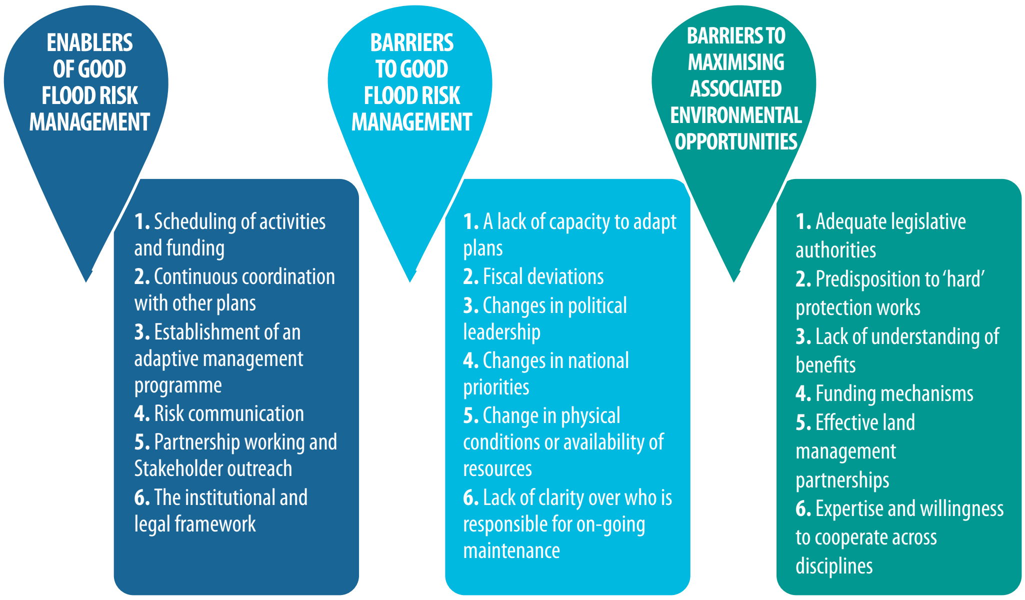
Box 1: Experience from the Mississippi demonstrates the need for coordinated policies and plans

For nearly 300 years, those living along the Mississippi River have experienced the devastating effects of floods. Over time, governmental and public organizations have attempted to provide increasingly high levels of flood protection. Some of these efforts have been very successful; others have failed. Three distinct approaches have been tried:

- focusing authority, responsibility and resources for flood management in one body
- a more laissez-faire approach allowing local, state, and federal entities throughout the upper Mississippi basin to act independently in an uncoordinated way
- again uncoordinated, but focused on defending against a specific flood threat, in this case a hurricane protection plan for New Orleans.

History teaches us that when a major flood occurs, the first approach works and the other two fail. The reluctance of all levels of government to concede strategic authority and the resources, fearing federal government take-over and a reduction in local influence on decisions, continues however to undermine good longer-term planning. There is a tendency to address issues on a yearly basis with little attempt to coordinate succeeding annual efforts. Only following Hurricane Katrina, and devastating floods, has need for a longer-term view and coordinated action been fully realized.

Figure 6: Enablers and barriers to implementing good flood risk management



Barriers to implementation

The best strategy is of little utility if it cannot be implemented. The barriers that prevent the delivery of good FRM and the enablers that promote its implementation are summarized in Figure 6. Many good plans have failed because of a lack of clear roles and responsibilities for policy, planning and implementation. Past attempts to provide flood management in the Iguassu River basin in Brazil, for example, have been hampered by a lack of agreement between national, regional and local authorities. Identifying the specific issues as early as possible and providing solutions before they become 'roadblocks' to successful implementation are a vital step – easily said but surprisingly often not done.

Principal supporting techniques and tools

The delivery of good FRM relies upon:

- **Appropriate risk and uncertainty analysis.** This involves exploring key questions on the issues of:
  - What might happen in the future?
  - What are the possible consequences and impacts?
  - How possible or likely are different consequences and impacts?
  - How can the risks be best managed?
- **Spatial planning.** Active controls on (re)development of land and property provide perhaps the most direct and effective means of reducing flood risk.

- **Infrastructure management.** Ensuring the acceptable performance of individual flood defence assets and the asset systems they make up is a considerable challenge. The concepts of risk help integrate short to longer-term actions to maintain, repair, improve or replace assets appropriately alongside nonstructural measures.
- **Emergency planning and management.** Loss of life and injury can be significant in major flood events. The Hyogo Framework for Action 2005–2015 (ISDR, 2005) highlights the central role for emergency planning in ensuring that a flood event does not become a flood disaster.
- **Flood hazard and risk mapping.** In recent years 'flood maps' have increasingly been used to communicate risks to a wide range of stakeholders. As the supporting technologies continue to improve, understanding the advantages and limitations of each is vital if communication is to be meaningful and useful.
- **Early warning systems.** Flash floods bring fast-moving and rapidly rising waters with a force to destroy property and take lives. Hurricane/cyclone intensity can quickly change and evacuation suddenly becomes necessary. Early warning of these hazards can dramatically reduce human losses and damage to high-value property contents.
- **Effective land controls and building codes.** Avoiding development in high-risk areas limits the areal consequences of flooding, and sound building codes can enable many structures to survive flood events with minimal damages.
- **Insurance.** For those insured, flood insurance provides a mechanism for them to transfer part of their risk and reduce their vulnerability to flooding, so flood insurance is a major and legitimate activity in managing flood risk and mitigating flooding consequences.

Box 2: Defining strategic flood risk management

As our understanding and experience develops, a common definition of good FRM is also emerging:

> The process of data and information gathering, risk analysis and evaluation, appraisal of options, and making, implementing and reviewing decisions to reduce, control, accept or redistribute flood risks. It is a continuous process of analysis, adjustment and adaptation of policies and actions taken to reduce flood risk (including modifying the probability of flooding and its severity as well as the vulnerability and resilience of the receptors threatened). FRM is based on the recognition that risks cannot be removed entirely, but only partially, and often at the expense of other societal goals.

Golden rules of strategic flood risk management

As FRM approaches continue to evolve, nine Golden Rules have emerged:

1. **Accept that absolute protection is not possible and plan for accidents.** Design standards, however high they are set, will be exceeded. Structures may fail (breach, fail to close and so on), and early warning systems or evacuation plans may not work as expected. Accepting that some degree of failure is almost inevitable, and this places a focus on enhancing resilience.
2. **Promote some flooding as desirable.** Floods and floodplains provide fertile agricultural land and promote a variety of ecosystem services. Making room for water maintains vital ecosystems and reduces the chance of flooding elsewhere.
3. **Base decisions on an understanding of risk and uncertainty.** An explicit trade-off between the risks reduced, opportunities promoted and the resources required to achieve them is central to FRM. The uncertainty within the data and models must be explicitly acknowledged.
4. **Recognize that the future will be different from the past.** Future change (climate, societal, structural condition and of other kinds) can profoundly influence flood risk. Developing adaptive strategies enable flood risk managers to respond to the reality of the future as it unfolds, minimizing regret, in a purposeful and planned way.
5. **Implement a portfolio of responses, and do not rely on a single measure.** Integrated management involves consideration of the widest possible set of actions. This includes measures to reduce the probability and measures to reduce the consequences (exposure and vulnerability) of flooding.
6. **Utilize limited resources efficiently and fairly to reduce risk.** The resources used must be related to the risk reduced and the ecosystem, economic and social opportunities promoted. Universal or generalized engineering standards of protection should not be used.
7. **Be clear on responsibilities for governance and action.** Governments, businesses, communities and individuals must be active participants – all sharing responsibility and contributing fiscal support within a clear framework of collaboration.
8. **Communicate risk and uncertainty effectively and widely.** Effective communication of risk enables better preparation and helps ensure support to mitigation measures where necessary. Communicating the risk after a catastrophe is too late.
9. **Reflect the local context and integrate flood planning with other planning processes.** The preferred strategy for a given location will reflect the specific risks faced (and not arbitrary levels of protection that should be achieved).

TABLE OF CONTENTS

FIGURES AND TABLES

Figures

Tables

LIST OF ACRONYMS

ABI	Association of British Insurers
ALARP	as low as reasonably practicable
BCR	benefit–cost ratio
CFMP	catchment flood management plan
Defra	Department for Environment, Food and Rural Affairs (UK)
DRBD	Danube River Basin District
DTM	digital terrain model
EAD	expected annual damage
EPA	Environmental Protection Agency (USA)
FEMA	Federal Emergency Management Agency (USA)
FMEA	failure mode and effects analysis
FRM	flood risk management
FRMP	flood risk management plan
FRMRC	Flood Risk Management Research Consortium
GA	genetic algorithm
GDP	gross domestic product
GIS	geographic information systems
GIWP	General Institute of Water Resources and Hydropower Planning (China)
GWP	Global Water Partnership
HSE	Health and Safety Executive (UK)
IBCR	incremental benefit–cost ratio
ICHARM	International Centre for Water Hazard and Risk Management
ICIWaRM	International Center for Integrated Water Resources Management
ICPR	International Commission for the Protection of the Rhine
IFM	integrated flood management
IHRM	integrated hazard risk management
IPCC	Intergovernmental Panel on Climate Change
IWRM	integrated water resources management
MPR	mandatory purchase requirement
NEPA	National Environmental Policy Act (USA)
NFIP	National Flood Insurance Program (USA)
PFMA	potential failure mode analysis
RDP	regional domestic product
RIBAMOD	River Basin Modeling, Management and Flood Mitigation
SAR	synthetic aperture radar
SMP	shoreline management plan
SUDS	sustainable urban drainage systems
TBRAS	Taihu Basin Risk Assessment System
USACE	US Army Corps of Engineers
WMO	World Meteorological Organization
WWDR	World Water Development Report
WWF	World Wide Fund for Nature

GLOSSARY OF TERMS

The following definitions focus on some of the important aspects associated with flood risk management (FRM), and are based on a variety of international sources adapted for specific use here, including definitions provided by the following organisations and projects:

- Asian Disaster Reduction Center (ADRC)
- Department for Food Environment and Rural Affairs (Defra) (England and Wales)
- Environment Agency (England and Wales)
- Federal Emergency Management Agency (FEMA) (United States)
- FLOODsite – EC Integrated Project
- International Commission of Large Dams (ICOLD)
- UNESCO Institute for Water Education
- UN University Institute for Environment and Human Security (EHS)
- US Geological Survey (USGS)
- World Health Organization (WHO).

Acceptable risk: The level of risk a society or community considers acceptable given existing social, economic, political, cultural, technical and environmental conditions. An understanding of acceptable (and hence unacceptable) risk helps guide the level of investment that may be appropriate to reduce the risk (where possible).

Adaptability: The ability to modify a particular measure (structural or nonstructural) or instrument (policy or regulation) as the reality of the future becomes known or future projections change.

Adaptation: The ongoing adjustment in natural, engineered or human systems in response to actual or changing expectations in climate or other drivers of risk. Adaptation may be either autonomous (and achieved through natural change) or planned (and achieved through purposefully adaptation planning; replacing the reactive adaptation often seen in response to an extreme flood that has invariably been characteristic of traditional flood control approaches).

Afflux: The increase in water surface elevation in a watercourse as a result of the presence of a constriction in flow (for example arising from a structure such as a bridge or culvert), relative to that which would exist without the constriction in place.

Alternative: When making a choice, the decision-maker selects from available alternatives (and holds options for future selection).

Asset management: Systematic and coordinated activities through which an organization manages its assets and asset systems.

Biodiversity: 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 FRM.

Capacity: The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.

Catchment (river): The area of land surface that drains to a given point in the river system.

Consequence: An impact such as economic, social or environmental damage or improvement that may result from a flood. Consequence can be expressed in many valid forms, either quantitatively or qualitatively by category (for instance, high, medium, low), or through description. The magnitude of the consequence will be influenced by the inherent vulnerability of the receptor and the value society places upon the harm caused. It may be expressed in monetarized form, the native form of the impact (such as hectares of habitat lost) or in more abstract units.

Control (flow): A means of modifying (typically limiting) the peak flow to the downstream system.

Conveyance (flow): The process by which water (or effluent within a sewer system) is transferred from one location to another.

Coping capacity: The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

Debris: Solid natural and anthropogenic material, carried through a watercourse by the flow, which has the potential to increase flood risk (either through the blockage, for example at bridges and culverts, or through collision with people and buildings). Debris can range significantly in size, from large woody material and shopping trolleys through to individual leaves and bags. In natural channels, and outside of the urban areas, natural vegetation is a positive and important contributor to biodiversity, so in these settings such material should not be termed debris. Typically, inorganic sediments are also excluded from the term debris.

Deterministic approach: An approach that adopts precise, single-values for all variables and parameters within a precisely defined model, giving a single value output.

Disaster: A serious disruption of the functioning of a community or society causing widespread consequences (including human, material, economic or environmental losses) that exceeds the ability of the affected community to cope using its own resources.

Effectiveness: The degree to which a measure causes risk to be reduced as expected or desired. In general the effectiveness of flood risk management as a whole is increased by adopting a portfolio approach, where the advantages of one option compensate for the disadvantages of another to minimize risk and maximize opportunities.

Efficiency: The degree to which goals are achieved with the minimum of resources such as time, effort, money or environmental capital. In general efficiency management seeks to develop measures that are synergistic, such that the sum effect is greater than the individual parts. In more specific terms, resources are said to be used inefficiently when it would be possible, by using them differently, to make at least one person or community better off without making any other person or community off. Conversely, resources are used efficiently when it is impossible, by using them differently, to make any one person or community better off without making at least one other person or community worse off.

Environmental impact assessment (EIA): A systematic assessment of possible positive and negative impacts that a proposed project may have on the environment; considering all natural, social and economic aspects. The purpose of the assessment is to ensure that decision-makers consider the ensuing environmental impacts prior to major decisions being taken and commitments made.

Exposure: The people, property, habitats, networks and other receptors (see below) that may be flooded and thereby subject to potential harm/losses.

Failure: In this context, failure can refer to either an ultimate limit state (such as breach of a defence) or a serviceability limit state failure (such as insufficient warning lead time). Failure may be associated with one or more failure modes, for example a breach could result from erosion of the downstream face of an embankment, internal erosion (piping) or many other modes. In turn, the different failure modes may result from one or more failure mechanisms.

Flexibility: The ability of a given management strategy to be changed as the reality of the future unfolds and or projections of the future change.

Flood: The temporary covering by water of land not normally covered by water. The nature of the flood can vary significant depending on the driving source, for example coastal floods (storm surge, wave overtopping and tsunamis), fluvial floods (caused by rainfall – such floods can range from lowland floods that develop slowly to rapid-onset flash floods), pluvial floods (caused by rainfall directly on the urban area) and groundwater floods. The principles of FRM are common to all types of flood, but the specific tools and available management options may vary.

Flood control: Measures taken to modify the behaviour of the flood wave and so reduce the probability of flooding in some areas and increase the probability of flooding others. Typically these are structural measures, either on a large scale (such as barriers and levees) or on a small local scale (such as run-off attenuation).

Floodplain: 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. The limits of a floodplain are notionally infinite, so it is normally defined by the maximum flood extent (associated with a given return period storm (in the absence of flood control structures).

Floodplain maps (flood): Maps that typically indicate the geographical areas which could be covered by a flood (during a given return period storm or extreme event) in the absence of control structures. The maps may be complemented by indication of the type of flood, the water depths or water level, and where appropriate flow velocity, plus often simplified hazard categories.

Flood risk management (FRM): The process of data and information gathering, risk analysis and evaluation, appraisal of options, and making, implementing and reviewing decisions to reduce, control, accept or redistribute flood risks. It is a continuous process of analysis, adjustment and adaptation of policies and actions taken to reduce flood risk (including modifying the probability of flooding and its severity as well as the vulnerability and resilience of the receptors threatened). FRM is based on the recognition that risks cannot be removed entirely but only partially, and often at the expense of other societal goals.

Fragility (curve): The relationship between the conditional probability of failure (for example the chance of a levee breach) and a given loading condition (for example the water level in the river). The fragility curve provides a graphical representation of this relationship over a range of loading conditions.

Hazard (flood): The potential for inundation that threatens life, health, property and/or natural floodplain resources and functions. The flood hazard is comprised of three elements: severity (depth, velocity, duration and extent of flooding), probability of occurrence and speed of onset.

Hazard zoning (flood): Delineation of areas with different possibilities and limitations for investments and development, based on flood hazard.

Individual risk: The risk faced by a particular individual (as distinct from societal or group risk, discussed below).

Integrated FRM (IFRM): An approach to dealing with flood risk that recognizes the interconnection of FRM actions within broader water resources management and land use planning; the value of coordinating across geographic and agency boundaries; the need to evaluate opportunities and potential impacts from a system perspective; and the importance of environmental stewardship and sustainability.

Mitigation: Measures and instruments, including any process, activity or design to avoid, reduce, remedy or compensate for adverse impacts of a given activity, development or other decision.

Nonstructural measures: Any measure not involving physical construction that use knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Option: When there is an option, a decision-maker has the opportunity to choose between alternative actions in the future. The option-holder can delay making the final decision, rather than having to make it immediately.

Outcome measures: Measures used to express, in quantified terms, the desirable outcomes that are considered important. This might include the reduction in annual expected lives lost, economic risk reduced, or biodiversity gained.

Overflow: Flow over a structure, such as a flood embankment or sea wall, by a progressive increase in water level.

Overtopping: Periodic flow over a structure, such as a flood embankment or sea wall, through wave action.

Pathway (of the risk): The connection between a particular initiating event (source of the risk – see below) and the receptor that may be harmed or experience loss (such as a property – see below). For example, the pathway may consist of the upland land surfaces, the river channel, the levees and the flood plain between an upstream inflow boundary (the source) and a particular house (the receptor).

Policy and regulatory instruments: Policies and regulations provide the principles and rules that guide the framework within which FRM strategies are developed, and decisions are made and, in some instances, delivered on the ground.

Portfolio approach: A management approach to reducing risk that relies upon the implementation of a wide range of options, in space and in time. In a portfolio approach the aim is to develop a strategy consisting of a range of activities where the advantages of one measure or instrument compensate for the disadvantages of another, and synergies provided by combinations of options are exploited (for instance in wetland creation and support, or flood warning).

Predictive models: Understanding cause–effect relationships – through either quantitative or qualitative models – forms the bedrock of predictive capability. These can be based on reductionist or complex system approaches. Increasingly models based solely on past observations are unable to provide meaningful predictive tools. For example, it is not meaningful to conduct a statistical analysis of the release from a reservoir, or indeed of the flow in a heavily regulated river.

Probability: A measure of the perceived likelihood that a flood will occur within a given time frame (such as annual or lifetime) or during a given event. This measure has a value between zero (impossibility) and 1.0 (certainty). There are two main interpretations:

- **Statistical frequency:** indicates the outcome of a repetitive experiment of some kind such as flipping coins. It also includes the idea of population variability. The measure is called an 'objective' probability because the outcome exists in the real world and is in principle measurable by experiment.

- **Subjective probability:** is a quantified measure of belief, judgement or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes. The majority of probabilities of interest to the flood manager/analyst are subjective and cannot therefore be formally validated by observation.

Probability of flooding: The chance of a particular part of the floodplain experiencing flooding after taking account of the performance of any associated flood control infrastructure (including both failure and nonfailure possibilities). The chance of flooding must be linked explicitly to an associated reference timescale (annual or lifetime probability for example) and specific characteristic(s) of the flood (depth, duration or velocity for example). The probability of flooding is not simply related to the return period of the driving storm.

Receptor: The entity that may be harmed by a flood. For example, in the event of heavy rainfall (the source) flood water may propagate across the flood plain (the pathway) and inundate housing (the receptor), which could suffer material damage (the harm or consequence).

Residual risk: The risk that remains after accounting for the performance of all FRM actions (that is, measures to reduce the chance of flooding and those taken to reduce vulnerability or improve resilience). To avoid confusion, the date at which the residual risk has been assessed should be communicated. Typically the stated residual risk of relevance to the public is associated with the present day. For planners however understanding how the residual risk varies in time because of climate or other changes is crucial.

Resilience: The ability of an individual, community, city or nation to resist, absorb or recover from a shock (such as an extreme flood), and/or successfully adapt to adversity or a change in conditions (such as climate change or an economic downturn) in a timely and efficient manner.

Resilient design: This fosters innovative approaches to the design, construction and operation of buildings and infrastructures that are resilient to natural and human-made disasters. Adopting an integrated approach incorporates resilience as one of the primary goals during building design. In addition to protecting the lives of building occupants, buildings that are designed for resilience can absorb and recover rapidly from a disruptive event. Continuity of operations is a major focus.

Return period: A statistical measure denoting the average recurrence interval over which a particular event (such as an in-river water level, or wave-overtopping volume) of a given magnitude will be exceeded (when considered over an extended period of time). While it is true that a ten-year event will, on average, be exceeded once in any ten-year period, the chance of encountering such an event in the next ten years is approximately 65 per cent, the so-called **encounter probability.**

Risk: The combination of the chance of a particular event (such as a flood) occurring and the impact that the event would have if it occurred. Risk therefore has two components, probability and consequence. The consequence of an event may be either desirable or undesirable. Generally, however, FRM is concerned with protecting society and hence it interprets risk as involving the likelihood of an undesirable consequence and our ability to manage it. (Note: Opportunities for positive gains should also be sought but recorded as 'opportunities gains' and not risks).

Risk analysis (flood): The application of tools and techniques to objectively determine risk by analysing and combining probabilities and consequences. It involves the use of available (and by definition uncertain) information to estimate the risk to individuals or populations, property or the environment from hazards. Risk analyses generally contain the following steps:

1. Scope definition.
2. Hazard identification (including source and pathway terms).
3. Receptor identification.
4. Risk estimation.

Risk analysis involves the disaggregation or decomposition of the flooding system and sources, pathways and receptors of risk into their fundamental parts at a resolution appropriate to understand the nature of the risk and determine its essential features at the scale of interest.

Risk-based or risk-informed decision-making: An approach to decision-making that supplements information on risk (both probability and consequence) with subjective trade-offs and issues of equity and opportunity gains.

Risk evaluation (flood): The process of examining and judging the significance of risk estimated through the process of risk analysis. The risk evaluation stage is the point at which values (societal, regulatory, legal and owners) and value judgements enter the decision process, explicitly or implicitly. Within risk evaluation consideration is given to the significance of the estimated risks and the associated social, environmental, economic, and other consequences together with an understanding of the investment needed to reduce the risk in order to develop an appropriate FRM strategy.

Risk identification (flood): A qualitative process of determining what could go wrong, why and how.

Risk management (flood): See **flood risk management.**

Risk maps: Maps that combining information on probability and consequences to spatially differentiate risk. The mapped risk is often expressed in terms expected annual risk (integrating all possible storm events and possible system responses that might occur in a year) or event risks (that is, the expected damages associated within a specified storm event). Risk maps typically display:

- numbers of potential deaths or serious injuries
- economic damages (national or financial)
- secondary impacts – for example arising from accidental pollution caused by flooding or loss of power to non-flooded properties.

Risk mitigation (flood): A selective application of options (both structural and nonstructural) to reduce either likelihood of a flood or its adverse consequences, or both.

Robustness: The degree to which an option or strategy continues to perform well across a range of possible future scenarios.

Societal concerns: Concerns engendered by those hazards which have the potential to impact on society as a whole if realized. The evaluation of a risk will reflect the degree of societal concern.

Societal risk: Widespread or large-scale consequences arising from an extreme hazard can provoke a sociopolitical response. Such large risks are typically unevenly distributed, as are their attendant benefits. For example, the construction of a dam might increase the risk to those close by but provide a benefit to those remote from the dam, or an action/decision might harm a future generation more than the present one (for example tying a future generation in to the results of poor, and expensive, planning decisions). The distribution and balancing of such major costs and benefits is a classic function of government, subject to public discussion. The results of such a debate shape the evaluation of risk and the nature of the management policies and approach adopted.

Source (of risk): The event(s)considered to initiate a potential flood (for example, heavy rainfall, strong winds, surge, or even human error/ attack – accidental opening of a gate or aircraft collision into a dam).

Stakeholder: Any person or group of people with a legitimate interest in the decisions being made.

Strategy (FRM): A coherent plan or set of plans that set out goals, specific targets, decision points and the mix and performance of both structural and nonstructural measures to be employed. Flood risk measures within the strategy are then grouped into coherent packages as the basis for further development and implementation.

Structural measures: Any physical construction to reduce the chance or severity of the flood waters reaching a **receptor**. Structural measures range from large-scale infrastructure responses, such as barriers and levees, through to local responses to improve the resistance and resilience of individual homes or critical installations.

Sustainability: First defined as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs', sustainability is a simple yet powerful concept. In particular it emphasizes the interlinkages between economic development, environmental health and social well-being – as not three separate objectives but one. Agenda 21 reinforced the notion of integration and stressed the need to move away from sector-centred ways of working to new approaches that involve cross-sectoral coordination and integration. Broad public participation in decision-making as a fundamental prerequisite for achieving sustainable development is also emphasized. Flood risk management is inextricably linked with issues of sustainability. Not only does FRM impact the physical environment, through the development of control structures and spatial planning measures, it also provides opportunities for, and constraints upon, human and natural activities in the long term.

System (flood risk): In the broadest terms, the social and physical domain within which risks arise and are managed. An understanding of the way a system behaves, and in particular the mechanisms by which it may fail, is an essential aspect of understanding risk. This is true for an operational system like flood warning, as well as for a more physical system, such as a series of flood defences protecting a flood plain, and importantly the system as a whole.

Tolerable risk: The degree of residual risk that society is prepared to tolerate in order to secure certain net benefits (such as environmental improvement, power generation, urban development, or limited expenditure on flood management). Tolerable risk varies from situation to situation and is not negligible or something that can be ignored. The associated residual risks must be keep under review and reduced further where appropriate.

Unacceptable risk: A level of risk that cannot be justified except in extraordinary circumstances. Typically there are circumstances where the continuation of the risk has been authorized by government or a regulator in the wider interests of society, and either further reduction of risk is simply not possible (for example all levees and dams, regardless of their design and maintenance regimes, have some, albeit small, chance of failure) or the resources required to reduce the risk are disproportional to the additional benefits secured.

Uncertainty: Any prediction/inference (timing of a storm, data, model or decision) that is not accompanied with complete sureness, whether or not described by a probability distribution. Uncertainty can be attributed to first, the inherent variability in natural properties and events (aleatory uncertainties), and second, incomplete knowledge of variables, parameters and model structures (both quantitative and qualitative models) (epistemic uncertainties).

Vulnerability: A combination of the inherent susceptibility of a particular group, people, property and or natural feature to experience damage during a flood event, and a society's preferred means of valuing the harm experienced. For example the vulnerability of a property is expressed through a flood depth against economic damage relationship, the vulnerability of an individual may be expressed through a relationship between flood depth/velocity and the chance of dying or being seriously injured. Vulnerability may therefore be modified through actions that reduce a receptor's susceptibility to experience harm (improved speed of recovery after a flood, for example).

Watershed: A general description for a drainage basin, sub-basin or catchment.

Wetland: A permanently moist and seasonally flooded area whose formation has been dominated by water, whose physical characteristics are largely controlled by water, and which supports a rich and diverse ecosystem that is specifically adapted to the prevailing hydrological regime.

INTRODUCTION

Background

This book is the result of a collaborative effort between the World Wide Fund for Nature (WWF), the General Institute of Water Resources and Hydropower Planning and Design (GIWP), Ministry of Water Resources, People's Republic of China, UNESCO, the Asian Development Bank (ADB) and a number of leading international experts from the United Kingdom, South Africa, Australia and the United States. It was originally conceived to review and disseminate modern approaches to water management in challenging environments, providing new insights into good strategic planning and risk management of water resources.

This book provides a focus on strategic FRM, and is one in series of six books, which together consider three fundamental water resources management issues: river basin planning (Pegram et al., 2013), basin water allocation (Speed et al., 2013) and strategic FRM.

The book is designed to provide the reader with a general understanding of the process and frameworks of strategic FRM, and guidance on the underlying philosophies and supporting techniques. It is not intended, however, to provide guidance on the detailed technical tools and means of analysis that form part of the FRM analytical process, for example detailed hydrological, hydraulic, ecological or economic assessment methodologies, as these are easily found elsewhere. Instead, it is intended to provide an overview of the emerging good practice in strategic risk-based FRM, the process of developing plans and policies, and the appropriate times and places at which these more specific techniques can be used.

There is a companion to this book, *Flood Risk Management: Experience from international case studies* (Sayers et al., 2011) which documents a series of detailed case studies for the Thames (Europe), the Mississippi (United States), the rivers of Bangladesh, the Iguassu (Brazil), and the Huai (China). Lessons drawn from these cases, together with other real examples, are referred to frequently here.

Scope

The book focuses on strategic FRM policy and practice, and provides an overview of:

- the historical developments and emerging trends in flood management
- the purpose and characteristics of modern FRM
- the goals, objectives and outcomes sought
- the ongoing challenges in developing and implementing FRM in practice together with some of the common pitfalls and misconceptions
- a summary of some specific tools and techniques and how they support good decision-making.

A cautionary note on terminology

As is emphasized throughout this volume, detailed approaches to and techniques for managing flood risk will always, to a significant degree, be shaped by local context, institutions, history and conditions. This means that there will always be important differences between the approaches and frameworks in different countries. It also means that there can be no single template or approach to FRM. This variety creates an important linguistic trap in attempts to compare approaches internationally or provide general guidance: the same concepts and words used in different contexts can mean very different things. Even the most basic concepts such as 'risk' and 'risk management plans' cover a broad array of very different approaches and concepts in different places. By way of further example, many countries produce a 'National Flood Risk Management Strategy' or a 'Regional Flood Risk Management Plan/ Strategy'. The different legal, political and institutional systems in different contexts mean that the objectives and contents of these plans will be very different. Attempts to draw approaches from one context across to another without a clear understanding of these differences can lead to mistaken approaches.

In this and the accompanying volumes, we have attempted to use consistent terminology, and our understanding is set out in the glossary on pages 21 to 26. Nevertheless, significant caution is required in the interpretation of the approaches set out here, and the application of any approaches to different contexts.

Structure of the book

Following this brief introduction the report is structured into three parts, each containing a number of self-contained chapters. Part A focuses on the history of and emerging trends in FRM. Part B explores the philosophy of strategic FRM and the contemporary approach to the issues. Finally, Part C introduces some specific tools and techniques for FRM.

PART A

HISTORICAL DEVELOPMENTS AND EMERGING TRENDS

Rivers and coasts have always been magnets for development. They have provided transportation, water supply for people and agriculture, channels for sanitation, water power, and protection against attack. From the beginning, development in floodplains brought communities and high-value agriculture together, and provided for centres of commerce, with inland ports providing links to regional, national and international locations. Along with opportunity, however, came risk.

This section of the book explores various attempts different societies have made to manage flood risk; from the earliest known efforts to build protective structures until the present time. It focuses on the general strategies used during different periods in history, the reasons for using these strategies, and reasons why they have changed and the events that precipitated these changes.

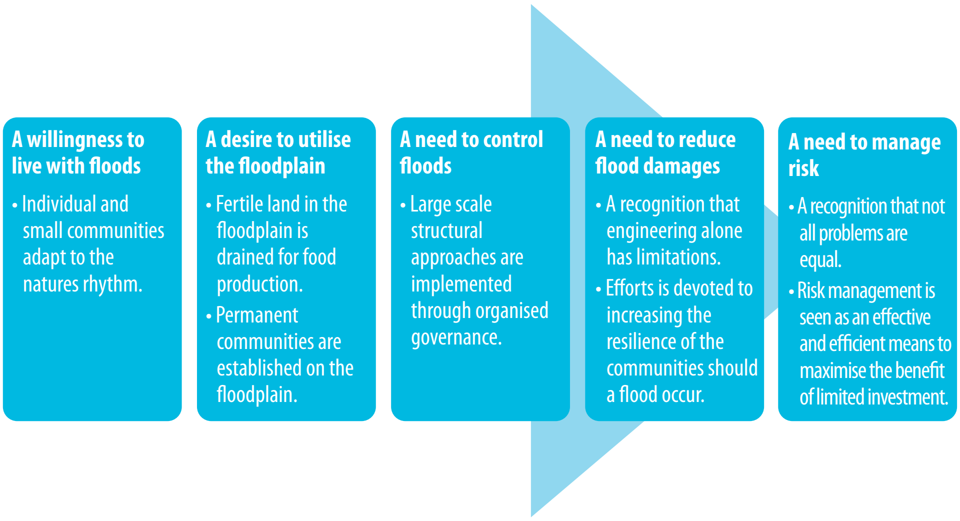
CHAPTER 1
HISTORICAL DEVELOPMENTS AND EMERGING TRENDS

1.1 Background

Floods have always offered benefits and presented challenges, enriching the land for agriculture and habitat creation by spreading sediment-laden waters across the floodplain, but making the creation of permanent river crossings difficult if not impossible. Nomadic communities learned to live with the episodic nature of floods, but as permanent settlements were established to take advantage of the floodplain, floods began to impact negatively on the lives of those living there. Societies therefore began to take steps to lessen the impact of flooding. At first, these efforts were minimal, consisting of little more than minor adjustments in living style. As populations increased and the economic importance of the floodplain land grew, societies began to take structural actions to keep flood waters away from important areas. Such measures were often difficult to sustain, and invariably were overwhelmed by the next great flood. Today, millennia after these first efforts, the challenges remain.

From the earliest recorded attempts of society to deal with flooding until late in the twentieth century, the principal means of mitigating the impacts of floods was flood control. Levees, dykes, diversion channels, dams and related structures were all constructed in an effort to control the natural and periodic rise of rivers and the coastal waves/surges that accompany major storms. In the middle of the twentieth century, there was a shift to an approach that sought to use structural and nonstructural measures both to prevent flooding and reduce the damages when it occurs. As populations and development grew, flood losses continued to increase, and the need to prioritize investment became increasingly acute. A new approach was needed, one that could not only identify the hazards and the consequences faced by society, but was also able to assess the relative significance of the risks faced. This new approach of FRM continues to evolve, but in less than three decades it has become widely accepted as an appropriate approach to dealing with one of the world's great challenges. This rich and sometimes complex history is discussed in more detail in subsequent sections, and is described across five major periods of development as shown in Figure 7.

Figure 7: The evolution of flood management practice through history



1.2 A willingness to live with floods

Millennia ago, continuous adaptation permitted individuals and small groups, with little collective effort, to live in harmony with the flooding and progressive changes in sea level. The close relationship between people and the natural environment provided for sustainable living, as the rivers continued to enrich the land and the ecosystems that inhabited the floodplain and local communities utilized the bountiful fish and wildlife populations they supported.

The first settlers of the floodplain quickly recognized that the best way to deal with occasional floods was to locate their settlements on the high ground near the river/coast or within the floodplain; often on naturally elevated ground created by outcrops of rock or first depositions of sediment by overflowing rivers. When these locations were not high enough to permit activities to continue during times of flood, the settlers would move temporarily to higher ground beyond the floodplain until the flood passed. In some cases, where high ground was distant, their structures were elevated to allow the flood to pass underneath and for life to continue nearly as usual.

In the coastal parts of the Netherlands (in the provinces of Zeeland, Friesland and Groningen), in southern Denmark and in Germany, artificial earth mounds were constructed within the floodplain (known as 'terps': Figure 8). These mounds provided safe havens at times of floods. Some historic Frisian settlements built artificial ***terpen*** (the plural form) up to 15 m above the floodplain as they adapted to the observed sea level rise. Similarly, in North America, there is evidence that as early as 100 BC large earthen mounds were placed strategically throughout some floodplains, especially in the Mississippi valley, to serve as both ceremonial sites and areas of safety in times of flood. The terp-building period dates from 500 BC and continued as the primary means of managing flood risk until the widespread use of dykes to protect low-lying ground some time around 1200 AD.

Figure 8: An example of Terpen on hallig Hooge, Netherlands

Source: http://hooge.de/

1.3 Early attempts at flood control (2000 BC to 1800 AD)

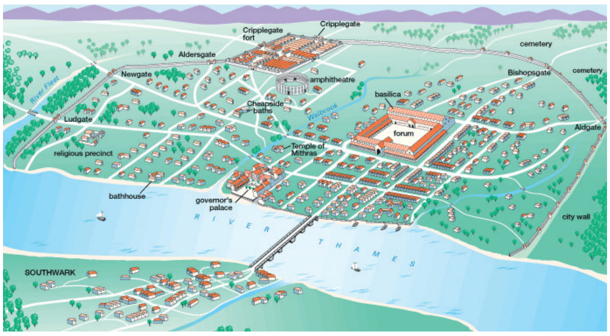
As populations grew and people began to gather together into larger villages, towns and cities, there was a need to increase agricultural production. Floodplains became more crowded with crops and permanent settlements. The periodic intrusion of flood waters became less acceptable. What was once seen to be an inconvenience became a challenge to societies.

This changing relationship is highlighted by the scholar Saxo Grammaticus in his works on the history of Denmark to 1185Davidson, 2002). In his geographic summary, Saxo remarks of the coastal marshes of south-western Jutland, facing the North Sea, that the land is particularly fertile due to flooding by the sea, but questions 'whether this is perhaps a case of buying gold too dear. Because it is a risky affair with that coast. When a violent storm comes about, it may well happen that the sea breaks the dikes that are built for protection, and intrudes so fiercely that not only the standing crop is flushed away, but also the houses together with the people and whatever.'

Some of the primary drivers for using floodplains and the engineering responses they prompted are discussed below.

- **For agriculture and irrigation.** The importance of the Nile to early Egyptian civilizations (from as early as 5000 BC) was evident in the elaborate irrigation systems that were put in place along its banks. While the principal purpose of river diversion structures was to distribute water for agriculture, many such structures also had a role in reducing the impact of Nile floods. Government organizations oversaw the system development, recruitment of labour forces, and initiation of scientific efforts to better understand the characteristics and occurrence of floods and droughts. At the same time, in Mesopotamia, modern Pakistan and northern India, similar efforts were underway to ensure adequate water supplies for growing populations, and where possible, to link the irrigation works to efforts to reduce periodic flooding. In most cases, as with the Nile, small levees and dykes were built along river banks to protect crops and population centres. The need for adequate maintenance to prevent rapid deterioration of the levees was soon recognized, together with the importance of sediment management to maintain the conveyance capacity of the channel and supply of fertile sediments to the floodplain. This tension between preventing floods and retaining a natural sediment regime marked the beginning of an enduring challenge.
- **For strategic advantage.** Coastal harbours and river crossings were seen as important to the development of early empires. This led to the growth of towns around river crossings. In 50 AD, Londinium (the starting point for today's London) was established at the point where the Thames was narrow enough to build a bridge, but deep enough to handle seagoing marine vessels. The growth of Londinium through the third century was probably the product of private enterprise; its site on a busy river crossing made it a perfect place for traders from across the Roman Empire to set up business. Early Roman flood defences and quay walls were a critical component of Londinium development (Figure 9). As with many modern issues, the Romans were advanced in developing modern water management principles. As Londinium grew, communication of flood issues was an important strand and there was a clear understanding that some communities would be flooded during major river events. Clear roles and responsibilities started to be established with government officials held responsible for limiting flood damages.

Figure 9: The Roman settlement of Londinium was located at a strategic crossing of the Thames estuary Image Museum of London.



Source: www.kids.britannica.com

- **For economic development and growth.** It is estimated that as far back as 4600 BC China was constructing dykes to control flooding. When, around 2500 BC a series of severe floods of the Yellow River breached poorly constructed dykes, Emperor Yu (2205 BC) began to recognize system connectivity, and designed and constructed nine separate diversion channels (lined with dykes through settled areas) to convey the flood waters of the Yellow River to other rivers and out to the sea. This approach was in contrast to previous practice in ancient China, which had focused on linear dykes, and initiated a period of major engineering interventions. The period between 403 BC and 221 BC saw the construction of further major control structures, including the Dujiang Weir, Zhengguo Canal and Hong Ditch. Around 6 BC development pressure continued to grow, and the engineering proposals became increasingly elaborate in an attempt to manage increasingly large and complex flood systems, with decreasing success. The concept of a more integrated approach started to emerge, and Jiarang, a Chinese government official, published a new flood management philosophy where he proposed that space should be retained for rivers or lakes within land development plans; but his advice went unheeded.

Throughout this period of history the strategy was to keep the water away from people and property, and to control water to agricultural areas through construction of levees, dykes and diversions or irrigation. As the structures became larger, the need for centralized construction and maintenance also increased, and so too did the need for resources– both people and funds – to support the flood control activity. Inevitably extreme flood events continued to bring about catastrophic results. Increasingly it was recognized that room should be left for flood waters, making use of the natural channels and the storage and retention provided by natural depressions.

Increasingly it was also recognized that while too much water was a problem, having too little water – either living in arid regions or experiencing long-term droughts in humid regions – would also require collective action. The need to be organized in order to address these water issues became apparent.

1.4 Increased flood control and floodplain use (c. 800 AD to 1900 AD)

The need to mitigate periodic flood events increased through the Middle Ages, a process that continued into the Industrial Revolution, which began in the United Kingdom. The scale of the engineered responses continued to increase in attempt to control flood waters for the convenience of humankind, but failed to prevent catastrophic floods and continued to bring problems of resources, maintenance and ecosystem destruction.

A NEED TO FEED A GROWING URBAN POPULATION – LAND DRAINAGE FOR AGRICULTURAL PRODUCTION

In the fertile coastal wetlands of northern Europe, particularly the Netherlands and the east coast of England, land started to be drained in earnest for agricultural production. The Dutch became expert at providing engineered dykes to protect the land from fluvial and coastal flooding, while building extensive drainage networks to prevent internal waterlogging. During the 1630s the 'Great Fen' in England's Cambridgeshire and Norfolk region was also drained and protected by dykes. The construction of this vast network of major and minor drains carried the major rivers of England that drain east through East Anglia and exposed large areas of fertile agricultural land. Wind pumps (Figure 10) were added to pump the drained water to high-level carriers (embanked water courses carrying the main river high above the level of the surrounding floodplain) which would take it to the sea. Increased pumping was needed to lift the water an ever increasing distance as the drained land subsided, through the consolidation of the underlying peat, leading to an increased threat of breach to those living and working in the natural floodplain. This risk was realized many times.

Figure 10: A windmill lifts water to channelized rivers that carry water at a high level above the floodplain to the coast ; typical in the Netherlands and England

Source: Chris Martin Bahr/WWF-Canon.

IMPROVEMENTS IN SCIENTIFIC UNDERSTANDING AND ENGINEERING KNOW-HOW ENABLE MORE ELABORATE INTERVENTIONS

Small farm dams were often used from the earliest times to store floodwaters for release once major rainfall events had passed, but the size of these dams was limited by the lack of technical knowledge and practical know-how. In the seventeenth century a better understanding of the mechanics of materials led to the growth in the size of dams, and their use for both water supply and flood storage increased. Spanish success in Europe carried over to settlements in central North America, where small flood control dams began to appear. The industrial revolution increased the use of dams for water power, with some of the structures also being designed to help address periodic flooding. Further increases in scientific knowledge and availability of monitoring tools led to better understanding of river mechanics, hydrology and hydraulics. Development in and around cities increased the flow into nearby rivers, and the clearing of land for agriculture similarly increased runoff. Exploration of the North American continent brought greater attention to the development of information about rivers and how flooding might better be controlled. At the same time in China, rulers during the Qing Dynasty (1644 to 1912) looked to new approaches to manage the growing flood problem, and initiated programmes that attempted to integrate structural and nonstructural measures.

In 1860 two US engineers, Captain Humphreys and Lieutenant Abbott of the US Army Corps of Engineers, conducted a major study of the hydraulics of the Mississippi River, concluding that while flooding would continue to be a problem, construction of levees would dramatically reduce the impact of these events. This 'levees only' approach would guide the mitigation activities in the Mississippi River basin for the next sixty-five years (Figure 11). As lessons were learned, the design and management practice for levees improved. For example, to prevent the continuing erosion of the river banks, revetments of tree branches and rock were placed on the slopes of riverside levees and at critical river bends to limit surface erosion and scour. Rock and wood dykes were also built into the streams to concentrate low flows in a defined channel, thereby increasing the ability of the rivers to transport sediment downstream while maintaining larger channel cross-sections for flood flows.

Figure 11: Material is delivered to an early levee construction on the Mississippi River (circa 1860–1925)

Source: US Government.

DEALING WITH THE RISING COST OF BUILDING AND MAINTAINING FLOOD CONTROL INFRASTRUCTURE

The rising cost of building and maintaining levees was a problem across the world. For example, China continued to struggle to control its major rivers, especially the Yellow River. Dyke heights were increased to accommodate the rising river levels resulting from the increasingly restricted channel storage caused by canalization of the natural channel. The huge resources demanded for levee maintenance were difficult to find as finite resources were often redirected during periods of war. The condition of levees and other structures deteriorated, resulting in many floods, including in 1194 multiple breaches along the main stem of the Yellow River which led to widespread flooding and the creation of new channels flowing to adjacent river basins.

Europe was experiencing similar problems. In the twelfth century, King Henry II introduced a flood tax for the maintenance of the coastal dyke systems in the agricultural areas on the south coast of England. Only those living in the floodplain, and hence benefiting from the flood defences, paid the tax known as the 'Scott', while those living in the surrounding hills were considered to get away 'Scott free'; an early example of hypothecation! In contrast, 'gentlemen adventurers' (private venture capitalists) funded the construction of the large-scale drainage of the Fens in England and were rewarded with large tracts of the resulting farmland.

Even with increases in technical ability and greater resource availability, those responsible for flood control struggled with the maintenance and periodic upgrade of levees, dykes, channels and pumps. Nature was relentless in its attack on the structures. Structures that were not properly maintained were subject to collapse, and continuing development in catchments brought about increased flows that strained the ability of locals to raise or strengthen structures. Something had to change.

1.5 The dawn of modern flood control (1900s)

At the dawn of the twentieth century, the universally preferred strategy was still aimed at controlling floods. While in undeveloped areas, adaptation still provided a useful approach, increases in population and the agricultural potential of floodplains continued to emphasize the need to keep flood waters away from both valuable farm land and urban areas. Flood control was seen as a local or regional responsibility, to be run by governments or quasi-governmental bodies at those levels. Flood control organizations in the same watershed coordinated with each other only loosely. Their focus was on protecting the area for which they were responsible, no matter what the impact might be on other locations.

Little attention was given to maintaining the beneficial relationship between floods and ecosystem services. In a near complete ignorance of the ecological value of wetlands, during the middle of the nineteenth century, the United States Congress passed legislation that supported the draining of wetland areas to provide room for agriculture and provided funding for flood control activities. The Congress saw little value in these periodically inundated areas. The lack of understanding of the natural and beneficial functions of floodplains inherent in this legislation set the tone for the treatment of the floodplain environment that would continue in the United States over the next century, and reflected practice across much of the western world.

Continuing settlement and development in the floodplains put more and more people and property in harm's way. Across the world, major flood events resulted in major catastrophes. A typical response was to demand even greater national management and resourcing of flood control activities. A few began to think about alternative approaches. Some of the most important of these events and their influence on practice are discussed below.

1917 AND 1927 FLOODS IN THE UNITED STATES – PROMOTED AWARENESS OF THE NEED FOR BASIN-SCALE INFRASTRUCTURE AND COORDINATION

Large floods in the United States in 1917 caused the federal government to take a greater interest in the Mississippi River and the Sacramento River basins. Local governance structures had been unable to deal with the major floods and sought federal fiscal support. In 1927, heavy storms across the Midwest created large floods in the lower Mississippi Valley (Figure 12) which eventually breached a locally controlled levee system and put hundreds of thousands of people out of their homes and off their lands for several months. It was labelled a national tragedy and brought about immediate attention from the national government. In 1928, by act of Congress, the US federal government assumed responsibility for construction and major maintenance of flood control structures in the lower Mississippi Valley. The 'levees only' policy was closely examined and deemed to be insufficient to deal with the challenge of major floods. A comprehensive plan for flood control was to include strengthening of the levees, improvement of the channel to provide for natural maintenance, cutoffs of river bends that were seen to be delaying the flow of waters to the Gulf of Mexico, floodways to serve as pressure relief valves during major events, and flood storage dams on the Mississippi River tributaries.

Figure 12: Area flooded in the 1927 Mississippi River flood

Source: US Government.

THE 1931 FLOODS IN CHINA AND THE FOLLOWING DECADES – A NEED FOR BASIN-SCALE INFRASTRUCTURE AND COORDINATION

A major flood in China in 1931 is generally considered the deadliest natural disaster ever recorded. The number of human deaths has been estimated to be from 1 million to as many as 4 million. These widespread floods were experienced across the three major rivers: the Yellow, Yangtze and Huai. The Yellow River flooded first between July and November 1931, killing 1–2 million people and leaving 80 million homeless. The worst period for the Yangtze was from July to August 1931, and affected 28.5 million people. The Yangtze along with the Huai River flood turned Nanjing city, capital of China at the time, into an island. The high water mark was reached on August 19 at Hankou, with the level exceeding 16 m (53 ft) above normal. These devastating floods were the catalyst to a more organized response to flood management in China. As one example, following the flood the Huai River Conservancy Commission, which had been formed in 1929, was charged with immediately addressing the flood problems. A lack of funding and support would, however, limit its effectiveness.

China continued to experience severe floods during the 1930s, 1940s and 1950s. As part of the government's programme in the early years of the People's Republic of China, action was taken to improve the capacity of flood control and land drainage systems. The measures typically included river dredging, raising and reinforcing dykes, connecting polder areas and building sluices. In some river sections reservoirs were constructed and flood storage and retention areas developed. Increasingly more scientific and technological methods were used to support the design of control and storage works, often achieving immediate, but not always lasting, success.

Figure 13: Pittsburgh, Pennsylvania (USA) under water in a 1936 flood.

Source: Carnegie Library.

THE 1936, 1937 AND 1951 FLOODS IN THE UNITED STATES – A NEED FOR NATIONAL RESPONSIBILITY

Major floods occurred across the United States in 1936, 1937 and 1951, causing major property damage and widespread loss of life (Figure 13). Following the 1936 US floods, the US Congress passed legislation establishing that 'flood control is a proper activity of the Federal Government …. Federal Government should participate if the benefits to whomsoever they accrue are in excess of the estimated costs', clearly placing responsibility for dealing with floods at the federal level. Immediately following the passage of this Act, the US Army Corps of Engineers (USACE) began the design and construction of dam and levee projects across the nation, with a focus on a high standard of protection.

THE 1947 AND 1953 FLOOD EVENTS IN EUROPE – A NEED FOR BETTER FOOD SECURITY, CLEAR ROLES AND RESPONSIBILITIES AND BETTER WARNING SYSTEMS

In March 1947, river floods occurred across much of Europe. The flooding was triggered by the rapid thaw of deep snow lying on a frozen catchment after one of the coldest and snowiest winters on record. The thaw was triggered by the arrival of a succession of south-westerly depressions, each bringing significant additional rainfall. Nearly all the main rivers in the south, midlands and north-east of England flooded, with thirty out of forty English counties impacted over a two-week period. Tens of thousands of people were temporarily displaced from their homes, and thousands of acres of crops lost.

Shortly after the 1947 fluvial floods, Europe experienced devastating coastal floods in 1953 when a surge tide swept south through the North Sea, overtopping and breaching many defences in England, the Netherlands and Belgium. An estimated 2400 people lost their lives across Europe. The storm was at its peak during the night, and with little or no warning flood waters breached the defences and washed away homes as people slept. On Canvey Island, at the mouth of the Thames Estuary, fifty-eight people died as the defences were breached (Figure 14).

The net effect of these floods was to emphasize the fragility of structural defences, and as had happened throughout history, the response was to increase the investment in levees, floodwalls, floodways and other structures. The event did however highlight the dramatic inadequacies in early warning systems and initiated the United Kingdom's national Storm Tide Warning Service – a service that continues today.

Figure 14: 1953 tidal surge floods on Canvey Island – a vulnerable community with only one route of escape and no warning. Residents had little chance when the 1953 surge breached defences in the night.

Source: www. canveyisland.org

The 1953 flood also had a profound impact on perception of flood risk in both England and in the Netherlands. The Delta Committee (Dantzig, 1956) in the Netherlands and the Waverley Committee (Waverley, 1954) in England were both commissioned to review what happened and propose a new way forward. Both committees reported a need to establish clear responsibilities for flood defence, and initiated discussions over what was considered an acceptable level of risk. In the Netherlands a national-scale benefit–cost analysis was undertaken and used to establish standards for each protective dyke ring for the first time . The water-related planning processes in the Netherlands were reorganized and clear national and local responsibilities introduced.

1.6 A focus on reducing consequences (from 1960 to the 1970s)

The intense period of flood events during the 1930 to 1950s forced western governments to rethink flood management. In the years following the Second World War (1939–45), academics and practitioners analysed the effectiveness of structural flood control measures and widely recommended that such measures were, in fact, exacerbating the consequences of floods. A number of changes in thinking and practice occurred throughout this period. The most important of these are discussed below.

A FOCUS ON THE WISE USE OF FLOODPLAIN AND FLOOD AWARENESS-RAISING

Many academics and practitioners recommended that the floodplain should be managed in a manner that permits development in those areas where such development is necessary and restricts development in those areas where such activity would only bring about severe consequences during a major flood. They further suggested that, in addition to flood control structures and wise use of the floodplain, flood mitigation strategies should include a focus on education, floodproofing, structure elevation, early warning systems, and insurance for those who remain at risk.

The floodplain however continued to be in high demand. For example, following the Second World War, the focus in the United Kingdom was on improving agricultural production and national food self-sufficiency. As a result considerable attention was paid to land drainage in support of agriculture and the associated protection from flooding by structural means. Government circulars issued in 1947, 1962, 1969 and 1982 emphasized the need to address flood risk in spatial planning and development control; however, since authority for carrying out this control was vested in the local governments, much potentially high-risk development and protection of lower-grade agricultural land was allowed to continue.

In the United States, the federal government attempted to influence local planning decisions through the introduction of a National Flood Insurance Program in 1968. This offered federally subsidized flood insurance to those living in communities willing to participate in the programme. To be eligible to participate, communities had to agree to establish control over future development in their floodplain. Between 1968 and 2011 more than 21,000 communities joined the programme.

RECOGNITION OF THE IMPORTANT ROLE OF FLOOD MANAGEMENT AS PART OF A BROADER GOAL OF SUSTAINABLE DEVELOPMENT

In the 1980s the United Nations put forward the concept of sustainable development (UN, 1987). The ideas of sustainable development supported the increasing concern associated with the environmental consequences of development in general and in floodplains in particular, and the critical role of maintaining ecosystem goods and services. This supported some national governments in moving away from flood management solutions based solely on structural approaches, towards providing a mix of nonstructural and structural responses. In other countries, such as the United States, the concept had more limited influence on policy.

Throughout the 1980s and early 1990s, the need to maintain connectivity in natural systems and to have the planning process reflect this connectivity was increasingly recognized. The European Commission issued a Habitats Directive in 1992 (EC, 1992) which further emphasized the importance of environmental issues in flood management. The creation of a National Rivers Authority in England and Wales in 1989 with responsibilities for flood management put additional focus on conservation. In China it was recognized that it was no longer possible, or desirable, to try to remould nature to control floods, which had been the cornerstone of Chinese policy up until then. It was progressively acknowledged that it was impossible to eliminate floods, and that in the long term, China needed to develop approaches that work in harmony with natural flood processes and avoid activities that destroy the eco-environment and overexploit land resources.

As a result of this change in thinking, the approach to planning throughout this period became more strategic. In the United Kingdom shoreline management plans (SMPs) were introduced, providing coherent management policies for littoral process cells rather than administrative units. Catchment flood management plans (CFMPs) followed in the mid-1990s, and provided planning at a river catchment scale. Both CFMPs and SMPs provided a vehicle for flood managers to challenge the status quo and take a longer-term view of how best to manage flood risk. Similar coastal zone management plans were being developed in many US states. Despite this change in thinking, on the ground practice however often failed to change, with a continued reliance on flood control and defence, and few examples of ecosystem-led solutions.

THE CONTINUED RECOGNITION OF THE NEED FOR CHANGE

In Europe in 1995, the Netherlands government re-evaluated its flood damage reduction strategy and established the concept of 'Room for the River'. This emphasized the need to consider restoration of natural floodplains as part of the process of dealing with floods. At the same time the International Commission for the Protection of the Rhine (ICPR) formed a committee of representatives of France, Germany, Belgium, Luxembourg and the Netherlands to develop methods to increase flood awareness and to encourage actions that would reduce flood levels on the Rhine River. In 1998 an independent review panel, formed after a major flood event in England and Wales, reported that greater attention needed to be paid to the human impacts of flooding and the necessity for improved flood risk communication.

1.7 The dawn of modern flood risk management (c. 1990s to the present day)

The concept of ***risk management*** is centuries old. Since the 1950s risk can be seen to have directly influenced flood management decisions. For example, following a major coastal surge flood in 1953, the Delta Committee in the Netherlands and the Waverley Committee in England used rudimentary risk-based methods to help determine the design heights and performance requirements for extensive new systems of flood defences and called for national flood warning systems to be established. It was not however until the start of the 1990s that 'risk' (probability and consequence) began to feature as a cornerstone of FRM, with many principles and concepts adapted from other sectors.

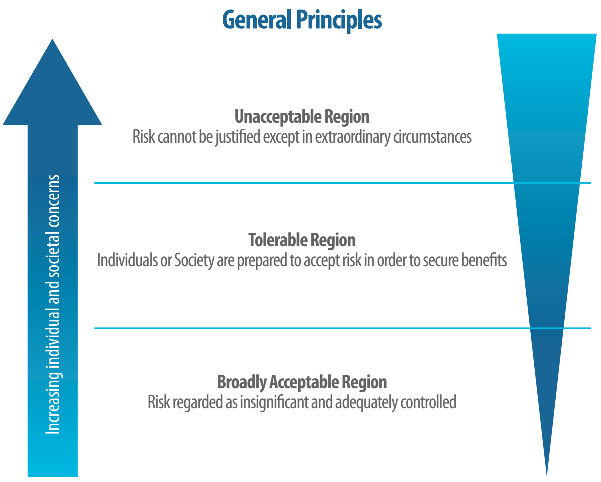
DEVELOPING RISK MANAGEMENT APPROACHES IN OTHER SECTORS

Until the latter part of the twentieth century, risk management was focused primarily on insurance activities and financial markets. Recognition that many unknowns influenced the success of trade led to the development of new methods that could provide better insight into the risks and how best to share the expected consequences. Throughout the early part of the twentieth century the management of financial risks became increasingly sophisticated, including establishing central regulation of the risk taken by the financial community. Natural disasters were certainly part of these risk calculations, but primarily in the context of calculating, and appropriately reinsuring, insurance liabilities.

Increased awareness of environmental issues in the mid-twentieth century brought attention to the risks to the natural environment of human activity in general. Similarly, risk to health from the widespread use of new chemicals in manufacturing and pharmaceutical production began to be recognized. In the late 1970s and early 1980s, the application of risk management techniques was extended to many other sectors. Professional organizations, such as the Society for Risk Analysis in the United States, were formed to bring together academics, government and business interests for the discussion and advancement of risk analysis.

In the United Kingdom, risk management began to feature more strongly in the governance of manufacturing industry, air travel and power generation (both hydro-electric and nuclear), covering all industrial activities that placed either the sector or society in general at risk. A seminal paper by the UK Health and Safety Executive (HSE) (HSE, 2001) set out a framework within which both the risk to individuals and society as a whole could be considered and traded against the benefits secured. The HSE introduced the concept that risks should be managed to a level that is as low as reasonably practicable (ALARP). In the ALARP methodology, 'practicability' is assessed through consideration of both costs (described as all costs, monetary and nonmonetary) and benefits (described as all benefits, both monetary and nonmonetary). The HSE also introduced the concept of 'unacceptable' risks. In this case, efforts must be made to reduce the risk unless the costs of doing so can be demonstrated to be disproportionate to the risk reduction achieved (Figure 15).

Figure 15: The framework of tolerable risk introduced by the HSE in the early 1990s in the UK manufacturing and process industries2



Source: Based on HSE (2001).

In the United States, in 1983 William Ruckelshaus, a former administrator of the US Environmental Protection Agency (EPA), told the US National Academy of Sciences that 'A climate of fear now dominates the discussion of environmental issues. The scientific community can help alleviate this fear by making a greater effort to explain to the public the uncertainties involved in estimates of risk' (Ruckelshaus, 1983). These remarks brought attention to the need to understand and manage uncertainty when dealing with environmental issues and natural hazards.

APPLYING RISK MANAGEMENT TO FLOODING

Through the 1980s to the present day, governments and private insurers have recognized that, in spite of decades of modern flood control and flood damage reduction, flood losses continue to rise. At the same time there has been a growing realization across the globe of the potential impact of climate change on natural disasters in general and flooding in particular. The establishment of the Intergovernmental Panel on Climate Change (IPCC) in the late 1980s focused even more attention on the challenge of dealing with an uncertain future.

Nonetheless, it was not until the early 1990s that the process of risk management started to be used more formally and routinely in flood management. In the United Kingdom for example, in 1993 the government published its first *Project Appraisal Guidance Notes* for flood and coastal erosion projects (MAFF, 1993). These embedded the concepts of assessing a range of probabilities and consequences as well as the whole-life costs of risk management schemes. Consistent methods of assessing flood damage to property and disruption were also established and provided as guidance (Penning-Rowsell et al., 2010). This was driven primarily by a need to improve the efficiency and effectiveness of public spending. In the late 1990s, many of the northern European countries bordering the North Sea started to move towards risk-based approaches and sought to use similar approaches in developing flood management strategies (see COMRISK.org).

Throughout the 1990s and 2000s, the methods of risk assessment and FRM continued to develop. In some countries the focus remained on providing 'strong' defences but using risk-based methods to help set safety standards (e.g. CUR/TAW, 1990; USACE, 1996) and target maintenance activities. Other countries started to use risk-based methods (e.g. Sayers et al., 2002) to aid the development of a portfolio of measures and to manage existing infrastructure (Sayers et al., 2010). In all cases, however, there was agreement that absolute protection from flood hazards was impossible and that decisions had to be made about what constituted acceptable residual risks.

Several countries, such as Austria, Finland, Spain, Ireland and the Netherlands, have chosen to debate this issue at a national scale and provide official guidelines or legal texts on the levels of protection against floods based on the people and property at risk. Others, such as the United Kingdom, chose not to provide a national prescription of standard, but instead provided guidance on how government investments will be prioritized on a consistent risk-informed basis (for example as described in priority scoring documents published by the Department for Environment, Food and Rural Affairs, Defra). Such systems allow governments to trade off investment in flood management with investment in other public safety issues (for example traffic safety) as well as promote multicriteria decision-making reflecting local issues and national preferences. The aim of the trade-off analysis in the United Kingdom is based on efficiency of national investment (maximizing the risk reduction for every unit of resource spent). Such an approach avoids the need to specify a threshold at which the risk becomes unacceptable but requires a clear framework of multicriteria decision-making. Resource allocation procedures in other countries, including the United States, follow similar economics-driven approaches.

THE INFLUENCE OF FLOOD EVENTS ON SHAPING MODERN FLOOD RISK MANAGEMENT

The developing detail of the modern FRM approach has been and continues to be shaped by flood events. Some of the most important of these recent events are discussed below.

Mississippi, USA, 1993 and 1997 – a need to recognize uncertainty

The 1993 Mississippi River flood was the US flood of the century in economic terms. Following this event, flood risk discussions began in earnest in the United States in 1994. The discussions focused on the uncertainties connected with the hydrology of flood events and how this uncertainty should be handled in studies being conducted by USACE. A first regulation for the Corps was issued in 1996, and established guidelines for the conduct of the hydrology and related economic aspects of studies that would assess the justification for new flood control projects. Although the document also required that this consideration of uncertainty should extend to analysis of the probabilities that physical structures would perform as designed over a range of natural events, little was done until after 2005 in this regard. No efforts were made to use risk methodologies to guide flood damage reduction activities in the field. At this point in time, the concept of FRM was not widely accepted, and in fact it was questioned by several organizations representing floodplain interests.

Europe, 1993, 1995, 1997 and 1998 – demand for a basin-wide and strategic approach using a combination of structural and nonstructural approaches

Major floods on the Rhine River in 1993, again on the Rhine in 1995 and 1997 and in the United Kingdom in 1998 brought increased attention to the growing challenge of flooding. The Rhine flood of 1993 threatened to inundate much of the Netherlands. It became obvious to government leaders that something needed to be done. As a result there was considerably more activity as both academic and governmental organizations moved to better deal with growing flood losses across the European Community. In 1996 the European Union launched a three-year research project, River Basin Modeling, Management and Flood Mitigation (RIBAMOD, 1999), to among other things identify the past difficulties in floodplain management, current best practices and areas for further research. The RIBAMOD process led to additional activities in the European Community that continued the exploration of new approaches, including risk, to deal with flood challenges.

In 2000 the European Union issued a Water Framework Directive addressing the steps necessary to reduce pollution in European rivers and establish river basin management as the framework for cooperative efforts to accomplish the objectives of the Directive.

In 2003 the water directors of the European Union noted that 'flood protection is never absolute and things can go wrong. The question regularly arises as to what safety is available at what price, and how much of the remaining risk has to be accepted by society. Risk management will be the appropriate method to deal with this challenge.' They further found that mitigation and nonstructural measures 'tend to be potentially more efficient and long-term more sustainable solutions' (Water Directors, 2003).

In 2004 the European Commission issued a communication to the Council and the Parliament proposing that Member States and the Commission work together 'to develop and implement a coordinated flood prevention, protection and mitigation action programme' (EC, 2004). The communication highlighted the need for the development of FRM plans for each of the European Union river basins, and outlined steps necessary to carry out such activity. At the same time, the Commission approved a major research project, FLOODsite (Samuels et al., 2010), to examine, in a five-year programme, the physical, environmental and socio-economic aspects of floods. FLOODsite launched projects throughout Europe to follow up on the work of RIBAMOD to further advance the knowledge of twenty-first century flood challenges. In 2009 it concluded that:

- Methods and tools are available and are being continuously improved to facilitate development of basin-level FRM plans and flood hazard and risk maps.
- Different approaches will be required for different areas with varying levels of detail and data requirements.
- Public participation and local knowledge will be invaluable in the conduct of risk management activities, although 'the optimal method of engagement will vary depending on the country and local conditions'.

Following additional flood events in Europe during the first decade of the twenty-first century, the European Parliament and Council issued a directive on the 'assessment and management of flood risks' (EC, 2007). A Floods Directive established a framework for this assessment and management, with the goal of reducing adverse consequences of flooding to human health, environment and cultural-economic activity in the European Community. As a first step, the Directive requires that Member States conduct preliminary flood risk assessment of the river basins in their territories, including the assessment of the potential impacts of climate change. It also directed that Member States prepare flood hazard and flood risk maps, and FRM plans for their river basins.

China 1991 and 1998 – a rethinking of flood issues: how to carry out disaster mitigation approaches more efficiently and effectively

In tandem with changes in Europe and the United States, the government of China also found that while investments for flood control continued to increase, so also did flood losses. After the major 1991 floods in the Huai River and Taihu Lake basins, and the 1998 flood in the Yangtze River, Songhua River and Nenjiang River basins, China began to seek new approaches. The desire of the government to support the coexistence of people and nature promoted a change in philosophy from a primary emphasis on structural flood control to one that had a greater emphasis on emergency planning and preparedness and the delivery of structural defences to a variable standard. The most important sections of major rivers, for example, would be designed to accommodate the largest flood within the most recent 100 years, while middle and small-sized rivers were focused on a capacity to deal with smaller 'normal' floods. The major sea dykes were planned to deal with floods with a return period of fifty years.

After the 1998 flood in the Yangtze River basin, China made strategic adjustments to its approach as the economic, natural and social impacts of flooding became better understood. The developing Chinese approach now focuses on regulating flooding by both employing structural measures and reforming social and economic development to be more resilient to flooding. As part of the shift from flood control to FRM, the Chinese government has begun to promote risk awareness (through a national programme of flood hazard mapping), enhance the socially focused management of flood control areas, and has moved away from attempting to eliminate floods totally, to recognizing the continued existence of a residual risk. Under this approach, the focus is on protecting people and property, and minimizing damage when floods do occur.

As part of its new approach, China also established flood control systems at national, basin and local levels. The national vice premier serves as commander in chief of the State Flood Control and Drought Relief Headquarters. The joint mission of the Ministry reflects the acute need to both manage floods and water resources in China's many water-scarce provinces. The seven major basins of the Yangtze River, Yellow River, Huai River, Hai River, Songhua River, Zhujiang River and Taihu Lake have established flood control and drought relief headquarters at the river basin level. Local governments at different levels have developed flood control responsibility systems, requiring the respective governors to assume full responsibility for flood activity. Expenditures for flood actions are funded primarily by the central government, and are supplemented by partial local counterpart funds.

Box 3: China's challenges

Since the founding of the People's Republic of China in 1949, more than fifty extraordinary floods and seventeen widespread severe droughts have occurred.

Two-thirds of the land area in China is prone to flood disasters; most of the areas also suffer from drought. The economically developed eastern and southern regions, which are most severely threatened by floods, contain over 50 per cent of the national population, 35 per cent of the national cultivated land and produce two-thirds of the national industrial and agricultural outputs.

Since 1990, the average annual loss from floods has been approximately 1.5 per cent of the national GDP. The annual economic losses from droughts during the same period have averaged 1 per cent of GDP.

On average seven typhoons hit China each year. In 2008, ten typhoons or tropical storms hit China, with unprecedented severity. As a result of emergency measures taken, 4.15 million people were safely evacuated, 650,000 ships were saved, the number of deaths was reduced by 70 per cent in comparison to previous similar events, and the number of buildings flooded was reduced by 60 per cent.

Earthquakes and other natural disasters often have severe impacts on flood structures. In 2008, the Wenchuan earthquake damaged 2473 reservoirs and 1229 km of embankment, and endangered 822 hydropower stations. Landslides resulted in 105 dammed reservoirs.

Asia, 2004, Indian Ocean (Boxing Day) tsunami – better warning, emergency planning and spatial planning

An earthquake in the Indian Ocean on 26 December 2004 triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean, killing over 230,000 people in fourteen countries, and inundating coastal communities with waves up to 30 m high. Indonesia was the hardest hit, followed by Sri Lanka, India and Thailand. This event provided two critical lessons for flood managers. The first was that given even the shortest of lead times, if you are able to warn people, they can react to reduce consequences if before the event they had gained an understanding of the risk and the actions to take. Prior to the Boxing Day Tsunami neither early warning systems nor awareness campaigns were in place. The second crucial lesson reflected the loss of critical infrastructure during the event; at the time it was needed most. Hospitals, transportation networks and community centres were often sited in the most exposed locations. Since 2004, considerable effort has been devoted to developing sophisticated early warning systems and mapping the probability of flooding to inform spatial planning and emergency response decisions. The success of these measures is yet to be tested, but will, inevitably, be tested.

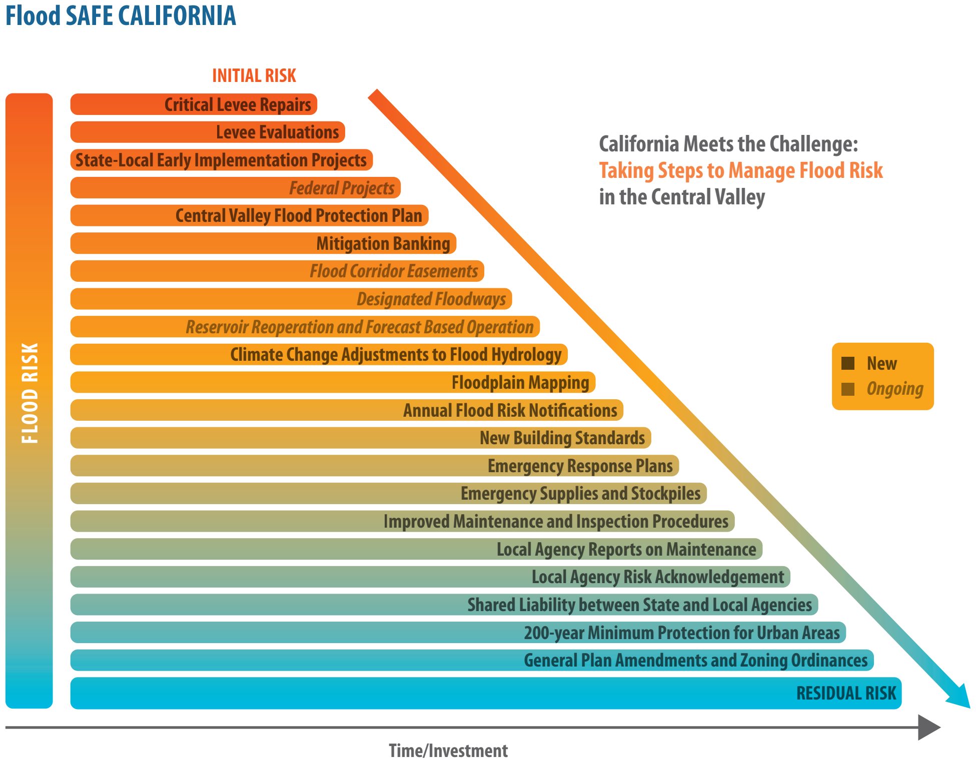
New Orleans, Louisiana, USA, 2005 – a need to better understand levee performance and the wide acceptance of the need for a risk management approach

It is often said that there only two types of levees: those that have failed and those that will fail. The flooding of New Orleans in 2005 reinforced this view across the United States. Hurricane Katrina hit the Gulf Coast of the United States in June 2005, taking over 1900 lives and creating damages and costs to those in the area and the nation that may well exceed $100 billion. Five years after this event much of New Orleans still had not been redeveloped, and the repairs and minimal upgrades to the protection in place at the time of the hurricane still not completed. The impact of Hurricane Katrina was felt around the world, and led to significant examinations of the abilities of flood structures to meet the challenges that they will face in the future given the potential impacts of climate change. Forensic examinations of the causes of the failure of portions of the levee system in New Orleans also brought into question the integrity of levee systems throughout the United States and in other countries, and emphasized the need for methods and techniques to assess accurately the condition of such earthen structures. Preliminary analysis of the US structural protection measures indicated that many of the tens of thousands of kilometres of levees were in unsatisfactory condition, and that the conditions of many more were unknown.

Faced with this situation, the federal government collectively began a rapid move from flood risk reduction to FRM. In May 2006 USACE and the Federal Emergency Management Agency (FEMA) established a national FRM programme 'to integrate and synchronize the ongoing, diverse flood risk management projects, programs and authorities of the … Federal agencies, state organizations and regional and local agencies' (USACE, 2011c). As one part of this effort, FEMA added emphasis to its National Flood Insurance Program by increasing its efforts to improve risk identification and communication.

Despite the long-standing federal leadership of flood control and flood damage reduction activities in the United States, the federal organizations identified that FRM should be the joint responsibility of all levels of government and those who live, work, or influence activity in flood risk areas. They also emphasized that FRM will not only require consideration of structural measures to deal with ongoing and future risks, but will also involve full use of all of the nonstructural techniques available. Figure 16, prepared by the State of California, illustrates a multifaceted approach to 'buying down' flood risk in the Central Valley of California.

Figure 16: The risk reduction concept as applied to the FloodSAFE program of the State of California, USA



Source: courtesy of California Department of Water Resources.

2007 floods in Hull, UK – a need to consider all sources of flooding and spatial coherence of events

Following a major flood in 2007, the British government commissioned Sir Michael Pitt to review the lessons learned from this event. The subsequent report to the government discussed both technical and organizational shortcomings. It also identified that having a legislative framework for FRM was fundamental, noting that 'the management of flood risk requires concerted action by public and private bodies, and this must be properly supported by appropriate legislation that would address all forms of flooding'. This was an important lesson highlighting that floods are generated by many mechanisms, and an understanding of each is required in order to manage flood risk effectively. Until then, coastal and fluvial (river) flooding had been the responsibility of one organization, and groundwater, and perhaps more importantly pluvial (direct rainfall) flooding, the responsibility of another. *The Pitt Review* (Cabinet Office, 2007) led directly to the development of surface water management plans in the United Kingdom, a layer of planning where all sources of flooding are considered and an attempt is made to develop integrated management strategies.

The Pakistan 2010 flood, the Japan 2011 tsunami and the 2011 Mississippi River floods – rethinking where and how people should live and the need to build in resilience

In July 2010, La Niña-affected monsoon rains began to fall on most northern sections of Pakistan and the upper reaches of the Indus River. The Indus River from north to south went into exceptional flood stages, driving people out of their homes, disrupting road, rail and electronic connectivity. By the end of September, Pakistan had seen over 6 million people displaced, over 1.8 million homes and 1.4 million acres of cropland destroyed, 1,700 people killed and damages exceeding US$43 billion estimated to have occurred. The unusual intensity of local rainfall (in some places more than 200 mm in twenty-four hours), coupled with the exceptionally high levels of the Indus, flooded areas that were ill prepared for such an event.

The full impact of the March 2011 Japanese tsunami has yet to be assessed. Over 15,000 people were killed and entire communities destroyed when the tsunami generated by a 9.0 Richter scale earthquake devastated villages and cities. In the most critical case, the design of the Fukushima nuclear power plant failed to prevent the tsunami destroying the critical power systems that were needed to maintain the safety of the plant. Nonstructural measures such as early warning and evacuation systems prevented even larger loss of life to a public that, for the most part, understood the risk they faced from a tsunami. Following the Indian Ocean tsunami, in 2005 the Japanese government undertook a review of the national tsunami protection system and initiated a series of actions to address shortfalls that surfaced in the review. The time needed to carry out major infrastructure modification is long, however, and not everything recommended by the review had been initiated or completed when the 2011 tsunami hit.

Major rainfall events throughout the US Midwest in April and May 2011 brought the lower Mississippi River to its highest stages in over seven decades, threatening the stability of the major federal levee works along the river. Through use of floodways and backwater storage areas in the lower Mississippi valley, a flood of 79,000 m^3/s (compared with the designed-for maximum flood of 85,000 m^3/s) was successfully passed into the Gulf of Mexico, and none of the areas protected by the federal system, including New Orleans, were flooded. Many areas between the federal levees and the river, along tributaries to the Mississippi, and in backwater areas where low-level levees (designed for example for 100-year interval incidents) provide protection were flooded, leading to considerable loss of property and cropland. Most of these areas have been protected from lower-stage, more frequent floods over the years, and unknowing residents took it for granted that their protection would extend to larger floods. In addition, considerable concern was expressed over the use of floodway land which was being used for agriculture even though the government had previously acquired the rights to flood this land in exceptional flood conditions. The Mississippi flood of 2011 brought national attention once again to the approach being taken to deal with occupancy of the floodplain and responsibility for flood protection. Writers in newspapers across the country opined that it was time to rethink flood control.

Table 2: The influence of past flood events in shaping policy and practice

Flood event	Impact on thinking, policy and/or practice
1917 Mississippi and Sacramento river basins, USA and 1927 lower Mississippi, USA	Promoted the need for basin-scale infrastructure and coordination
1931 and the following decades, across three major rivers: the Yellow, Yangtze, and Huai, China	Promoted the need for basin-scale infrastructure and coordination
Major floods across the United States in 1936 (and to a lesser extent 1937 and 1951)	A need for national responsibility
In March 1947, river floods across much of Europe, Shortly afterwards in 1953,devastating coastal floods in Europe	Issues of food security, the need for clear roles and responsibilities and the performance of warning systems
1991 and 1998, China	A rethinking of flood issues: how to carry out disaster-mitigation approaches more efficiently and effectively
1993 and 1997, Mississippi, USA	The 1993 Mississippi River flood was the US flood of the century in economic terms. Following this event, new regulations were issued (1996) that established the need to include uncertainty in assessment and justification for new flood control projects

Flood event	Impact on thinking, policy and/or practice
1993, 1995, 1997 on the Rhine and 1998 in the United Kingdom	Led to a demand for a new basin-wide and strategic approach to flood management using a combination of structural and nonstructural approaches
2004, Asia tsunami (Boxing Day)	A recognition of the vulnerability of coastal communities and need for better warning, emergency planning and spatial planning to reduce risk
2005, New Orleans, USA	A wider recognition that levees fail. A need to better understand levee performance and the wide acceptance of the need for a risk management approach and the communication of residual risks
2007 in Hull, UK	A need to consider all sources of flooding and spatial extent of events, as pluvial, fluvial and tidal sources combine
2010, Pakistan, 2011, Japan, and 2011, Mississippi	A need to re-evaluate the use of floodplains, limitations of structural systems, and the need to improve the resilience of critical infrastructure and prevent secondary and tertiary risks developing

1.8 Lessons learnt, ongoing challenges and live issues

Flood risk management continues to change, and many management challenges persist. While there is no single roadmap for flood managers to follow, they can learn from the experience of others. Some of the emerging issues and ongoing challenges that will no doubt influence the manner in which future FRM will be delivered are discussed below.

Lessons learned from selected international case studies

Flood risk management is now generally accepted as a sound basis for managing the competing needs of people, economies and the environment. As part of the preparation of this book, case studies were prepared to highlight international experiences with the implementation of FRM (see Sayers et al., 2011). The techniques for implementation continue to evolve, and examples exist both of where they have been implemented well and of incidents where practice has been poor. In both cases lessons can be learned, including:

- Careful consideration of uncertainties supports rational long-term solutions, forcing planners to deal with uncertainty in the data presented on present-day defences, populations and other issues, and about future conditions. Adopting a spectrum of possible future scenarios enables a wide range of plausible futures, including sea level rise, new return periods, changing river flows and patterns of development, to be factored into the decisions made.
- Risk-based methods do not necessarily demand more data than traditional approaches, but they enable uncertainty to be recognized explicitly and data collection programmes to be prioritized to address areas where the lack of uncertainty is material to the choice being made.
- Flood risk changes over time. Changes in climate conditions, land use and management actions make historical comparisons difficult if not impossible. Appropriately recognizing the nonstationary nature of flood risks in both the calibration and validation of flood models and planning decisions presents a considerable challenge, and one where considerable research effort is now focused..
- Flood risk management planning is most effective when planners consider multiple sources of flooding. Too often projects are designed for specific threats when in reality there are multiple threats. Planners may have to consider sea level rise, storms, hurricanes and cyclones, and riverine and pluvial flooding possibilities, both individually and in combination.
- The effectiveness of FRM planning is most effective when it is delivered in a comprehensive manner at a watershed or basin level. Considering all of the water-related activities in a geographic region as well as the interaction between the 'water plans' and wider economic, environmental and social development plans helps ensure that a comprehensive view is developed.
- Different predictions and conflicting advice from the many models used in FRM planning should be expected and reconciled. Models may not always agree with each other but through a transparent process, the reasons for the differences can be understood and accounted for appropriately in the decision process.
- Communicating the risks, widely and truthfully, can significantly reduce the anxiety of those threatened by floods and increase their support for ongoing activities. Keeping the public informed on the steps being taken to reduce flood risk plays a significant role in minimizing concerns. In the absence of official communication, the wrong messages will fill the void and increase public concern.
- Effective and efficient FRM rests on use of a portfolio of management responses, taking full advantage of all methods of mitigation to reduce risk. Typically a mix of structural and nonstructural measures provides the most robust, resilient and sustainable approach.
- Urban development, unless appropriately controlled, can significantly increase casualties and economic losses. Appropriate zoning and building regulation are an important component of a portfolio of responses.

- Making space for flood waters, by setting aside flood detention areas (that act during extreme floods but have limited influence on more frequent floods) and making room for the river can have a significant impact on reducing risk at a watershed or basin scale.

- Progress in FRM planning becomes very difficult when viewpoints at the national, regional and local level are not the same, or coordination amongst the different levels of government is limited. In this case, high-level plans and concepts developed nationally and seemingly forced on local governments create suspicion and sometimes hostility, and disagreements will develop between governance levels. To overcome these difficulties it is important that they are addressed early in the risk management process, with those with responsibility for providing a strategic overview role being well defined.

- When structural components of a FRM plan are not properly maintained the effectiveness of the entire system may be put in jeopardy. Engineering systems should be maintained, and where appropriate improved, through a continuous process of review and update. Frequently, the chance of flooding increases as a result of the lack of maintenance and presence of ageing systems – an increase that can go unrecognized by the public and professionals alike.

- Flood risk management plans must be easily adapted to changing conditions. Not knowing what the future will bring means it is impossible to agree on a single expected future, optimize a management plan to deal with that future, and then expect that future actually to be realized.

- Close attention must be paid to the feasibility of project execution in development of FRM plans. Analysis must be made of the life-cycle costs of both structural and nonstructural measures and the ability of the resourcing agency to provide the necessary funds. Uncertainty about fund availability for project development and continuous maintenance and upgrading all undermine efforts to manage risk effectively.

- Standards-based planning is inefficient (as it does not target resources according to risk) and can place an unwarranted focus on 'protection' rather than management. Achievement of arbitrary levels of protection and providing the same level of protection to all areas without consideration of the differences in risk levels that exist is inefficient and creates drains on scarce resources.

Ongoing challenges and live issues

Flood risk management practice continues to evolve, and solutions to some of the most difficult questions remain elusive. Some of these live issues are outlined below.

How can general integration of flood risk management with water resources and spatial planning be achieved?

Increasingly flooding is seen as part of the wider process of water management. Practice however continues to emphasize structural measures and often fails to deliver integrated solutions. The need for integrated action, is well recognized and influential documents provide a 'call to arms'. For example:

- In May 2005, the Third International Symposium on Flood Defense (ISFD3) concluded that there was a need to move from flood defence to flood management, with integrated risk-oriented approaches as extensions of this approach. In 2005 the Asian Disaster Preparedness Centre in Bangkok, Thailand issued a primer on integrated FRM, noting that contemporary approaches to integrated FRM link it with the concept of integrated water resources management (IWRM) with the goal of maximizing floodplain use while at the same time minimizing loss of life and biodiversity. It went on to note that individual flood interventions have implications for the whole system. Integrated delivery is difficult, but not impossible, to achieve in practice.

- In 2010, UNESCO formed the International Center for Integrated Water Resources Management (ICIWaRM) in the United States to advance the science and practice of IWRM in order to address water security and other water-related challenges on the global and regional scale. A key element of ICIWaRM's initial portfolio has been attention to identifying government-level efforts to develop FRM programmes and to identify emerging best practices. In this latter effort it is working closely with the Japan-based UNESCO International Centre for Water Hazard and Risk Management (ICHARM) (www.icharm.pwri.go.jp), which is also exploring approaches to effective FRM.

- In recent years, China has placed a focus on flood control, drought relief and disaster reduction as the major elements in plans to improve the livelihoods of its people. By giving equal importance to flood disaster response and drought relief, shifting from flood control to flood management, and moving from single-purpose drought efforts to integrating these approaches with urban, rural and ecological needs, they are seeking to blend structural and nonstructural approaches effectively and improve the overall efficiency of their efforts.

How can flood risk management be better organized to ensure better multifunctional planning and more secure long-term financing?

Who has the responsibility? The second half of the twentieth century began a move towards full public participation in decision-making and development of shared responsibilities among all levels of government for implementation and resourcing of FRM activities. Modern FRM carries this collaborative institutional approach into the twenty-first century. In China, a flood control and drought relief command system has been set up at national, river basin and local levels. The European Union operates a FRM framework agreed to by all of the participating nations. In the United States the responsibilities are not clearly defined, and this lack of clear identification of roles and responsibilities continues to be a barrier to advancement, particularly in the area of spatial planning where responsibility is placed at the state level, but FRM activities are federally driven – an arrangement echoed in many countries.

What can be done to improve the reliability of structures throughout their life? For most of recorded history, brute force has been used to control floods. China, in more than 4,000 years, has built over 280,000 km of dykes, over 86,000 reservoirs and ninety-seven key flood retention areas, all of which require continuous maintenance. Most other nations have been equally aggressive in developing structural approaches. From the beginning of work on flood mitigation structures, maintenance has been an Achilles' heel. Far more effort is typically placed in the initial construction of such facilities than is devoted to the periodic maintenance and needed upgrade of the same facilities. But without adequate resource support new defences can rapidly deteriorate and fail to provide the level of performance they were designed to provide, undermining the entire plan. China has explicitly recognized this issue and promoted the maintenance and reinforcement of flood control works through a series of policies, regulations and actions to ensure the normal operation of the flood control system. Since Hurricane Katrina, the United States has focused its efforts on developing programmes that ensure better inspection and maintenance of government and locally sponsored structures. As increasingly community-based structures (sustainable urban drainage, temporary and demountable defences) appear, questions are raised about who will provide programme oversight and the resources for long-term maintenance (including demolition and removal). This remains an important challenge.

Nonstructural measures employed. What steps can be taken to improve the adoption and reliance on nonstructural measures? Experience shows that structural features can be prone to failure, and often deal poorly with flood events larger than those for which they were designed. As a result, during the mid to late twentieth century there was an increasing focus on taking actions that would move people and property out of harm's way, or enable them to remain in place with minimal damages to themselves or the natural environment should a flood occur. This philosophy remains a cornerstone of FRM going forward worldwide, and has had a particular focus in China and the United States. Flood detention areas for temporary storage of flood waters that cannot be passed within the river channel and floodways that allow flood waters to bypass river choke points have been in use in China for four millennia and in the United States for nearly a century. As population and agricultural pressures increase, the continuing use of such valuable land for flood mitigation purposes has come into question. Overcoming the political, social and economic (including compensation) issues associated with deliberate flooding of populated or agriculturally rich detention and floodway areas are a growing issue.

How can new laws, policies and planning act in concert to support flood risk management? Laws, policies and planning are the foundation of FRM. The clear definition of how decisions to invest in FRM will be made and the acceptable level of residual risk remain issues for ongoing debate in most nations. Providing clarity and transparency on how decisions are made to invest or not to invest resources to reduce risk will be a critical element of FRM as it goes forward.

As effort is shifted from flood control to FRM, a greater emphasis is placed on understanding the relationship between flood control/water utilization and aquatic ecosystems. If progress to minimize the negative impacts and maximize the positive opportunities for the environment is to be made in practice, a stronger desire to coordinate and integrate efforts, both inside and outside FRM, will be needed.

New laws and policies will also be needed to secure long-term funding. For example, some Chinese scholars have begun to look into the improvement in the investment mechanisms in China, making them more public interest oriented. The United States is investigating public–private partnerships to finance flood risk reduction programmes. Under these proposals, communities would permit private sources to build, maintain and operate flood facilities and allow them to charge fees for their efforts. Policy recommendations such as establishing a standing fund for flood management and increasing management fees are being developed. The notion that the beneficiary pays is starting to gather pace in the United Kingdom and elsewhere, but the ability to disaggregate the specific beneficiaries of supported actions and determine how much each recipient benefits remains an ongoing challenge.

Will flood managers be able to utilize advances in data, science and technology?

What data will be available, and how accurate and accessible will they be? Flood risk managers have always made decisions based on limited data – with deficiencies in the record length, spatial extent or accuracy. In recent years access to higher-quality data has increased significantly (for instance, the advent of LiDAR has revolutionized the ability to assess potential inundation). This trend is set to continue, and how flood risk managers utilize this growing wealth of data could dramatically change the way in which FRM is delivered. Communication technologies, cell phones, tablets and similar devices put communications tools in the hands of the public, business and the government. Cloud computing will enable more complex simulation models to be run and used in the development of strategy at all levels of government. Real-time dense networks will offer significant improvement in warning.

How this data will be used, managed and made accessible will be a significant but exciting challenge. For example, sharing data between upstream and downstream countries is still a serious impediment to planning in some transnational basins. Overcoming the political and operational barriers to share data, and increasingly share the management of major rivers, provides a significant opportunity. Examples of good practice do exist, and are increasing (for example through the Danube incentive).

What information and knowledge base will guide activities? Increasingly sophisticated analysis techniques will continue to be developed to support the understanding of flood risk. These advances will no doubt continue. They range from real-time control of reservoir operation to pervasive sensors (from street-based monitoring of flood wave propagation through to real-time condition monitoring of levees) and whole-system models to better understand the 'true' performance of the system and the risks associated with marginal performance. Under the background of climate change and rapid change of socio-economic settings, simulation models are providing an improved ability to explore future change, and will help flood risk managers identify robust FRM responses. Significant challenges remain, however. For example predicting and modelling intense rainfall events and the demand for whole-system understanding (integrated modelling of all sources of flooding and its integration with people and ecology) continues to expose scientific and modelling inadequacies. How future flood risk managers utilize these advancing tools will be crucial to determining whether or not whole-system understanding and integrated management is delivered in practice.

How can the public and other stakeholders influence decisions more directly? Until late in the late twentieth century, little was done to involve those other than farmers living in the floodplain in the development of flood mitigation activities. Public participation is now universally considered to be an essential element of FRM, and will take an increasing role. Attention is being focused in Europe and the United States on use of advanced public involvement techniques such as shared vision planning and similar approaches that bring the public into the decision process in a collaborative manner. China has successfully worked to organize the army and civil society to manage flooding on a scale largely unseen elsewhere. Ownership of local ecosystem rehabilitation and construction activities is starting to emerge, such as returning farmland to forests, planting trees and conserving soil and water to restore original ecological features, together with the engagement of the public in monitoring the condition of river channels and dykes.

The next decades, with the ubiquitous availability of information through multiple media, will see an increase in demand for participatory decision-making by those affected by and having an interest in FRM. Flood professionals will have to develop methods to better educate and engage the public on the new risk management processes, and secure their active participation in planning efforts – both locally and nationally – to ensure support for what is likely to be significantly increased resource expenditure.

How can impacts be reduced and opportunities maximized, or is this even possible?

Over the centuries structural protection measures have caused significant harm to the natural environment of the floodplain and reduced the value of ecosystem goods and services. Society's understanding of the impacts of flooding continues to evolve, and will increasingly demand that flood management :

- **Delivers multiple benefits and promotes multiple uses of rivers and coasts.** Many rivers were managed during the nineteenth and twentieth centuries with a single purposes – which might have been navigation and trade, flood control, hydropower, or provision of a water supply. Today, and into the future, there will be an increasing emphasis on promoting multipurpose use. Managing rivers and coasts therefore presents both opportunities and challenges for joint uses and multiple benefits. Flood storage behind the reservoir could, for example, be traded for hydropower production to create a fiscal profit pool that could be used in turn to compensate those in the floodplain for damages. Trading navigation storage for hydropower or water supply in some reaches could be balanced against navigation operations in other reaches. How best to combine these demands in an effective and practical way will be an enduring challenge demanding much stronger strategic basin planning.
- **Provides protection and enhancement of the natural environment.** In the last decades of the twentieth century, and the first decade of the twenty-first, there has been increasing pressure on our rivers and coasts. In some places however good management has started to improve ecosystems services: for instance, many rivers and coasts in the developed world are now cleaner than they have

been for many years. This trend to improve ecosystem health continues. Multibillion-dollar restoration projects are underway in many places, including the Danube River in Europe and the Florida Everglades in the United States, and many other restoration projects are planned (on large and small scales). Many groups are examining how restoration projects could be used to not only preserve or recreate endangered ecosystems, but also serve as valuable adjuncts to FRM efforts. Restored wetlands do provide flood storage. The wise use of areas behind levees for flood retention can also create concurrent flood damage reduction and environmental benefits. Increasing attention to protection of the environment and restoration of legacy destruction will offer opportunities to create additional tools for FRM.

- **Promotes carbon capture.** As the world begins to accept the necessity to mitigate climate change, there will be increased pressure to reduce emissions of carbon dioxide (and other greenhouse gases). Floodplains offer opportunities for carbon sequestration through careful crop and land use choices. Experiments are taking place around the globe to determine physically, economically and fiscally how such programmes might be developed. The use of existing and restored wetlands may become extremely important in carbon-banking scenarios. There has been limited research to date on the positive and negative aspects of this use of floodplain areas and the impact it might have on FRM activities.

How can major structures be developed without adding to national or regional security concerns? Flood control structures have always been seen as potential targets for those attempting to do harm to a population. Long linear systems such as levees are difficult to guard or monitor, and dams have also been a potential target for terrorists. In an increasingly volatile world, protecting from wilful attack may be an increasingly important consideration for the flood risk manager.

How can flood mitigation strategies be developed that address local issues as well as those of the larger watershed?

How to improve integration and collaboration in thinking? Governments and businesses have always been most comfortable operating within an organizational structure that permits activities to be carried out that relate to their narrow field of interest. Although it is now widely accepted that flood management must be addressed at the whole river basin or coastal cell level, or even the entire country, such efforts require considerable collaboration. Narrow thinking within functional or sectoral 'silos', or 'stovepipes', limits the horizontal and vertical integration required. Collaboration and integration continue to be perceived as inconvenient, threatening to existing functional relationships, or an added burden. Changing these perceptions will remain a significant practical challenge going forward. Even when there has been national oversight of flood mitigation efforts, the political process has limited the ability of those developing flood mitigation plans to operate on a watershed or basin level. In Europe, the Water Framework and Flood Assessment and Management directives promise to support more effective basin-level planning and cooperative efforts in transboundary situations.

Resolving upstream and downstream conflicts. The need for planning on a basin scale to avoid upstream–downstream conflicts is now well recognized within the FRM community. Its uptake and impact on broader planning processes and behaviour are less clear. Going forward, ensuring that flood risk plans are carefully coordinated with other functional activities such as land use, industrial development and national intentions will be a significant and important challenge.

PART B

THE PHILOSOPHY AND PROCESS OF FLOOD RISK MANAGEMENT

As flood risk continues to increase, the need to make space for water and relearn how to live alongside the natural functioning of rivers and coasts is increasingly recognized. Risk management is widely accepted as the dominant focus in good flood management decisions, and the concept of an integrated risk-based approach to flood management is now well established (e.g. Sayers et al., 2002; Galloway, 2008). This section of the book presents the motivation underlying modern FRM and explains how it differs from traditional flood control approaches. The important processes and considerations associated with strategic FRM are also presented and discussed.

There are six chapters in this section dealing with:

> modern FRM

> goals, objectives and outcomes

> governance frameworks for FRM

> the adaptive process of FRM

> safeguarding and promoting ecosystem services through FRM

> implementing FRM – barriers and enablers.

CHAPTER 2
MODERN FLOOD RISK MANAGEMENT

2.1 Setting the scene

Modern FRM recognizes that there is seldom a single solution to managing flood challenges. Instead, portfolios of FRM measures and instruments are utilized. Such portfolios assembled a range of actions in such a way to reduce risk in an efficient and sustainable manner, and draw upon:

- 'hard' structural measures (such as construction of dykes, levees and dams)
- 'soft' structural measures (such as wetland storage)
- nonstructural measures (such as improved flood forecasts and warnings)
- policy instruments (such as land use planning, insurance and other funding incentives, such as homeowner grants for flood proofing).

The criteria for assessing FRM strategies are no longer solely economic, but involve consideration of a much broader set of outcomes, including social justice and ecosystem health. Equally, an increasing recognition of nonstationarity within the flood system (that is, climate, geomorphologic and socio-economic change) forces an explicit consideration of a full range of plausible ways in which flood risk may shift in the future. This continuous process of adaptation is distinct from the 'implement and maintain' philosophy of a traditional flood defence approach.

Implementing FRM places a high demand on its stakeholders. It involves the collective action of a range of different government authorities and those outside government, including the public and business. This places an increasing emphasis on effective communication and mechanisms to reach consensus without succumbing to the short-termism that may be present in the many competing views. Increasingly, the move towards FRM is becoming embedded in national government policy. This includes, for example, *Making Space for Water* in the UK (Defra, 2005), the European Directive on the Assessment and Management of Flood Risks (EC, 2007) and progressive evolution of floodplain management in the United States (IFMRC, 1994; Galloway, 2005; Kahan et al., 2006) to name a few.

Compelling as modern integrated FRM certainly is, it is not easily achieved. The potential gains however are substantial.

2.2 The dimensions of risk

Before exploring the attributes of modern FRM in detail, this section introduces a number of important concepts that underlie the understanding of risk, and explains how these are used to inform the process and context of FRM decision-making. One of the most important of these concepts is risk, and it is essential to understand its multiple, and sometime subtle, dimensions.

UNDERSTANDING THE COMPONENTS OF RISK

Risk has two components – the chance (or probability) of an event occurring and the impact (or consequence) associated with that event, therefore:

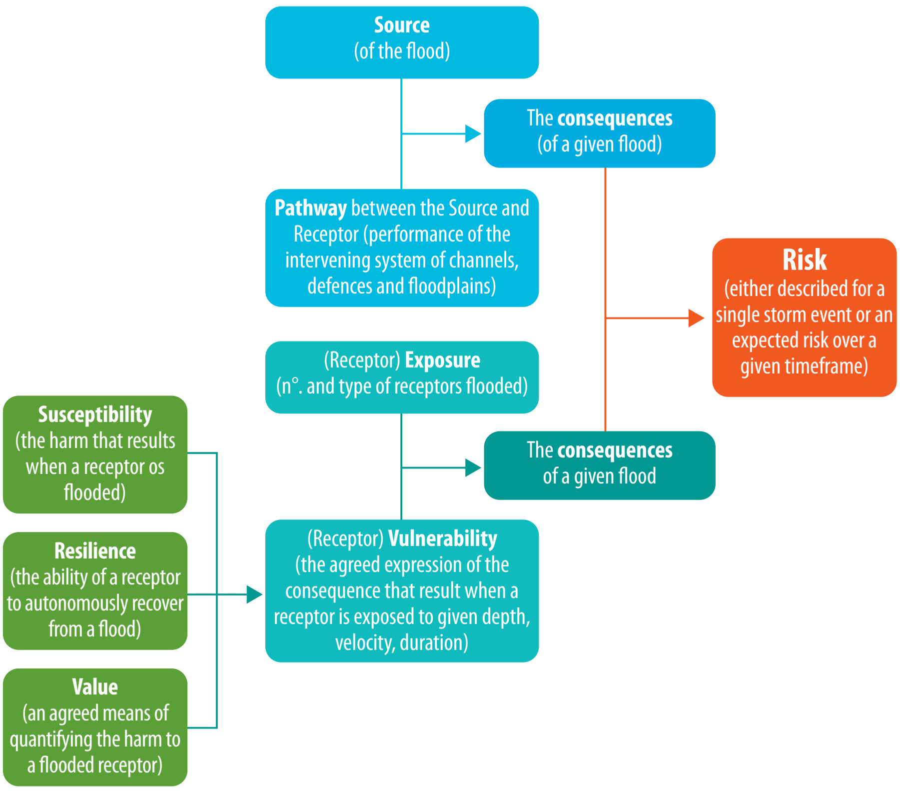
Risk = f (probability of inundation and the associated consequences)

These basic components of probability and consequence can be usefully disaggregated further into their constituent components, as discussed below and shown in Figure 17:

- The **probability of occurrence** of inundation. This reflects both the probability of the occurrence of the initiating event (the ***source*** of the flood such as rainfall or a marine storm) and the probability that flood waters will reach a particular location in the floodplain, taking account of the performance of the intervening system of wetlands, channels, dams, levees, floodwalls and other structures (the ***pathway*** of the flood water).
- The **consequences** should flooding occur. This reflects both the vulnerability of the ***receptors*** and the chance that a given receptor will be exposed to the flood, where:
  - **Exposure** quantifies the number of properties or people, area of habitats, and so on that may be exposed to a given flood event should it occur. Exposure is not as simple as it might seem. Some receptors, such as residential properties, can be considered as static, but other receptors such as people, cars and much wildlife may be dynamic – that is, they are liable to move – and they may or may not be present in the area at the time of a flood. The degree of exposure will influence the risk: for example it will differ depending on the time of day the flood occurs (rush hour, night time and so on).
  - **Vulnerability** describes the potential for a given receptor to experience harm during a given flood event. To further understand vulnerability, three supporting aspects need to be considered:
    - **Susceptibility** describes the propensity of a particular receptor to experience harm during a given flood event. This includes material destruction – a carpet might be destroyed – loss of or damage to particular flora or fauna, and human death or injury.
    - **Value** externalizes the value system used to express the degree of harm to a receptor. For example, the system might adopt a development or welfare economic basis for monetization of impacts (discussed further later in this chapter).
    - **Resilience** describes the ability of the receptor that has been harmed by a given flood event to recover without aid.

In understanding the likely consequences of a flood it is therefore important to understand the nature of the receptor and how a flood will impact it.

Figure 17: The components of risk



UNDERSTANDING THE SIGNIFICANCE OF RISK

Intuitively it might be assumed that risks with the same quantitative value have equal significance, but this is often not the case. It is important to understand the nature of the risk, distinguishing between rare, catastrophic events and more frequent, less severe events. The approach to managing low-probability/high-consequence as opposed to high-probability/low-consequence events, even though the 'calculated' risk would be the same, may be (and is likely to be) different. Many other factors also influence how society or individuals perceive risk, including the availability of insurance and public trust.

ACCEPTING RISK AS NONSTATIONARY

Climate change, land use change, deterioration of defences and so on, can over time affect the probability of occurrence of a flood. Growth in the population of a city together with intensification of development could greatly increase the associated consequences. In all cases the risk changes with time.

UNDERSTANDING RISK CASCADES – FROM PRIMARY TO SECONDARY AND TERTIARY RISKS

Numerous natural hazard events have highlighted the highly interconnected and mutually dependent nature of infrastructure (Little, 2002). For example, pollutants might be released from a flooded sewerage works, water supply could be disrupted and roadways blocked. In each case, secondary risks are generated. In some cases these might be more harmful and prolonged than those resulting directly from the flood waters.

Risks also cascade through business supply chains, even global ones, as recent experience from tsunamis impacting Japan and Thailand testifies. Increasingly businesses remote from a flood might rely on products produced by those affected. As a consequence prices rise, as alternative suppliers see demand increase, or in the case where unique suppliers are flooded, entire production runs can be lost.

Understanding how risks cascade (from a primary source to a secondary source or through the supply change) and how such interconnections might escalate the risk in the process, supports a 'whole' system view and is a central requirement in understanding how best to manage it.

CONDUCTING ANALYSES OF APPROPRIATE SOPHISTICATION

The concept of appropriateness (finding the balance between uninformed decision-making and paralysis by analysis) is well established in risk management. This concept is being translated into tiered flood risk assessment methodologies that are appropriately detailed depending upon the circumstances and consequences of any particular decision. For example, determining national policy and priorities demands a different resolution of evidence than is likely to be required for regional policy, subcatchment and community explorations.

TAKING A COMPLETE WHOLE-SYSTEM VIEW

Notwithstanding the concept of appropriateness, a risk approach places a number of additional demands on the analyst in comparison with traditional methods. In particular these include understanding and appropriately representing:

- **Joint extremes** – how likely are multiple sources to occur simultaneously? For example storm surge might occur together with local rainfall (as is associated with a typhoon), and earthquake loading (and liquefaction of foundations) and tsunami wave loading are also linked (as was experienced with the sea defences along the coast of Japan in 2011). Is a particular reservoir more likely to experience an earthquake when full?
- **Spatial coherence of the flood events** – how widespread is a single event likely to be? What is the chance of flooding impacting the whole region or basin (as in the floods in Pakistan in 2010) compared with its being highly localized (as occurs with a thunderstorm-induced mudslide or flash flood)?
- **Temporal coherence of the flood events** – are certain sequences of events more or less critical than larger single events? For example, how important is the temporal sequencing of the source events to, first, the performance of reservoirs, and their ability to deliver water resources and flood protection, and second, the protection afforded by natural defences, such as dunes and wetlands, that might have been denuded of sediment by a recent more moderate storm?
- **Whole system behaviour** – this involves understanding the whole system of risk and interactions between sources, pathways and receptors, and in particular the performance of the intervening infrastructure assets.

USING RISK AND UNCERTAINTY TO INFORM DECISION-MAKING

An understanding of risk enables alternative choices to be compared and actions prioritized. Through the assessment of risk and uncertainty the effort devoted to the analysis and the portfolio of measures adopted can be tailored to be commensurate in scope with the risk that must be faced. The risk assessment therefore presents the decision-maker with an appropriate understanding of the relationship between the actions proposed to be taken and the resultant reductions in risk, benefits gained and opportunities sacrificed.

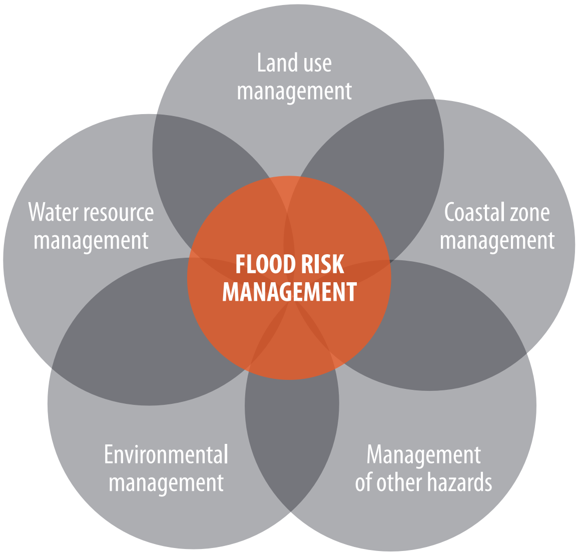
REMEMBERING THAT THERE WILL ALWAYS BE RESIDUAL RISK

Risk cannot be eliminated totally. It is impossible to remove all risks, and it is said that there are only two types of levee, those that have failed and those that will fail. There will always be a future flood event that threatens and overcomes the most robust of defences. State-of-the-art warning systems can fail. Communicating the residual risk is a central component of FRM. Only through knowledge can individuals and organizations take their own measures and make their own choices regarding the acceptability of the residual risk.

2.3 Motivation for flood risk management

The overarching motivation for FRM is to support the broader aim of sustainable development (see Box 4). Flood risk management sits at the intersection of many other management considerations, and as such is in a pivotal position to be a positive force in promoting desired societal, environmental and economy outcomes (Figure 18). When developing FRM plans and judging the success of those plans, achieving sustainability involves much more than simply the ability to maintain the long-term integrity of structures and other measures taken to control floods. It also requires that steps be taken to ensure the long-term health of the associated ecosystems, societies and economies.

Figure 18: Flood risk management sits at the intersection of many other considerations and has a pivotal role in promoting societal well-being, ecosystems and economies

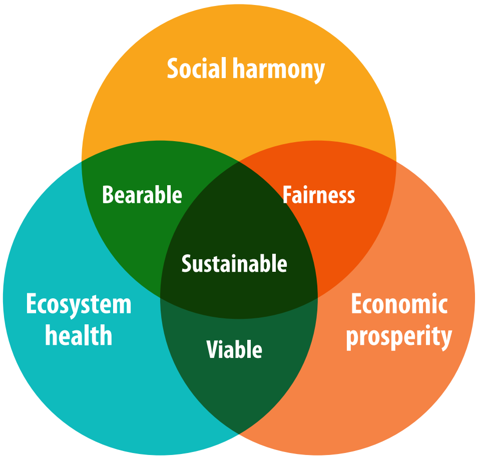


Box 4: Three pillars of sustainable development (the Brundtland Report)

In 1987 the United Nations released the Brundtland Report (WCED, 1987; UN, 1992), which first defined sustainable development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'. This is a simple yet powerful concept. In particular it emphasizes the interlinkages between economic development, environmental health and social well-being – not as three separate objectives but as one. Sustainable policies and practice therefore seek to resolve conflict between various competing goals, and seek to achieve simultaneously economic prosperity, ecosystem well-being and social harmony.

In 1992, the UN Conference on Environment and Development (known as the Earth Summit) held in Rio de Janeiro identified the need and set out a blueprint to achieve sustainable development in practice (Agenda 21). Agenda 21 reinforces the notion of integration, and stresses the need to move away from sector-centred ways of working to new approaches that involve cross-sectoral coordination and integration. Broad public participation in decision-making as a fundamental prerequisite for achieving sustainable development is also emphasized.

These new principles of sustainability have been a key factor in the revolution in flood management thinking, with the recognition that human beings are at the centre of concerns for sustainable development and are entitled to a healthy and productive life in harmony with nature. Flood risk management is therefore inextricably linked with issues of sustainability. Not only does FRM impact the physical environment, through the development of control structures and spatial planning measures, it also provides opportunities for, and constraints upon, human and natural activities in the long term.



Sustainable development demands a balance of economic prosperity, ecosystem health and social harmony

Flood risk management, as opposed to traditional flood defence or flood control paradigms, can therefore be seen as a continuous process that attempts to utilize limited resources of time, social effort, environmental capital and money to deliver multiple benefits (see Figure 19).

In meeting these aspirations the modern flood risk manager no longer relies on engineered flood defences alone, but uses a range of other measures and instruments to deliver the desired outcomes. This paradigm shift, away from engineering design and safety standards to a risk management approach, has a profound influence on the way flood management is considered and implemented. Fully understanding the importance of this change is not straightforward, but is a prerequisite to delivering good FRM in practice.

To help highlight the key differences this change demands, Table 3 presents a comparison of different management approaches and how each influences delivery. In particular, FRM places a much greater emphasis on promoting multiple benefits across a range of criteria (ecological, societal and economic) by using a portfolio of responses chosen to efficiently minimize risk and maximize opportunities. This is in contrast to traditional paradigms which are often characterized by the need to achieve single objectives and rely on a restricted range of management/ engineering actions.

Figure 19: The primary purpose of flood risk management

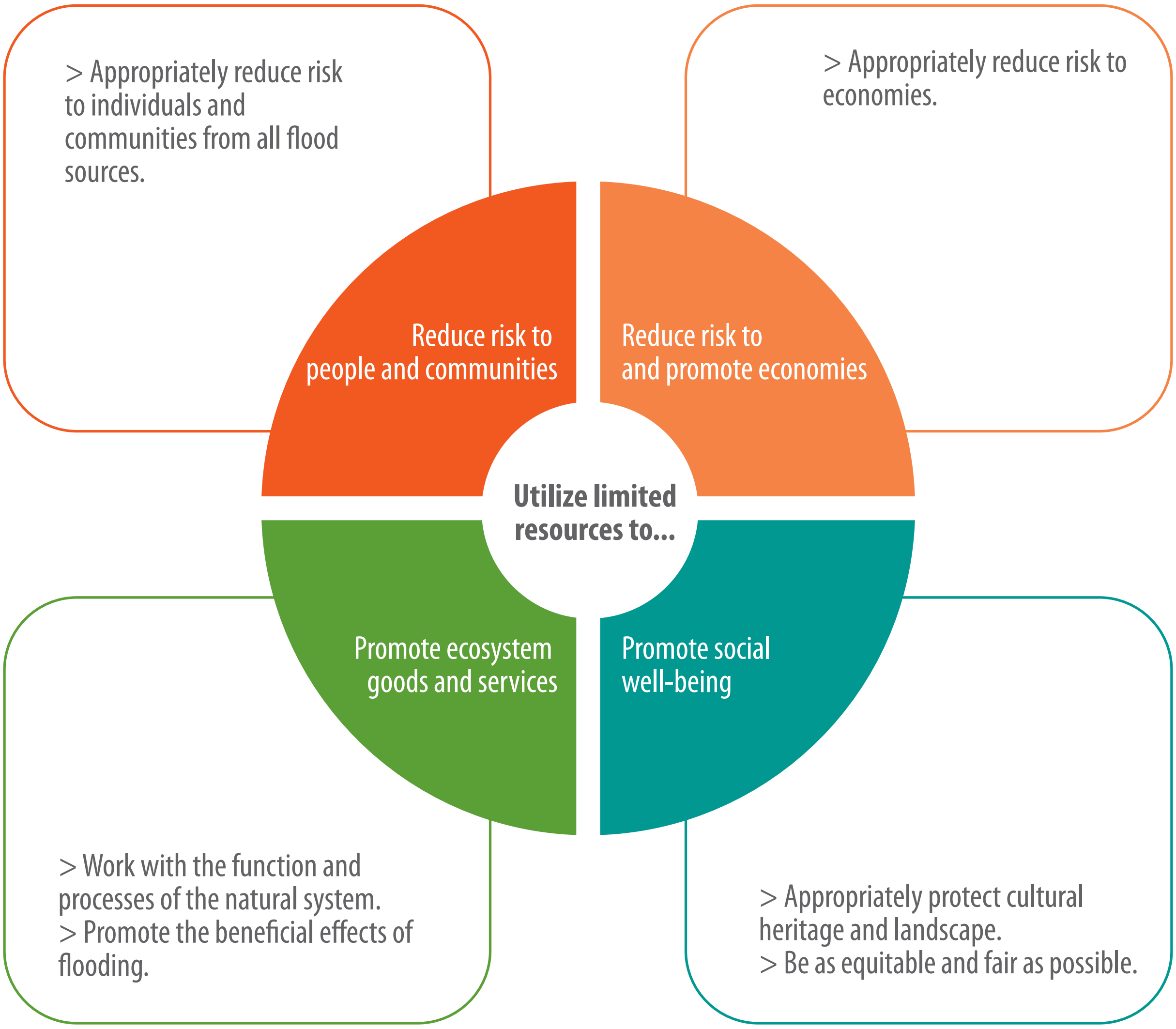


Table 3: A paradigm shift – from flood control to flood risk management

Management paradigm	Basis		Characteristic motivation	Example objective
Engineering design / safety standards (traditional approach)	*Probability*	*Historical event*	To prevent flooding during a repeat of a specified historical event.	Design the flood defences to withstand the 1822 flood
		Single-design events	To prevent flooding during a storm event of a specified return period.	Design the flood defences to withstand a 1:100 year flood
		Multiple-design events	To prevent flooding for a given design storm event set according to the nature of the land use/asset protected.	In highly urbanized areas design the flood defences to withstand a 1:200 year flood. In rural areas design the flood defences to withstand a 1:20 year flood.
	Consequence	*Safety regulation*	To limit the consequences of flooding during the a given design flood event to a specified level (safety standard) regardless of the cost of doing so.	During the probable maximum hydrological flow ensure no individual is exposed to a chance of dying in excess of 10^{-4}. Ensure the chance of >1000 people dying is less than 10^{-7}.
Risk management (modern approach)	*Risk*	*Resource optimal and multicriteria*	To implement a range of interventions that maximize benefits (across multiple criteria) and minimize whole-life resource inputs.	Implement a portfolio of measures and instruments to reduce risk effectively and efficiently while achieving societal preferences for equity, safety and ecosystem health. The increased resource inputs required to provide progressively greater reductions in risk should not be disproportionate to the additional benefits secured.

The reactive approach that is characteristic of an engineering design/safety standards methodology can lead to the need for future unplanned adaptation, as either greater storm events are experienced or other requirements come to the fore. This process of progress – unplanned, and hence often costly, adaptation – is exemplified in the stratification of modifications clearly visible in the flood walls of the Thames Estuary (Figure 20).

Figure 20: A traditional response to floods can lead to progressive unplanned adaptations, as seen here in the Thames a series of flood events lead to the need to raise and re-raise the flood walls

Source: courtesy of Rachael Hill, Environment Agency.

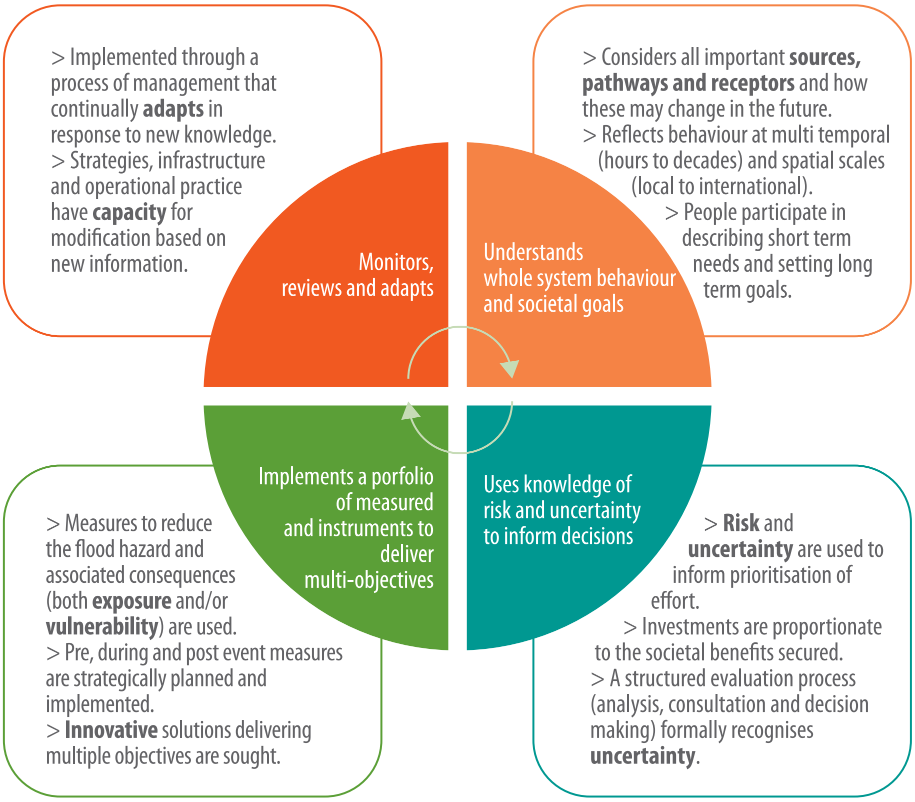
2.4 Characteristics of good flood risk management

Good FRM is characterized by a decision process that:

- is based on an understanding of whole-system behaviour and societal goals
- uses knowledge of risk and uncertainty to inform decisions
- implements a portfolio of measures and instruments
- operates as a continuous process that adapts to the future as it becomes known.

These four primary characteristics are summarized in Figure 21 and discussed below in more detail.

Figure 21: The four characteristics of good flood risk management



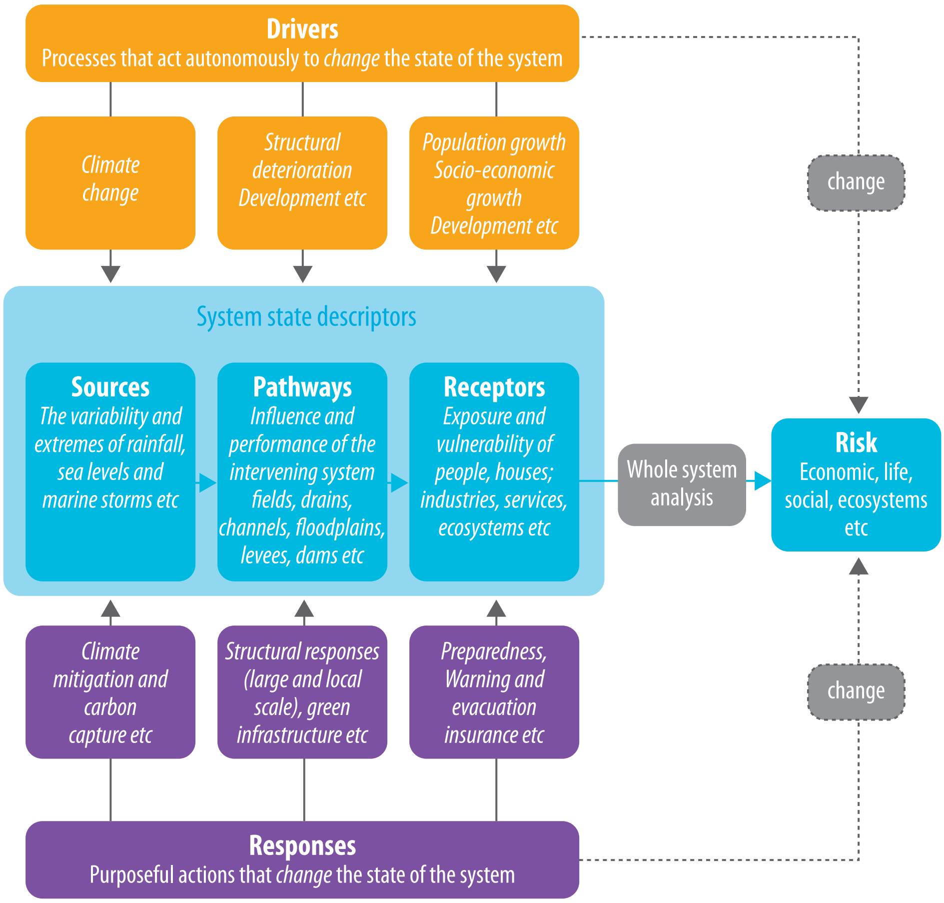
CHARACTERISTIC 1: UNDERSTANDS WHOLE-SYSTEM BEHAVIOUR AND SOCIETAL GOALS

An appropriate understanding of the whole flooding system (that is, river basins, subcatchments, coasts and communities) in a way that accounts appropriately for all of the external drivers of change (such as climate and demographic change) as well as the potential management responses (structural, nonstructural and policy) that might alter present and future flood risk is increasingly recognized as a fundamental building block of good FRM.

Developing such an understanding is not trivial, however, and presents a number of challenges. Attempts to simply upscale traditional modelling tools and techniques have often failed, producing analysis that is too complex and reliant upon detailed datasets that often cannot be provided in practice. In recent years broad-scale models and nested modelling methods have been applied successfully to help understand 'whole system' behaviour (e.g. Hall et al., 2003a; Evans et al., 2004a, 2004b). These successful approaches invariably adopt a structured framework of thinking which explicitly recognizes uncertainty (while making no attempt to reduce it until it is shown to be material in the decisions made). When successfully applied, such approaches are hierarchical in nature (cascading information from bottom up and top down) and use local knowledge where it exists to inform broader-scale and longer-term understanding (Sayers and Meadowcroft, 2005).

The discipline that derives from adopting such a framework forces the systematic consideration of all aspects of the flooding system (including the sources, pathways and receptors of risk) and how they might change (because of both largely autonomous drivers such as climate change and purposeful management responses such as the control of development through spatial planning). This framework of whole-system thinking is shown in Figure 22.

Figure 22: A structured framework of whole-system thinking based on understanding the sources, pathways and receptors of risk



Source: adapted from Evans et al. (2004a, 2004b).

To develop a well-founded whole-system understanding of risk, consideration must be given to:

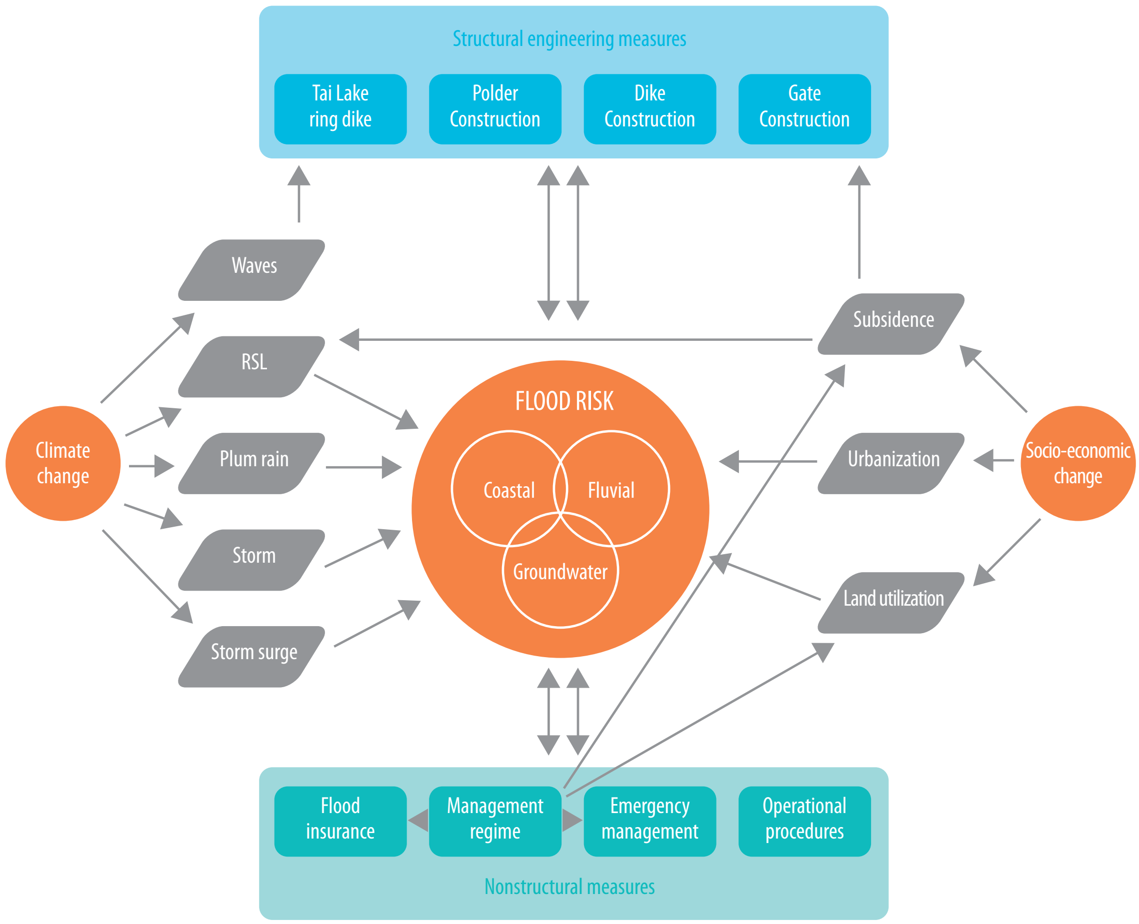
- **The need to consider all important sources, pathways and receptors and their interactions.** Flooding is usually a result of a combination of conditions, for example resulting from an extreme meteorological event, the overtopping or breach of a levee and the consequent flooding of vulnerable people or property. To be credible, and useful, the understanding of risk should be based on a consideration of all sources of risk (including a wide range of storm conditions and return periods), the pathways through which these flow (including the potential for breach, blockage and so on) and the receptors impacted. This comprehensive consideration is in contrast to a more limited view of the kind often taken by traditional flood control approaches, which optimize actions in the context of a single type or magnitude of a flood 'event'.

- **The need to reflect behaviour at multiple temporal and spatial scales.** Flood risk management decisions operate at multiple spatial scales (from high-level policy decisions at a national level through to catchment or regional level, and ultimately single communities). Decisions are also nested in time, ranging from policy and strategy decisions that focus on achieving long-term sustainable outcomes (for example setting management policy for a city or river basin) through to operational choices that influence actions in the short term (for example deciding to open or close a gate during a particular storm). An understanding of these interactions enables the effort devoted to the analysis and the portfolio of measures put in place to be tailored to the risk that is faced.

Box 5: Understanding the whole-system behaviour can change choices – an example from the Taihu basin

An understanding of whole-system behaviour and a comprehensive view of how risks are generated is a critical precursor to good management. The importance of developing an appropriate understanding has been demonstrated many times through projects and real events. Some of these are discussed below.

- **A lack of understanding of all sources of flooding** (Coulthard and Frostick, 2010). The floods in the United Kingdom on 25 June 2007 occurred in the wettest month recorded in the county of Yorkshire since 1882. In the city of Hull, the flooding was largely caused by heavy and prolonged rainfall falling on a catchment that was already saturated (pluvial flooding). Of the watercourses and open land drains in the area, only the Setting Dyke came out of bank. The pluvial nature of the flooding and very low surface gradients led to slow rises in floodwater across the city rather than the rapid inundation associated with point-source flooding such as a breach of flood banks. In many cases, floodwaters rose up beneath houses through the underfloor cavities and foundations. Under these circumstances, sandbags, although widely deployed, were of limited use, and in some areas internal flooding reached a depth of 3 m. The June 2007 floods came from an unexpected source: surface water flooding. This revealed a major weakness in UK flood defence strategy, which had limited capability for forecasting or warning from pluvial flooding. The disaggregated nature of the responsibilities for different kinds of flooding exacerbated the problem, since at the time there was no lead agency for the management of all sources of flooding.
- **A lack of understanding of system connectivity** (Thorne et al., 2012). Spatial interactions exist throughout the river and coastal system. It is well recognized that construction of flood defences upstream may increase water levels downstream. Similarly, structures that intentionally, or unintentionally, trap sediment can have profound implications further afield. Recognizing the need for the management of coastal and river morphology as a valid component of the flood system – not simply the ecosystem – is now starting to become a central theme.
- **Quantitative whole system risk analysis has the power to promote a change in policy** (Evans et al., 2004a, 2004b; Cheng et al., 2013). Whole-system models (which represent all the spatial and temporal interactions) are starting to emerge worldwide. For example, building on the UK Foresight future flooding studies, which were instrumental in the development of a change in government policy towards a more comprehensive long-term risk approach, an analysis was made of the Taihu basin (located in the delta region of the Yangtze River in eastern China, with a population of 36.8 million and a GDP of 1,890 billion yuan (approx. US$290 billion) in 2003). The Taihu basin Foresight project involved a complete 'end-to-end' flood risk analysis, from the generation of climate and socio-economic scenarios, through hydrological, hydraulic and damage modelling, to a final geographic information systems (GIS) system, the Taihu Basin Risk Assessment System (TBRAS). TBRAS enabled all sources of the flood hazard to be simulated and a comprehensive view of the flood risk to be established as a precursor to aiding the development of resilient long-term management policies.



Conceptual model of the interaction between climatic and socio-economic factors driving future flood risk in the Taihu basin

CHARACTERISTIC 2: USES KNOWLEDGE OF RISK AND UNCERTAINTY TO INFORM DECISIONS

Good FRM relies on credible and transparent evidence. This includes evidence on:

- **Risk:**
  - What are the risks?
  - Where are the areas of greatest risk?
  - What drives the risk at these locations?
- **Uncertainty:**
  - What confidence can be placed in the estimates of risk, now and in the future?
  - How sensitive is the performance of the proposed strategy to this uncertainty?
- **Outcomes expected or achieved:**
  - What risk reduction has been achieved?
  - What opportunities have been realized?
  - Is the investment of resources effectively, efficiently and fairly used?

The way in which this need for evidence characterizes decision-making for FRM is discussed in more detail below:

- **Risk informed.** Flood risk management is by definition informed by risk. It considers the probability of a full range of flood events occurring and the consequences of those events. It provides a powerful and rich understanding of the system behaviour and has many subtle dimensions (see Box 5). Perhaps most importantly however, risk provides a rational basis for developing and comparing alternative management strategies.

- **Uncertainty informed.** Managing flood risk is characterized by the need to deal continuously with uncertainty. The timing and severity of a storm, the associated performance of structures and the reaction of individuals and communities to flood events cannot be known with certainty. A risk approach enables this uncertainty to be recognized explicitly in the decision process. In turn this supports making choices that are robust to that uncertainty. For example, an often held misconception is that it is necessary to remove uncertainties from data or models, to gather ever better data and apply increasingly sophisticated models to manage flood risk successfully. This is not the case. Uncertainty is only important when it influences the choice to be made; if it does not, any additional expenditure on data or analysis is wasted. Some uncertainties do however have a profound influence on decisions. The importance of a given uncertainty (for example on the location of vulnerable people or ecosystems because of gross uncertainties in future climate or demographics) can only be assessed in the context of a specific decision. Flood risk management provides a framework within which uncertainty can be identified explicitly and managed (for example promoting strategies that are robust to future change, performing well in all plausible futures, and capable of adapting to new information as it becomes known). When they recognize uncertainty explicitly, flood risk managers are offered a choice on how to best to respond to it.

- **Outcomes focused.** The advantage of a risk approach, and perhaps what above all distinguishes it from other approaches to design or decision-making, is that it deals with outcomes: the risk reduction achieved and opportunities gained. This enables the benefits and costs of structural and nonstructural intervention options to be compared on the basis of their impact on risk (taking into account both changes to the frequency of flooding and the associated consequences) over the short and long term.

The provision of transparent and comprehensive evidence is of course only the first step, and ultimately people make decisions. An open and participatory process is therefore critical to delivering the successful outcomes (Aarhus Convention: UNECE, 1998). The evidence provided by a risk approach offers a step change in the effectiveness of the engagement process and the dialogue with communities in developing, funding and delivering risk management.

CHARACTERISTIC 3: IMPLEMENTS A PORTFOLIO OF MEASURES AND INSTRUMENTS

Flood risk management is an ambitious approach that builds broad stakeholder commitment to a strategy containing a portfolio of responses (including the use of technological, engineering, institutional or social measures, and instruments such as policy incentives, new institutional setups and new technologies). A diverse portfolio can only be developed through inclusive participatory and multidisciplinary processes, expanding beyond the traditional physical sciences and engineering disciplines that have often been the sole contributors to flood control.

Through the use of a portfolio of interventions a number of desirable traits are promoted:

- **Efficiency and effectiveness** – where the advantages of one option compensate for the disadvantages of another to minimize risk and maximize opportunities, or where the measures are synergistic such that the sum effect is greater than the individual parts.

- **Reversibility and flexibility** – the use of many measures, as opposed to a single major intervention, often promotes greater flexibility, with individual measures more easily modified and adapted, or indeed removed.

- **Adaptability** – promoting measures that can be modified in response to future change, with planned adaptation becoming the norm (replacing the reactive, and occasionally maladapted, response to an extreme flood that has occurred throughout the history of flood control approaches).

- **Robustness** – identifying combinations of measures that are likely to offer acceptable performance regardless of the reality of the future.

Good FRM therefore seeks to implement multiple interventions (Table 4).

Table 4: Summary of measures and instruments that form the basis of a portfolio based flood risk management strategy

Categories of action to management risk	Example options
Reduce the **chance** of flooding	Influencing the **source of floodwaters:** Through, for example, storage at or close to source (inland water bodies and lagoons, reservoirs, groundwater recharge, bogs, marshes, fens, sustainable urban drainage systems – SuDS). Land management: forestry/ floodplain woodland, ponds and wetlands, field scrape/infiltration trenches, soil management, riparian buffer strips etc. Influencing the **pathway of floodwaters:** Through, for example, morphological, debris and vegetation management, wetland and washland creation as well as permanent and temporary structural defences, pumps and barriers.
Reduce the potential **consequences** should flooding occur	Influencing the **exposure of receptors:** Through, for example, development control and flood-aware land use planning; evacuation planning including use of safe refuges and clear evacuation routes. Influencing the **vulnerability of receptors:** Through, for example, raising awareness and preparedness of people and business, providing post-event recovery systems (insurance and state help).
Mitigate climate and demographic change	Influencing **future climate change:** Through, as a minimum, use of low-carbon-use solutions. More ambitious flood risk managers will look for solutions that sequestrate carbon through for example use of existing wetlands and restoration of damaged wetlands to promote natural carbon capture and storage. Influencing **demographic change:** Positively influencing population growth, integrating flood management with food and water resource security.

In developing such portfolios, the flood risk manager is guided by the need to provide:

- **Innovative solutions delivering multiple objectives.** While delivering multiple objectives in practice does not come without challenges, it also offers opportunities. For example, river restoration projects, such as those for the Danube River in Europe and the Florida Everglades in the United States, not only improve endangered ecosystems, they also make a significant contribution to FRM efforts (providing concurrent flood damage reduction and environmental benefits). Progressive planning policies, which seek to avoid inappropriate development within the floodplain, can have a significant influence on a community's exposure to risk.

- **Assessment and selection against a range of criteria.** Extending beyond simply economic efficiency through to indicators of social fairness and ecosystems enhancement, as well as indicators that reflect the robustness and resilience of the strategy as a whole, underlies the move towards modern FRM and a wider appreciation of the desired outcomes.

Box 6: Progress in implementing a portfolio response

The World Meteorological Organization (WMO) and the Global Water Partnership (GWP) issued an *Overview Situation Paper on Flood Management Practices*. The paper examined the results of eighteen case studies of flood management carried out on rivers in Asia, Europe, North America, Africa, South America and a Pacific island, which sought to determine whether flood mitigation efforts in these areas were being carried out under the concept of integrated flood management (IFM). IFM was defined as an approach that integrates land and water resources development in a river basin, in the context of IWRM. IFM includes within it FRM.

The report noted that the flood management approaches observed in the case studies 'show that there is ability in the countries to apply flood management measures that reduce the flood risk by avoiding increase in flood hazard, avoiding exposure and decreasing vulnerability or increasing resilience in the society against floods'. The extent of these measures depends on the economic development in the country, and the level of investment in capital and human resources. The report also notes that 'moving away from concepts such as "flood control" or "taming the river" form[s] a welcome departure point for IFM'. In 2006, the European Network of Environmental Authorities (ENEA, 2006) reported that 'a holistic catchment management strategy is the only sustainable way of reducing the risk of flooding'.

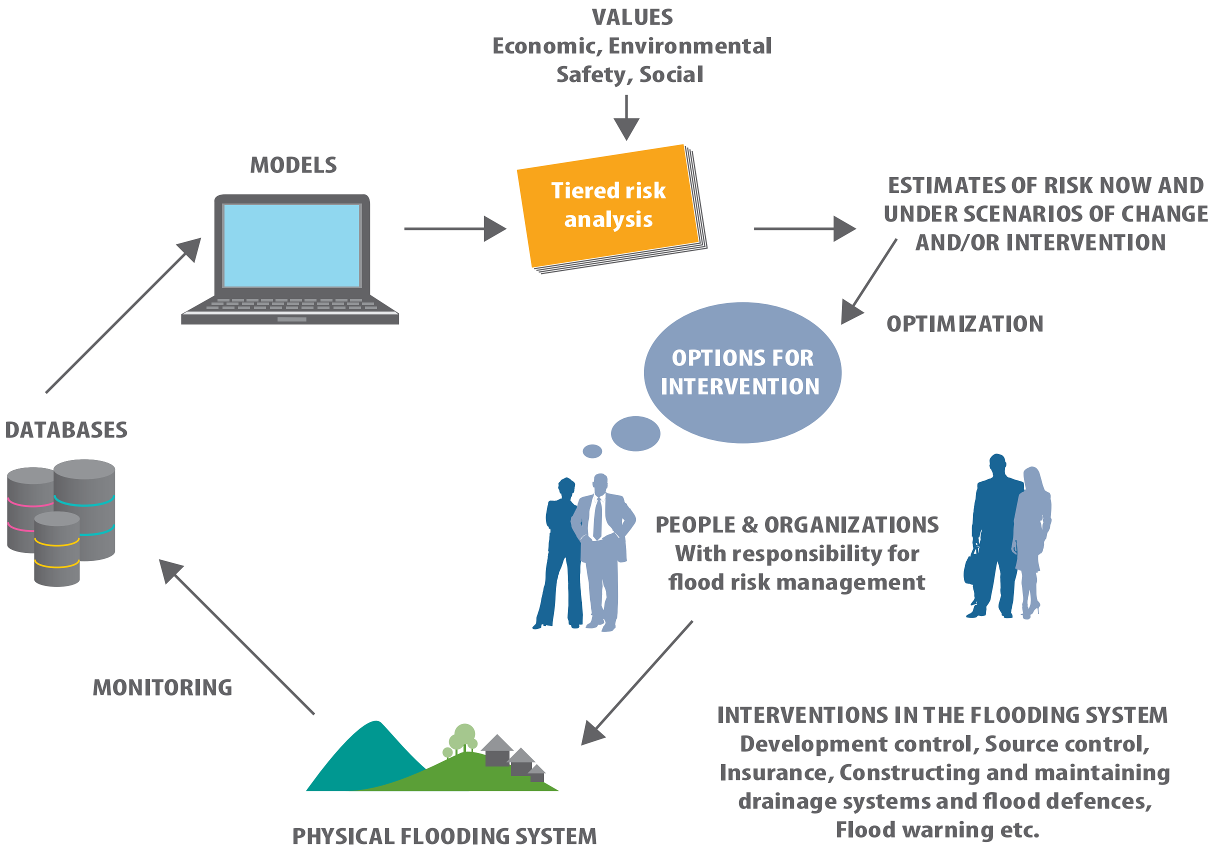
Source: WMO (2005).

CHARACTERISTIC 4: MONITORS, REVIEWS AND ADAPTS

Changing climates, changing socio-economic contexts and deterioration in structural defences all present the decision-maker with complex policy choices. Every time a decision is taken on a major project (such as roads, rail, hospitals, schools, new housing, flood defence and water resources infrastructure), the capacity for society to respond to future change in the medium to longer term is altered. Poor decisions can 'lock in' maladaptation that would poorly serve a changed future society, and are very expensive to reverse. Recognizing the need to monitor, review and adapt is therefore a fundamental part of the FRM process. Such a philosophy is in stark contrast to the assumed single future and 'construct and maintain' approach inherent in a traditional flood control paradigm.

The uncertainties of future change present the flood risk manager with rational doubts over what courses to pursue. The gross uncertainties associated with climate and demographic change, for example, cannot be reduced through improved data or models. Instead FRM takes a different approach, based on a longer-term, more strategic planning process. Such an approach embeds the concept of building in the capacity to adapt. This is done in the expectation that the future will be different from the present, and policies and actions will need to be changed as new knowledge becomes available. Modern FRM therefore takes place as a continuous process of acting, monitoring, reviewing and adapting (Figure 23).

Figure 23: Flood risk management is continuous process of acting, monitoring, reviewing and adapting



Source: Hall et al. (2003b).

Delivering adaptive FRM in practice is not straightforward. Good adaptive FRM recognizes that:

- **History teaches us less and less.** There is no certainty about what the future holds, and increasingly a historical analogy provides limited guidance (in terms of climate forcing but also more broadly societal expectations and preferences).
- **Multiple futures are plausible.** To compare the performance of alternative FRM strategies, all plausible futures must be considered. Judgements made about the most likely future can precondition the answer in an undesirable and suboptimal manner. Conversely, overcomplication must be avoided, including unnecessary detail. Lack of imagination in describing possible future changes can condition actions based on current knowledge and experience.
- **A long-term view must be promoted and short-termism avoided.** The planning and implementation of flood risk strategies is often biased towards 'quick wins'. More progressive strategies that embed longer-term progressive management offer significantly greater opportunity to challenge the status quo and promote radical and adaptive solutions, but these are often more difficult to develop and implement.
- **Ownership of the strategy needs to be shared.** Long-term strategies demand action by many stakeholders over extended periods. Buy-in to such decisions can be difficult to achieve, and requires continual reinforcement and review. Often the ability to implement strategic management is

undermined by independent actions. Significant flood events, or indeed the lack of flooding, can dramatically alter the perception of the risk that floods pose. Collective memory is often short-lived and priorities can change rapidly. Implementing a long-term plan requires long-term commitment and continuity to be successful, a goal that it is often difficult to secure in practice.

- **Radical solutions that challenge the status quo must be sought.** Flood risk managers need to be brave enough to propose new or radical solutions. These include land banking, synergetic solutions (such as energy generation and flood storage, habitat creation and the management of flood flows), and innovative large-scale spatial planning (use of urban blue highways, building codes and so on).

- **Sunk investment must be fully utilized where possible.** Few places offer a blank canvas, and much of the developed world, and developing world, has significant sums already invested in ageing flood control structures (dams, levees, pumps and so on). Utilizing and adapting this existing infrastructure presents a difficult challenge.

- **Risk perception and value continue to vary.** The past decades have seen an ever-changing societal view on what is and is not important. These judgements will continue to change into the future, and flood managers must recognize the potential for such changes and be ready to deal with them.

- **Multiple opportunities and constraints exist.** Increasingly flood management does not take place in isolation from other sustainable development goals. Achieving and understanding multiple (and changing) objectives presents many challenges; objectives often conflict both in the short term and perhaps more fundamentally in terms of setting the long-term 'direction of travel'.

2.5 The golden rules of flood risk management

Nine golden rules can be identified as the cornerstone of good FRM practice. These nine golden rules are summarized in Figure 24 and discussed below.

Figure 24: The golden rules of good flood risk management

1 Accept that absolute protection is not possible and plan for exceedence

2 Promote some flooding as desirable

3 Base decisions on an understanding of risk and uncertainty

4 Recognise that the future will be different from the past

5 Do not rely on a single measure, but implement a portfolio of responses

6 Utilise limited resources efficiently and fairly to reduce risk

7 Be clear on responsibilities for governance and action

8 Communicate risk and uncertainty effectively and widely

9 Reflect local context and integrate with other planning processes

1. **Accept that absolute protection is not possible and plan for exceedence.** Engineering design standards, however high they are set, will be exceeded. Engineered structures may also fail (breach, fail to close and so on). Nonstructural measures such as early warning systems or evacuation plans taken to mitigate flood consequences are also susceptible to failure. Through an acceptance that some degree of failure is almost inevitable, a focus is placed on building resilience into all aspects of the planning process (urban development planning, flood control structures, warning systems, building codes and so on).
2. **Promote some flooding as desirable.** Floods and floodplains provide for fertile agricultural land and promote a variety of ecosystem services. Making room for the river and the sea, utilizing the natural ability of this space to accommodate flood waters and dissipate energy, maintains vital ecosystems and reduces the chance of flooding elsewhere.
3. **Base decisions on an understanding of risk and uncertainty.** An explicit trade-off between the risks reduced, opportunities promoted and the resources required to achieve these outcomes is central to FRM. This does not mean however that the information will be perfect, and the uncertainty within the data and models must be equally acknowledged and choices made that are robust to that uncertainty.
4. **Recognise that the future will be different from the past.** Climate and societal change as well as changes in the condition of structures can all profoundly influence flood risk. Accepting FRM as an ongoing process of iteration (taking account of better information as it becomes known) and adaptation (responding to the reality of the future as it unfolds) helps minimize regret.

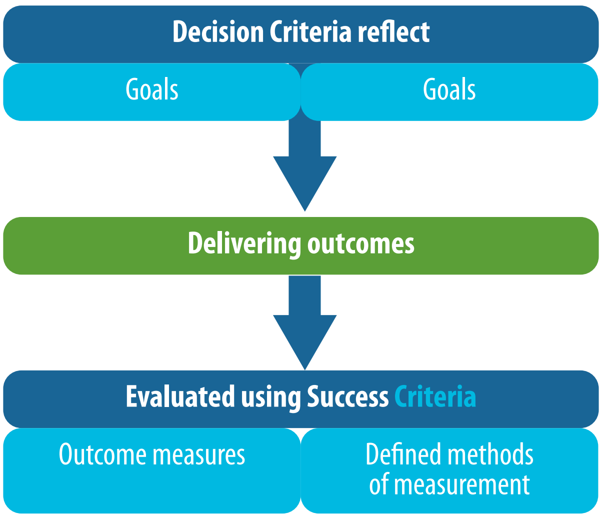
5. **Implement a portfolio of responses, and do not rely on a single measure.** Integrated management of flood risk involves consideration of the widest possible set of management actions. This includes measures to reduce the probability and measures to reduce consequences (exposure and vulnerability).
6. **Utilise limited resources efficiently and fairly to reduce risk.** The level of effort used to manage floods and their consequences must be related to the nature of risks, and not based on universal or generalized engineering standards of protection. Management strategies are developed following consideration of the efficiency of mitigation measures, in terms of not only the risk reduction achieved and resources required, but also their fairness and ability to maximize ecosystem opportunities.
7. **Be clear on responsibilities for governance and action.** Governments, businesses and other organizations (including the affected communities and individuals) must be active participants. Sharing of both responsibility for, and fiscal support of, FRM within a clear framework of collaboration amongst government and nongovernmental organizations and individuals helps to ensure active participation across all stakeholders.
8. **Communicate risk and uncertainty effectively and widely.** Decision-makers and the public alike must understand the risks that they face; frequently they do not. Effective communication of risk enables both communities and individuals to appropriately prepare and support mitigation measures where necessary. Communicating the risk after a catastrophe is too late.
9. **Reflect local context and integrate with other planning processes.** The preferred strategy for a given location will reflect the specific risks faced (and not arbitrary levels of protection that should be achieved).

CHAPTER 3
GOALS, OBJECTIVES AND OUTCOMES

3.1 Introduction

The development of policies, strategies and plans is tied closely to clear identification of the desired outcomes from the FRM process. The definition of associated outcome measures, together with a means of measurement, enables the success, or otherwise, of the FRM efforts to be judged (Figure 25).

Figure 25: Relating goals and objectives to outcomes on the ground and evaluating the success of flood risk management efforts through outcome measures



The desired outcome goals and objectives, and their specificity, will differ by level of governance. The closer to an on-the-ground action, the more specific the outcome measure. The approaches and challenges surrounding the development of the goals, objectives and outcome measures in the context of FRM are discussed in the following sections.

3.2 Goals and objectives

The general purpose of FRM is to support the broader aim of sustainable development (see Chapter 2). This is much more than simply the ability to maintain the long-term integrity of structures and other measures taken to control floods, but also requires ensuring the long-term health of the associated ecosystems, societies and economics. The manner in which these higher-level goals are translated into specific objectives shapes the nature of the FRM delivered. Some of the most important considerations in this process of translating goals to objectives in a way that reflect the characteristics of a FRM paradigm are discussed below.

DELIVERING EFFICIENCY AND FAIRNESS – DISTRIBUTING LIMITED RESOURCES IN A SOCIALLY JUST MANNER

Flooding is not fair in itself, because of the inherent natural spatial inequality in the frequency and extent of flooding, plus the legacy of differential interventions. Every intervention in FRM tends to prioritize one group over another, creating further inequality and 'unfairness'.

Philosophers have analysed fairness and 'social justice' for centuries. Three social justice models – procedural equality, Rawls's maximin rule (Rawls, 1971) and maximum utility –

are the most relevant to FRM and embody the principles currently employed in FRM decision-making today (Table 5). In this regard it is important to separate procedural equity ('is everyone treated the same?') from outcome equity ('does everyone face the same (residual) risk?'). The former is at least possible and may be realistic. At a national or regional scale the latter is naïve and unattainable. At a very local scale it may be possible but it is generally still difficult to attain.

In seeking to provide a fair approach, FRM decision-makers aim to address all three of the justice principles: that is, to maximize utility while ensuring that investment is distributed through an equitable process and that the most vulnerable members of society are protected. This requirement raises a number of practical problems. To manage flood risk more fairly in the future, a move in the direction of government funding of nationally consistent nonstructural strategies that are available to all (for example better forecasting, improved building codes and grant\compensation schemes) offers a greater contribution to equality and vulnerability-based social justice principles than the status quo. Simply putting most effort into protecting parts of the population (by flood defence means) is demonstrably unfair, although it may be effective and efficient.

Table 5: Social justice ('fairness' and 'equity') and flood risk management

Justice principle (type)	Rule/criteria	Meaning for FRM	Potential implications for FRM
Equality (procedural)	All citizens to be treated equally	Every citizen should have the equal opportunity to have their flood risk managed	A greater focus on vulnerability reduction and state-sponsored self-help adaptations that can be provided for all – avoiding the inherent unfairness in providing structural solutions that benefit the few
Maximin rule (distributive)	Options chosen to be those that favour the worst-off best	Resources should be targeted to the most vulnerable	Need to identify, and target assistance at, the most vulnerable members of society, even when greater economy returns can be found elsewhere
Maximize utility (distributive)	Options chosen to be those that secure the greatest risk reduction per unit of resource input	Assistance provided to those members of society to which the benefits offer the greatest gain to society	Need to identify a set of measures that deliver the greatest risk reduction for minimum resource. This is likely to be associated with a broad range of measures. The greatest risk reduction, for the most vulnerable, is most likely to be provided in the form of nonstructural responses, for example state-assisted self-help homeowner adaptations and improved preparedness, with more capital-intensive structural solutions provided to areas of high economic activity.

Box 7: Efficiency and fairness in traditional engineering standards and FRM approaches

In a traditional engineering/safety-standards-based approach, the decision-making procedure is simple and follows along the lines of (adapted from Hall and Penning-Rowsell, 2010):

1. Establish the appropriate design standard (such as the '100-year return period' river level) based either on the land use of the area protected, reasons of uniformity or tradition.
2. Estimate the design load, such as the water level or wave height with the specified return period.
3. Design structures to withstand that load (features such as crest level and structural strength).
4. Incorporate safety factors, such as freeboard allowances, to account for local uncertainties using local guides.
5 Incorporate warning systems – based on forecast river water levels, or sea waves/surge, and establish appropriate trigger levels and associated actions.

Such an approach has a number of shortcomings in terms of efficiency and fairness, and leads to:

- unfairness, protecting some and not others
- inefficiency of spend at a given location, by providing design standards above the minimum for economic efficiency in some areas and below in others
- inefficiency of spend across a region or nation, as the additional benefits accrued through the provision of a design standard above the minimum at one location are usually less than if the additional money had been spent elsewhere (this typically occurs because the costs of reducing risk tend to increase much more quickly than the damages decrease).

A modern risk management decision process proceeds as an iterative process, along the lines of:

1. Identify all possible sources and pathways of flooding and a range of potential strategies (strategic alternatives – including a portfolio of structural and nonstructural responses) and possible future scenarios (reflecting plausible changes in climate, demographics, funding and so on).
2. Evaluate the performance of each strategic alternative against multiple criteria representing societal preferences for economic efficiency, ecosystem benefits and social equality.
3. Consider investing proportionately greater resources to protect the vulnerable and deliver ecosystem benefits.
4. Identify a preferred strategy – then continue to monitor and adapt the strategy as the reality of the future becomes known.

The approach has a number of advantages in promoting robust, resilient and flexible strategies, but raises the questions of what level of residual risk is acceptable at any given location, and how much additional investment should be provided above a minimum level for maximum efficiency. Determining how best to allocate finite resources is an issue for debate in many countries as they transition from engineering standards to risk approaches. There is no single answer, but this question must be addressed clearly in the funders' policy framework.

IDENTIFYING THE WINNERS AND LOSERS OF FRM

Different FRM choices will differ in terms of:

- who is affected
- what is affected
- how they are affected
- when this effect occurs.

Some will win (in terms of increased opportunity or decreased risk) and others will lose (in terms of restructured opportunity or increased risk). For example, improved protection might be able to be provided to one area at a higher or lower level from that provided to neighbouring areas, or the actions in one location might increase the chance of flooding elsewhere in the region. In the development of plans for the restoration and protection of coastal Louisiana, USA, the state government determined that it would be unable to provide the same level of structural protection to all areas because of the physical and geographic realities, and promised instead to provide for those with less protection an increased level of nonstructural measures. In other cases, efforts to reduce risk in a downstream area might require the areas upstream to take actions that were considered detrimental to their long-term development, such as limitations on development in the floodplain and potential flood storage areas.

An ability to understand who wins and who loses from any change in strategy is therefore a crucial step in assessing the preferred approach.

DEVELOPING STRATEGIES AND ACTIONS THAT ARE APPROPRIATE TO THE SETTING

There remains considerable variation in the capacity of different countries to implement FRM. Although the principles remain the same, the specific tools and management options will vary from place to place. For example, the nature of the flood threat (coastal, flash, lowland or pluvial flooding) will influence the alternatives available. In some locations major infrastructure might be an appropriate response, while in others empowering specific groups to take local action might be more appropriate. For example, in some countries (Thailand, Viet Nam and elsewhere) women play a distinctive role in flood risk assessment and flood preparedness. Tailoring FRM to the specific local context is therefore central to its success.

ACHIEVING MULTIPLE BENEFITS BY COMBINING SEVERAL CRITERIA

Benefits are usually defined as the flood losses avoided and the opportunities gained in the future as a result of implementing specific actions. The definition of losses and opportunities should include a full range of economic, ecosystem and social impacts and a transparent means of assessing them in combination. Typically, three distinct approaches exist for combining such diverse criteria.

Leave risks in their native units and undertake a subsequent process of weighting

In this approach risks are expressed in terms that most directly describe them. For example, a risk of ten people dying per year would be expressed as an Expected Annual Loss of Life = ten people. A risk of habitat lost would be expressed as an Expected Annual Loss of Habitat = 1000 ha, and the Expected Loss of Ancient Monuments over 100 years from the Forbidden City = 0.6 (Forbidden City monuments). The decision-maker is then faced with the task of evaluating the importance of different risks that have been evaluated using different units of measurement (so-called risk metrics).

Adopting such an approach has a number of implications for the decision process. The multiple criteria can be combined through a subsequent process of weighting, either taking a lead from nationally provided preferences or through local discussion, or they could be left separate, and risks associated with one strategy could be compared with those of another (using for example pairwise comparisons or another of the many techniques available: see for example DETR, 2000). The advantage of these approaches is that they present risk in terms that are intuitive to the decision-makers, thereby supporting judgement-based trade-offs and modification of the preference weighting as the reality of the risks faced, and the resources available for their management, become known. They also enable the 'worst' and 'best' strategies to be identified quickly at a general level, without the need to aggregate information across different attributes. The disadvantages of such approaches are the potential introduction of local bias (towards the concerns of the most vocal stakeholders and/or experts) and difficulties in comparing marginal changes in benefits (is saving one more life annually equal to protecting ten more hectares?). The prioritization of national (centralized) resources can also become difficult in the absence of national consistency in the evaluation process, as the comparison of the combined risks at different locations becomes very difficult (although comparison of risks expressed in common native terms remains straightforward).

Use of a common currency of risk and a pre-process of conversion

An alternative to maintaining measurement of risks in their native parameters is to construct a common currency of risk. Typically this methodology aims to convert all risks to a monetized base or other predefined common unit of measurement. This can be done nationally, away from the emotion or bias of a specific project, which helps to ensure that national policies and preferences are reflected in the assessment. Typically a monetized value should not simply reflect financial loss, or loss in economic development potential, but be based on welfare economics and provide an expression of the perceived value to the nation and society as a whole.

Adopting a common currency approach in the decision process has many attractions. For example, once established it is straightforward to rank risks to confirm their relative importance. There are however significant challenges in adopting such an approach. Establishing a consensus over the societal value of a range of risks presents many problems, in particular when it comes to valuing intangible losses (associated with damage to habitats, loss of life, emotional stress and so on).

The actual investments used to reduce risk are however always finite, indicating that there is an implicit value assigned to all losses that is also finite. As a result, various countries have made attempts to monetize various risks (for example, in the United Kingdom the government places a value on a single human life of £1.45 million, at the base date 2000) or develop common pseudo currencies (for example the 'house equivalents' proposed in Chatterton, 1998) that provide 'risk-based' averages of damage. Such attempts have had limited take-up in FRM, as few national valuations provide a satisfactory representation of the risk faced at a local level (reflecting the uniqueness that exists in each habitat and community). This is perhaps the underlying reason why no country (known to the authors) currently uses a fully monetized approach. The monetized valuation of risks using local analysis has been done with some success using both behavioural valuation methods (using either stated or revealed preferences) and nonbehavioural valuation methods (Jongejan et al., 2005), and this is typically applied to elicit the value of protecting habitats or enhancing amenity. However in many countries such valuations are yet to be given weight in the decision process.

It is important in an approach where benefit–cost ratio (BCR) analysis is a central theme to avoid bias in the analysis. For example the use of property risk-free market values can introduce a systematic bias towards 'wealth' areas, because the rating for protecting ten $50,000 properties that provide homes for forty people might suggest that less benefit is achieved than from protecting a $11 million property that is home to two people. In assessing flood risk, a focus on the national value of the assets lost (material goods) rather than risk-free market values often provides a more equitable assessment of the value of damage per person flooded.

In a monetized approach to damage assessment, equity is further promoted by adopting a welfare economic basis to valuation (as adopted in England and Wales) rather than a more narrow approach based on economic development (as has historically been used in the United States).

A hybrid approach

The emerging consensus is that those impacts that can appropriately be converted to monetary values should be converted to them. In this case, reference monetary valuations for a range of criteria (based on a combination of political and statistical analysis) are centrally provided where appropriate. A local valuation can be used to replace those centrally determined, but care must be taken not to bias the assessment. A fully monetized system is not without its difficulties. It could be argued that various impacts (for example loss of life) are better maintained in their native parameters. The monetized and nonmonetized values can then be combined through a subsequent process of multicriteria evaluation as outlined above.

Whichever of the above approaches is chosen, the decision-maker must have a means of comparing the assessment of the risk with the resources needed to reduce it. Without an ability to do this, there is no firm basis on which to make decisions about the use of resources to reduce risks. For example, one strategy might enable protection of biodiversity but at a higher risk to humans than another strategy that does not enable it as successfully. It is only through explicit and transparent treatment of multiple criteria (either evaluating them using a common currency, or by working in their native parameters) that the decision process can be considered risk-based.

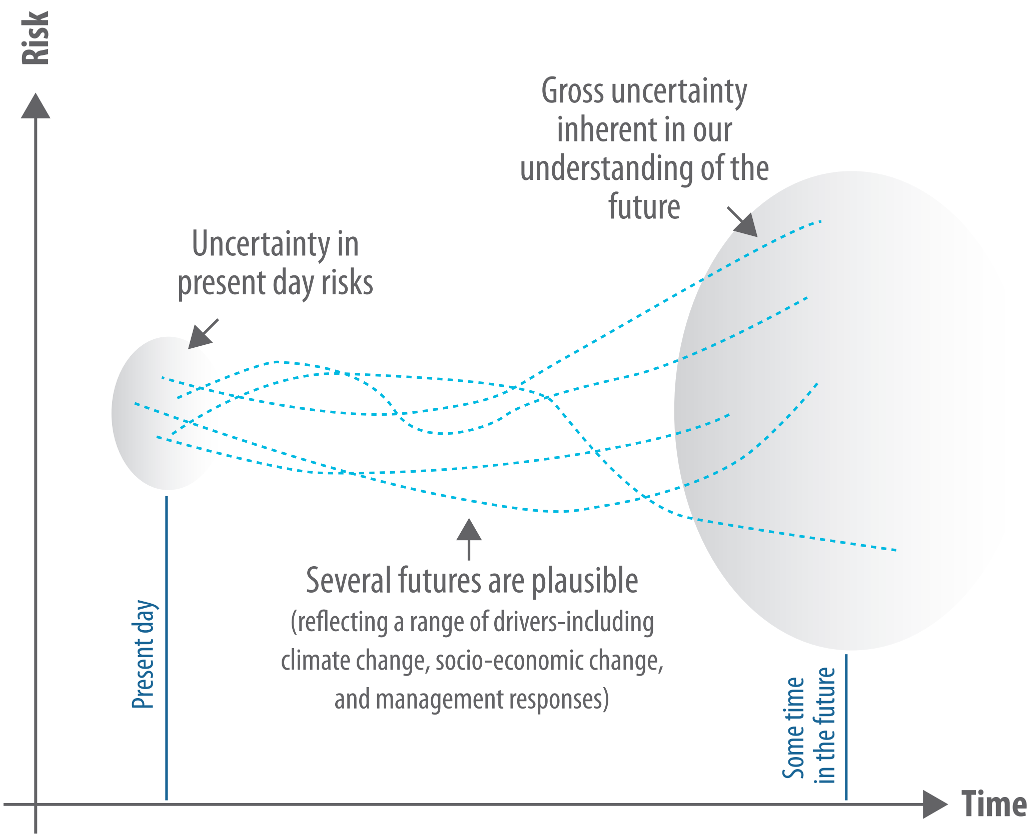
SETTING GOALS IN AN UNCERTAIN WORLD – BUILDING RESILIENCE AND ADAPTIVE CAPACITY

> By 'uncertain' knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty …. Even the weather is only moderately uncertain. The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention …. About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know. Nevertheless, the necessity for action and for decision compels us as practical men to do our best.
>
> John Maynard Keynes (1937)

It has been, and always will be, necessary to make decisions in the absence of perfect information. In the past, uncertainty was implicitly accounted for in FRM decisions through safety factors and allowances rather than explicit analysis of uncertainties. Recognizing uncertainty does not prevent decisions from being made. In fact, recognizing uncertainty is a key requirement for appropriately designing adaptive capacity and resilience into FRM choices. Only by quantifying and acknowledging uncertainty are we best placed to decide how best to manage it.

Perhaps the largest of these uncertainties is that associated with future conditions (Figure 26). Climate and demographic change can have a profound influence on FRM and the infrastructure design choices made. Making the right choices under this severe uncertainty is a significant challenge. Infrastructure choices made today will persist for several decades if not centuries, so taking a longer-term strategic view when planning infrastructure investment is critical to making the right choice. This chapter explores various methods and approaches that have been applied in practice, as well as those emerging from research, to support good decision-making under uncertainty, including scenario development, robust decision-making and adaptive management (based on multi-stage interventions) and in particular how adaptive capacity can be appropriately embedded within infrastructure design and management using real option approaches.

Figure 26: Uncertainty increases with time as we simply do not know what the future holds, for aspects including demographics, societal preferences and levee condition change



Both developed and developing countries are seeking to promote communities that are resilient (in respects that we will go on to explain) in the face of natural hazards, and capable of adapting to unknown future changes. Both are struggling to turn good theory into practical action. In building resilient communities and implementing adaptive management it is clear that engineered structural measures will continue to play a significant role. However, they will increasingly be working alongside a wide range of nonstructural measures and instruments (Evans, et al., 2004; Sayers et al., 2012a, Hall et al., 2003b). As yet no blueprint is available for resilient design or adaptive management. A common understanding is however starting to emerge. It acknowledges resilient and adaptive design as a process that, as part of a wider portfolio of responses, fosters innovative approaches to the design, construction and operation of buildings and infrastructures (US NIBS, 2010; Bosher et al., 2007).

Emerging principles of resilient design

- A resilient design is resistant to a wide range of threats, including ones that were not necessarily foreseen during the design process.
- Performance does not decay catastrophically when exposed to events more severe than the design level. For example a levee will be overtopped but should not collapse or breach without warning; critical infrastructure such as pumping stations, bridges and gates must continue to operate.
- Recovers rapidly from a disruptive event (supporting the rapid return to normality – avoiding the need for complex plant, highly specialized skills or difficult to source materials).

Emerging principles of adaptive management

- Uses responses that do not foreclose future options or unnecessarily constrain future choice.
- Uses responses that are effective under the widest possible set of plausible future scenarios.
- Observes change through targeted monitoring and continues to reassess scenarios of the future.
- Appropriately modifies policies, strategies and structure plans.

Delivering resilient infrastructure involves much more than simply reducing the chance of damage through the provision of 'strong' structures, and adaptive management involves much more than simply 'wait and see'. Both are purposeful approaches to design that are inherently risk-based and importantly, seek actively to manage uncertainty. A risk-based approach is now widely accepted and maturing in practice (Table 6). Accepting the future as unknown, although widely recognized as important (Evans et al., 2004a, 2004b; Hall and Harvey, 2009; McGahey and Sayers, 2008; Milly et al., 2008), is yet to become a routine consideration in FRM. Accepting this premise has a number of profound implications, and how such gross uncertainties are managed shapes the nature of the strategies, engineering designs and nonstructural options that are developed. In particular, engineers now seek to embed resilience and adaptive capacity into the choices made. This is in contrast to the linear model of strategy development, based upon a more certain view of the future, that is characteristic of traditional flood control decisions (Table 6).

Table 6: The recognition of uncertainty has a profound impact on strategy development; forcing the traditional linear design model to be replaced with adaptive strategies

Stages of strategy development	Traditional (certain) model of strategy development and decision-making	Adaptive (uncertain) model of strategy development and decision-making
Deciding what is needed	Predefined system of goals, objectives and desired outcomes. Defined set of activities and resource demands.	Emerging pattern of goals, objectives and desired outcomes. Flexible configuration of resources and priorities.
Deciding how to achieve it	Sequential process of planning, programming and implementation. Top-down strategy development.	Continuous alignment of plans, programmes and implementation activities with the changing world. Continuous reconciliation of the bottom-up initiatives and top-down strategies.
Understanding the external and internal influences	Stable system of decision-making. Predictable (deterministic) future change – climate, demographics, deterioration, preferences etc.	Changing decision processes and priorities. Unknown future change – climate, demographics, deterioration, preferences etc.

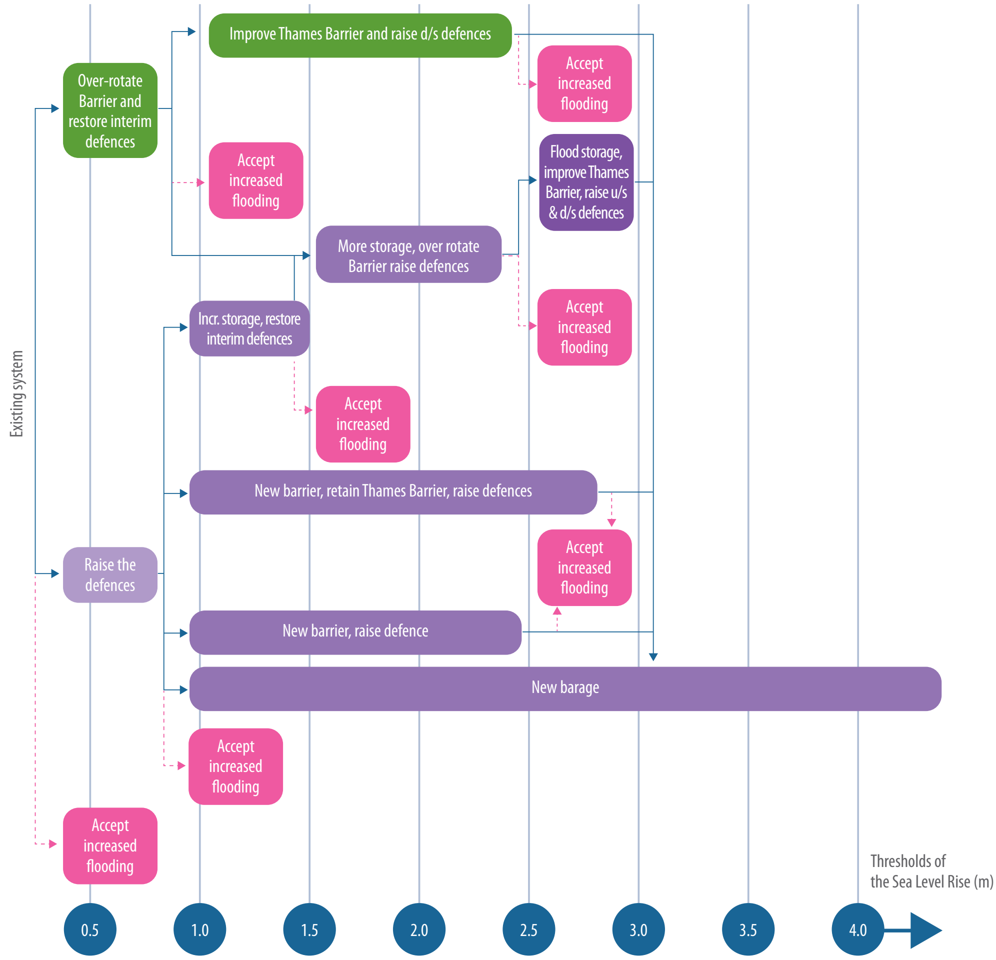
Source: adapted from Hutter and McFadden (2009).

The desire for adaptive management also introduces additional decision criteria associated with the performance of the strategy as a whole and the engineering measures it may contain, including:

- **Robustness:** ensuring the strategy performs acceptably in widest set of plausible future scenarios; avoiding strategies that are tailored to a given view of the future or historical setting, and only perform well in that context.
- **Flexibility:** ensuring the strategy can be changed based on monitoring and observation; avoiding measures that foreclose future options where possible while promoting others that keep future options open. By considering multistaged decisions rather than single trajectories, flexible strategies can be developed with clear decision points.

Adaptive management is now becoming embedded in FRM as supporting methods and guidance mature. For example expert lead intervention scenarios and decision pipelines, as applied in the Thames Estuary, UK (Figure 27) provide a useful framework to analyse a limited range of expert derived decision pipelines that describe a logical progression of management choices. A series of decision points, constrained by previous actions, are set out and the risk at each point assessed against different possible future states. The performance of each decision pathway under each future can then be assessed against a range of future scenarios and the most robust strategy identified. Perhaps the greatest strength of this methodology is its ability to identify both those actions that can be taken now, and those that should be delayed.

Figure 27: The performance of different strategic alternatives (represented by unique routes through the future decisions) enable adaptive strategies to be developed that reflect future uncertainty – an example based on the Thames Estuary 2100 studies



Source: adapted based on Environment Agency (2009a).

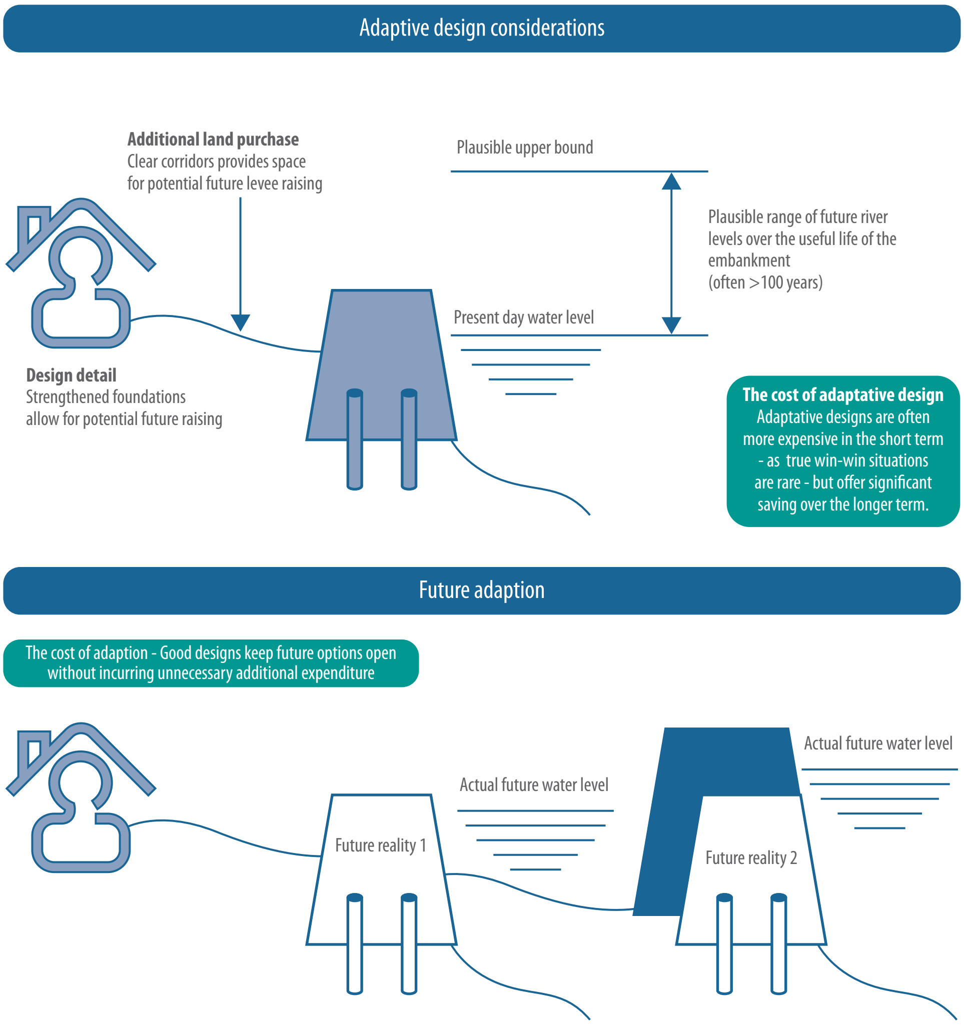
Severe uncertainty not only impacts on strategy planning, it fundamentally influences the way actions and designs are developed. Two additional criteria are emerging as most important:

- **Resilience:** ensuring that engineered structures and nonstructural options perform (and do not fail catastrophically) during storm events that exceed design criteria or are of an unforeseen nature.
- **Adaptability:** ensuring a given measure (such an embankment) or instrument (such as insurance) used within the strategy can be readily changed (for example raised or widened, modified to reflect changing home owner or industry needs or to support changing management policies, such as promoting uptake of household scale measures and/or discouraging floodplain development).

Assuming a worst-case climate change scenario during designing a flood defence for example is likely to be inefficient and would most likely lead to an overdesign. Equally designing for the most favourable future is likely to a lead to an underdesign, potentially placing people and property at unacceptable risk. In a changing world it therefore makes sense to adapt solutions that can be modified if the future should turn out to be different from expectations, and adaptive management is much easier in systems that are flexible. Various examples exist of adaptable design, for example purchasing land in the lee of an embankment to facilitate future raising or widening, or designing foundations that anticipate a heightened embankment in the future. Such options often demand greater upfront expenditure than perhaps would be the case if future change had been ignored; there are seldom true win-win situations. Flexible solutions are however likely to be more cost-effective over the longer term. For example, beach nourishment is often promoted as a flexible solution in that the amount of fill placed on the beach can be modified from one nourishment campaign to the next, in the light of improving understanding of beach behaviour and changing objectives with respect to risk reduction.

A simple example of this philosophy is shown in Figure 28 in the context of a simple embankment, but similar thinking can be applied to all measures.

Figure 28: Adaptive design keeps future options open without incurring unnecessary additional expenditure. Real options methods provide a means of valuing the efficiency of increased expenditure initial investment to provide future flexibility in an the context of an uncertain world.



Source: Sayers et al. (2012a).

3.3 Outcome measures

Increasingly multiple measures are used to describe the desired outcomes from an ongoing FRM effort. Typically such outcome measures include risk to economies and people as well as the risk to ecosystems. They also include societal and individual risks, and reflect risk arising during a specific event, annual expectations and long-term performance.

The most common outcome measures typically focus on the three pillars of sustainability (introduced in Chapter 2). The detail of the chosen outcome measures varies according to the decision-making level they relate to (national or regional governance for example) and local context of the issues. The general framework of the outcome measures will however remain the same. It will include consideration of:

- **Measures of economic sustainability.** These focus on the likely economic losses that could be incurred in either a single event or an annual expectation. Importantly, measures of economic sustainability link to social systems and ecosystems through the concepts of fairness and viability. Economic measures of sustainability therefore place potential losses in the context of local and national wealth (as measured for example through gross domestic product, GDP) and the availability of resources to deliver FRM to reduce losses, now and over the longer term. Some typical outcome measures are highlighted in Table 7.

- **Measures of social sustainability.** These focus on the impact that flooding, and its management, may have on the well-being of society and individuals, and link to economic and ecosystem sustainability through the concepts of fairness and bearability. In providing these measures, the degree to which risk management decisions consider the needs of all individuals and treat all groups fairly (with special attention to the most vulnerable) can be assessed. No single quantified definition of social justice exists, and many have developed different interpretations of what constitutes fair treatment and a just share. It is therefore important for the flood risk manager to define these in the context of a flood risk analysis and the decision-making process to be adopted. Table 8 provides a summary of potential social sustainability objectives and some possible quantifiable indicators.

Table 7: Summary of economic sustainability objectives and outcome measures

Economic sustainability objectives	Outcome measures
Viable	**Relative economic pain** The proportion of the national or local economy (for example characterized by GDP/regional domestic product (RDP)) taken by flood risk management activities and residual flood losses. A ratio that is considered too high is likely to make the flood risk management effort unsustainable and require a rethink of the approach. **Security of appropriate resources in the short and longer term** Is there a commitment to a long-term investment strategy that reflects whole-life costs (both capital and maintenance –for both structural and nonstructural measures, during-event emergency response costs and post-event recovery costs) and contains secure funding streams? **Economic benefit and costs** Are the economic benefits well understood and assessed, including: ▪ direct losses avoided – risk reduction to residential properties and commercial properties? ▪ indirect losses avoided – risk reduction to business continuity and community (tourism, etc).? ▪ opportunities provided – risk reduction to those supplied by floodprone businesses? ▪ a positive benefit to cost ratio? **Degree of public outrage** (Sandman, 1987) The acceptability of risk and the perception that FRM is equitable is ultimately associated with the degree of public outrage. For example, to experts, risk might mean the expected annual mortality. But to the public, risk means much more than that. The public often pay too little attention to hazard; the experts often pay too little (or no) no attention to outrage. Not surprisingly, they rank risks differently. However for equity to be perceived as being achieved it is important to minimize the *degree of public outrage* in the face of floods as seen in media reports, political speeches, and calls for action.
Fair	Are resources distributed to the most vulnerable? Average annual probability of flooding per household (disaggregated by social group)? Average annual damages per household (disaggregated by social group)? Average expenditure on FRM per household protected (disaggregated by social group)?

- **Measures of ecological sustainability.** These focus on maintaining the environment's natural qualities and characteristics, and its capacity to fulfil its full range of functions, including the maintenance of biodiversity and ecosystem connectivity and function. Ecological sustainability links to economic and social well-being through the concepts of viability and bearability. Objectives and possible indicators are shown in Table 9. These are typically measured in terms of long-term gains and losses to the ecosystem, or a measure of the relationship between organisms and their environment and how this could potentially be enhanced (or impacted). Table 9 provides a summary of potential ecological sustainability objectives and some possible quantifiable indicators.

Table 8: Summary of social sustainability objectives and outcome measures

Social sustainability objectives	Outcome measures
Bearable	**An enhanced quality of life:** Changes in an indicator such as the Life Quality Index that reflects the expected length of life in good health and enhancement of the quality of life through access to income. **Life and limb appropriately protected and adverse impacts on health (mental and physical) avoided:** ▪ annual number of deaths from floods ▪ annual number of serious injuries from floods ▪ annual number of people exposed to frequent, moderate and rare flooding (with defined probability boundaries) ▪ annual number of people exposed to short-term physical and mental health risks arising from floods (e.g. flood borne pathogens from sewerage spills, short-term distress) ▪ annual number of people experiencing long-term mental and physical health issues as a result of floods. (*Note*: All measures should be disaggregated by social group). **Protection and where possible enhancement of the historic and cultural environment:** ▪ number of archaeological sites protected from floods ▪ number of listed/historic buildings protected from floods ▪ number of museums, art galleries etc. protected from floods. The number of facilities protected must be balanced against the relative importance of these facilities. **Community resilience (risk to critical infrastructure)** Access to emergency infrastructure and safe evacuation is an important aspect of resilience. Simple measures include: ▪ number of hospitals protected (available during flood periods) ▪ number of schools protected (available during flood periods) ▪ number of utilities able to operate during flood periods. ▪ quality of emergency planning. Length of road/railway flooded (measure of inconvenience of finding an alternative routes).
	Equity of access to resources and positive effects of management activities A measure of risk transfer within society through the spatial distribution of: ▪ number of properties where flood risk has increased ▪ number of properties/people where flood risk has decreased.

Table 9: Summary of ecological sustainability objectives and outcome measures

Ecosystem health sustainability objectives	Outcome measures
Bearable	**Maintenance and enhancement of the landscape and visual amenities to include recreational areas:** ■ protection or enhancement of characteristic landscape features ■ sympathetic character/design of new flood works ■ number of amenity and recreational sites protected. **Protection, maintenance and where possible enhancement of ecological functions and biodiversity:** ■ increase/decrease in the variety within species, between species, and the variety of ecosystems ■ landscape quality and nature ■ increase/decrease in the flood risk to species and ecosystems. **Maintenance and where possible improvement of local habitats** Impacts on habitat as a result of flooding (both positive and negative).
Viable	**Maintenance and where possible improvement of water quality and water supply** Increase/decrease in water quality and water supply **Maintenance of existing soil quality** Increase/decrease in soil quality. **Minimizing impacts on air quality** Increase/decrease in air quality.

3.4 Success criteria

Success criteria define the desired level of achievement for each outcome measure (at local, regional and national scales). The definition of success criteria is an iterative process, and evolves as information is gathered and policies and strategies are implemented and reviewed. Although difficult, setting out measurable criteria of success, if done well, enables:

- transparent goal setting that can be challenged
- objective review of progress against well-defined goals.

Success criteria should not focus on how to achieve the outcomes (for example by suggesting an engineering or design standard for flood control works). Neither should they be based on historical performance of flood systems or individual projects. Instead they describe the desired outcomes from the FRM effort. The ambition in the success criteria must be practical (taking into account the state of the existing system and plausible limits on resources) and maintained under review.

The level of specificity in the success criteria will vary by the level of governance to which they apply. National measures will be higher-level, reflecting achievement of policy goals (but still in a specific and measurable form), while regional and local success criteria will have more local detail and relate to the nature of the risk and opportunities in specific subregions or sub-basins in the jurisdictions, and for specific aspects of a strategy as well as FRM effort as a whole (for example, flood warning).

Table 10 provides examples of success criteria. To be meaningful, the descriptions and associated quantified measures must be specific to the national and local conditions, and debated to achieve wide acceptance and buy-in. An example of the national scale success criteria used in England and Wales is provided in Box 8.

Table10: Examples of measures of success

Issue of concern	Rationale and example of success criteria
National reputation and pride	Flood risk perceived to be poorly managed. *Example:* Perception of effective flood risk management (e.g. pre-event information shown to be accurate; emergency response shown to be effective; no unwarned events, catastrophic events avoided)
Individual security	Public perception of safety and associated outrage in times of flood. *Example:* Capability of government bodies to either protect flood-prone residents or evacuate them from flood-prone areas in the event of a flood. Successful operation or exercise of emergency preparedness plans.
Loss of life	Loss of life during an event of a given probability or annually. *Example:* less than 100 fatalities nationally, on average, each year
Property damage	Value of (or number of) properties damaged by event or annually. *Example:* total damage to personal property less than 0.5 per cent of GDP (nationally and by province), on average per year.
System effectiveness	Costs of actions taken to minimize flood effects during the flood event compared with losses avoided. *Example:* for each $1 million spent $1–5 million damages avoided.
Post event recovery	Costs to the government to reinstate the affected area to pre-flood conditions. Speed of recovery (time taken to return to normality). *Example:* flooded communities will, on average, be fit for return within three months of the flood.
Damage to critical infrastructure	Impact of flood on critical facilities such as communication centres, power systems, hospitals, emergency response facilities. *Example:* major facilities will continue to operate during the worst plausible events (up to the 1:10,000 year storm).
Impact on, and opportunities for, agricultural production	Hectares of agricultural land lost to production for growing season; Area of fertile land available for agricultural use. *Example:* fertile floodplain available to food production increased by 10 per cent by 2015.
Commerce interruption	Number of supply linkages broken; Factory closures; loss of commercial revenue. *Example:* business disruption will be minimized with recovery to pre-flood activity within three months for floods with a severity of 1:100 years or less.
Social disruption	Number of individuals displaced from their homes; length of displacement; permanent displacements. *Example:* all flooded communities provided with a timely opportunity to evacuate safely; all those displaced provided with support to return to their homes within six months (as above).
Damage to, and opportunities for improvement of, ecosystems	Disruption to nature reserves and impact on fisheries. *Example:* no endangered species or critical habitat permanently disturbed; hectares of biodiverse habitats created.

Box 8: Making Space for Water and associated national measures of success in England and Wales

The UK Government set out its strategic direction of travel in *Making Space for Water* (Defra, 2005), published on 29 July 2004. The approach involved taking account of all sources of flooding, embedding flood and coastal risk management across a range of government policies, and reflecting other relevant government policies in the policies and operations of flood and coastal erosion risk management.

The document set out the aim to manage risks by employing an integrated portfolio of approaches which reflect both national and local priorities, so as to, first, reduce the threat to people and their property, and second, deliver the greatest environmental, social and economic benefit.

A wide-ranging programme of action was set in process, featuring:

- ensuring adaptability to climate change becomes an integral part of all flood and coastal erosion management decisions
- better understanding of risks faced
- better consideration of the impact of flood risk in the planning process
- better promotion of the environmental pillar of sustainable development through greater use of solutions such as the creation of wetlands and washlands, and managed realignment of coasts and rivers
- integrated urban drainage management – to supports the concept of integrated management of urban drainage.

Following the publication of *Making Space for Water*, the Department of Food and Rural Affairs (Defra) identified a number of associated outcome measures together with targets for each. These measures and targets, shown below, express the balance of outcomes required from government investment in the flood and coastal erosion risk management programme. The objectives of setting out such measures were:

- To provide a basis for monitoring the effectiveness of Defra policies and policy interventions.
- To define and communicate to stakeholders the balance of the programme which ministers want to see delivered. As part of this wider purpose, outcome measures are seen as a mechanism to replace the priority scoring system in determining the priority of projects for the capital programme.
- To monitor the Operating Authority's delivery performance and provide the basis for performance review.

Outcome measures for 2008-2009 to 2010-2011	Definition	Minimum target
Economic benefits	Average benefit cost ratio across the capital programme based on the present value whole life costs and benefits of projects completed in the period 2008-2009 to 2010-2011.	Five to one average with all projects having a benefit cost ration strongly greater than one.
Households protected	Number of households with increased standard of protection against flooding or coastal erosion risk.	145,000 households of which 45,000 are at significant or greater flood risk.
Deprived households at risk	Number of households in the 20 per cent most deprived areas for which the likelihood of flooding reduces from significant or greater risk.	9,000 of the 45,000 households above.
Nationally important wildlife sites	Hectares of SSSI land where there is a programme of measures in place, agreed with Natural England, to reach target condition by 2010.	24,000 hectares.
UK Biodiversity Action Plan habitats	Hectares of priority Biodiversity Action Plan habitat including intertidal, created by March 2011.	800 hectares of which at least 300 hectares should be intertidal.

Sources: table: Defra (n.d)..

3.5 Maximizing opportunities through integration

Flood risk management strategies are often developed with reducing risk as the primary goal (understanding risk, reducing the probability of flooding, reducing the consequences of flooding). In doing so, such strategies can fail to recognize the need to maximize the opportunities for other benefits (often at low, or even no, additional cost, but simply requiring more coordination and innovation). This broader view of FRM is now starting to emerge (e.g. Hall et al., 2003b; WMO, 2009; Samuels et al., 2010), requiring integration with other thematic plans relevant to a basin or coastal zone. The integration with wider plans and the need to maximize the opportunities this brings are discussed further in Chapter 4.

3.6 A summary – clear goals and outcomes

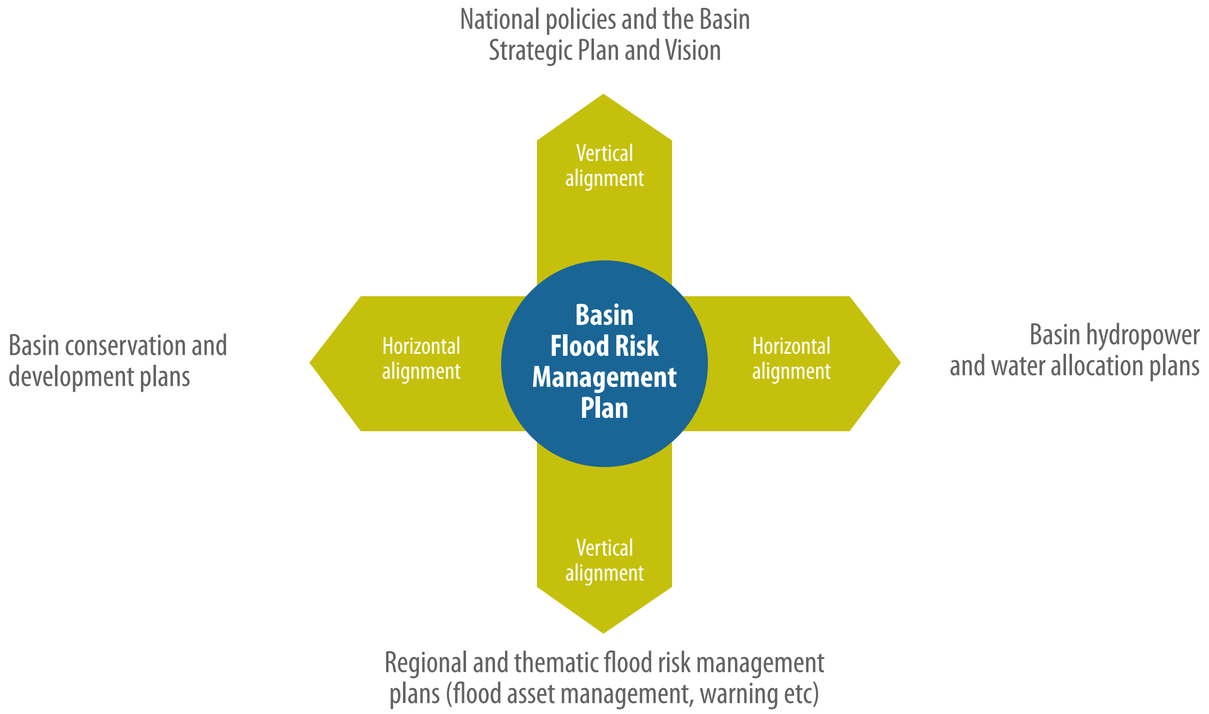
The goals and desired outcomes of FRM policies, strategies and actions need to be clearly described – with national governments providing the lead for lower-level governance to refine or supplement these goals and objectives as the context demands. The goals and outcomes should address the most significant societal concerns. In the absence of clearly defined objectives, future generations are unlike to view FRM as a success.

CHAPTER 4
GOVERNANCE FRAMEWORKS OF FLOOD RISK MANAGEMENT

4.1 Introduction

FRM plans should be developed and implemented in the context of wider water policies and strategies and related development, environment and other planning activities at the national, basin and local levels (Figure 29). This chapter provides a discussion of how FRM policies and plans are linked, and explores the challenges and issues associated with achieving vertical alignment (from national policies to local actions) and horizontal alignment across sectors.

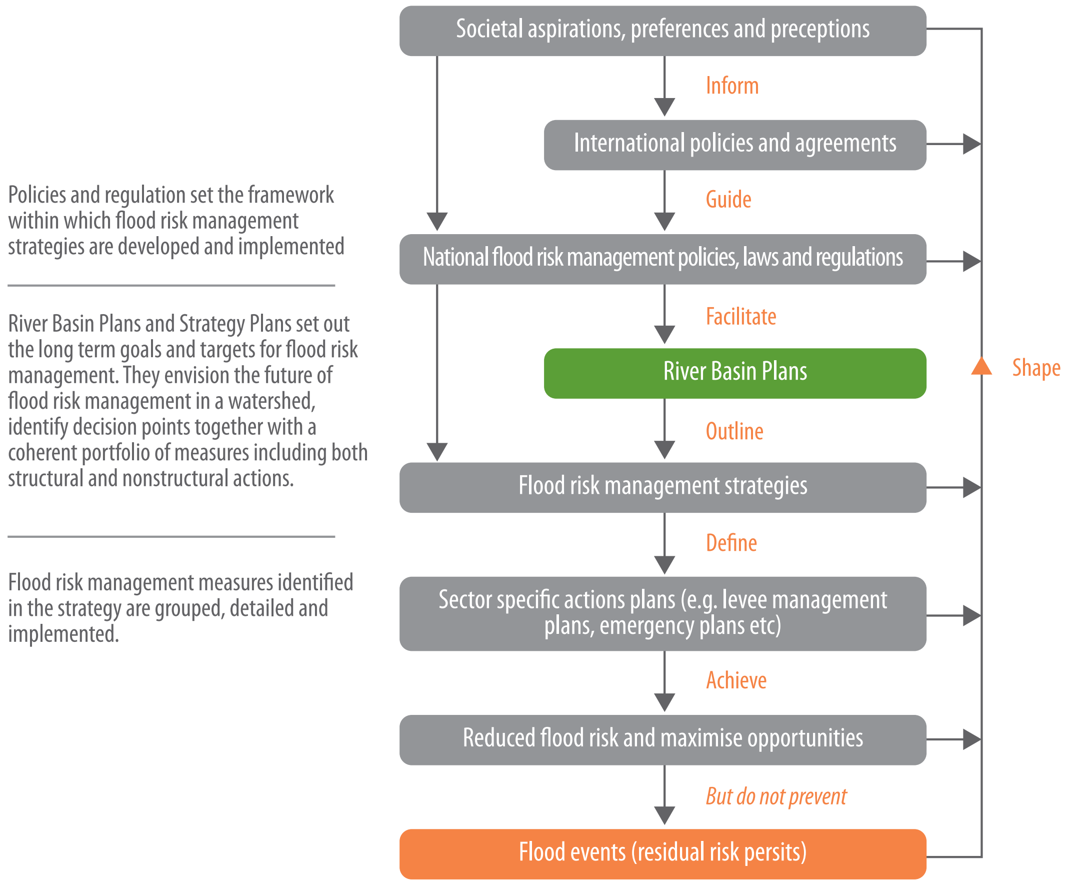
Figure 29: Flood risk management planning as part of the overall national and basin level water planning activity



4.2 Translating societal aspirations into action

FRM is a key component of rational water management planning and execution. It involves the development of policies and strategies as well as plans for implementation and associated means of review. These activities are carried out at the national, regional (basin), provincial (sub-basin) and local (sub-basin) levels, and form an iterative, and sometimes chaotic, process. Each component of this process is shown in Figure 30 and discussed in more detail below.

Figure 30: The relationship between policy, strategy plans, action plans and on-the-ground outcomes



SOCIETAL ASPIRATIONS, PREFERENCES AND PERCEPTIONS

Singular events occurring anywhere in the world may spark societal action. The combination in the 1960s of environmentally focused books and articles in magazines, recognition of growing health challenges, and tragic events (such as oil spills and polluted rivers on fire) seen on television and in film brought international attention to the need to protect of the environment through new policies and legislation. Better understanding of climate change and the importance of renewable energy production are currently driving changes in the manner in which development is being carried out. Such societal aspirations, preferences and perceptions, now often shared through social networking, are important to international, national and local leaders, and must be taken into account in the development of policies, strategies and action plans.

INTERNATIONAL POLICIES AND AGREEMENTS

Geographic and political relationships frequently result in consensus on the directions to be followed in dealing with flood and related issues. The EU Floods Directive, promulgated in 2007, created obligations for all European Member States to manage risks to people, property and the environment by concerted, coordinated action at river basin level and in coastal zones in order to reduce the risks of floods to people, property and environment. In particular it requires all Member States to identify areas at a significant risk from flooding and develop FRM plans for these areas. The nature of the assessment and plans is not specified, leaving Member States to interpret this for themselves. Typically, the government department or agency with responsibility for the environment is identified as the competent authority for overseeing the implementation of the directive in each European country.

The Kyoto Protocol on greenhouse gas emissions, while not adopted by all nations, provides an important consideration for the world community as well as national FRM organizations. Bilateral agreements, such as the US–Canada Boundary Waters Treaty, define agreed national responsibilities for dealing with shared problems, which include floods.

NATIONAL POLICIES, LAWS AND REGULATIONS

Policies and laws represent the highest level of guidance, and can exist at each level of government. Normally, in reaction to international guidance (the case of the European Union) or policy development processes within a nation, national guidance in the form of laws and implementing regulations is prepared to facilitate development of flood strategies at all levels of governance.

In 1969 the US Congress passed the National Environmental Policy Act (NEPA), which promulgated a national policy with respect to the treatment of the environment, and implemented a process that required all federal agencies, prior to the initiation of a major programme or project that had significant impacts on the natural environment, to publicly document these impacts. The implementation of NEPA resulted in a major change in the way the federal government conducted its environmentally related activities, and led to the development at state level of similar laws and implementing regulations. In 2000, the governments of Australia and New Zealand published *Flood Risk Management in Australia: Best Practice Principles and Guidelines* (SCARM, 2000) to provide high-level guidance for FRM activity throughout Australia, and the UK Government issued *Project Appraisal Guidance* on development of FRM plans (MAFF, 1993). In 2006, the UK Government issued *Planning Policy Statement 25* (CLG, 2010), a document that sets out policy on the relationship between development and flood risk. It has since been supplemented with a *Practice Guide* (CLG, 2009) which provides greater detail on implementation of planning policy. These provide the basis for the development of local or regional structure plans, in which areas for future development and floodplains where development should be avoided where possible are identified.

The success of such laws, regulations and guidelines in limiting floodplain development remains variable at best, with overriding local interests sometimes prevailing. Increasingly floodplain development is being recognized as undesirable and unsustainable in the longer term (in economic as well societal terms), identifying the need for legal instruments that enforce the need for 'risk neutral' development.

RIVER BASIN PLANS

At the core of the strategic planning process are river basin plans (Pegram et al., 2012). There are a number of high-level political decisions about priorities for the river basin that shape, or should shape, FRM considerations. As basins become increasingly stressed, it is no longer possible to meet all of the demands on a river and its resources: choices and trade-offs need to be made between different objectives.

In the basin planning process, these trade-offs can take a number of different forms. In some basins, the planning exercise may focus in particular on any one of these issues; in other more complex basins, a range of trade-offs may be under consideration at any one time.

- **Water allocation between sectors and regions.** In stressed or 'closed' river basins where no further water resources can be developed, key decisions need to be made over who will be allocated scarce water resources. The way in which this is provided will go hand in hand with FRM considerations.
- **Hydropower versus consumptive water use.** In basins with significant hydropower development, important trade-offs can exist between the needs of hydropower, and the needs of agricultural and industrial consumptive water users in the basin. Reservoir operations typically have a key influence on FRM, and the parameters set at the basin level will have direct influence over the FRM strategies developed.
- **Flood storage versus hydropower versus navigation.** Among the most complex trade-offs in basins with significant infrastructure are decisions over the operations of major infrastructure in the basin for the sake of different functions. Much of this relates to issues around water timing, the operating rules that govern the release of water from dams, and where development should be constrained. In any given context, it is therefore likely that one or more of these objectives will be in conflict, and within the strategic opportunity provided through the river basin plan, FRM can be poorly focused or even at odds with wider societal needs.
- **Water quality.** Decisions over desired water quality levels represent an inherent trade-off between upstream and downstream water users and between the preferences of different sectors; issues that interact directly with FRM choices (land management and land use choices).
- **Environmental functioning versus other water uses.** There is almost always a need to maintain ecosystem functioning to include environmental flows, but this can conflict with the needs of other water uses in the basin. This

trade-off is manifest in many ways in basin planning, and not least in the preference given to green infrastructure (wetland creation, use of the functional floodplain and so on) in the approach to FRM. River basin planning provides the opportunity to set out these preferences.

A key to successful strategic basin planning is the ability to identify those trade-offs that need to be made in the basin plan, which will therefore shape the thematic planning process.

FLOOD RISK MANAGEMENT STRATEGY DEVELOPMENT

Building on policies, laws and regulations, strategy development seeks to provide the framework for development of coherent plans to manage risk. It includes identification of specific long-term goals (100 years in the future or even beyond), aims, targets and decision points for a specific basins and sub-basins, together with an outline of the associated mix and required performance of both structural and nonstructural measures.

In the United States, the state of California has prepared a flood strategy to deal with the threat to those living in its massive central valley. Its public strategy includes a shared vision for the desired future flood management conditions in California (vision), definition of what will be accomplished within the next five to twenty years to begin realizing the vision (goals and objectives), who will be involved to accomplish the objectives (partners) and how the state will lead a set of collaborative efforts to accomplish the objectives (guiding principles and implementation framework). In the United Kingdom, national policy is based on evidence of national flood risk and how it might change in the future under different investment strategies (an understanding supported by projects such as the Foresight Future Flooding studies: Evans et al., 2004a, 2004b). Catchment FRM plans take these national policies forward to develop strategies for specific catchments.

ACTION/IMPLEMENTATION PLANS

Following strategy development, implementation plans are then used to develop the detail of each component of the strategy necessary to achieve the desired outcomes and minimize residual risk. The recent construction by the Netherlands of the Maeslant flood barrier across the Rhine River represented the execution of one part of a strategy for flood protection of the lower Rhine area.

RESIDUAL RISK

Communicating the residual risk is a central component of FRM. Acknowledging residual risks enables individuals and organizations to take their own measures to reduce risk that supplement those taken centrally.

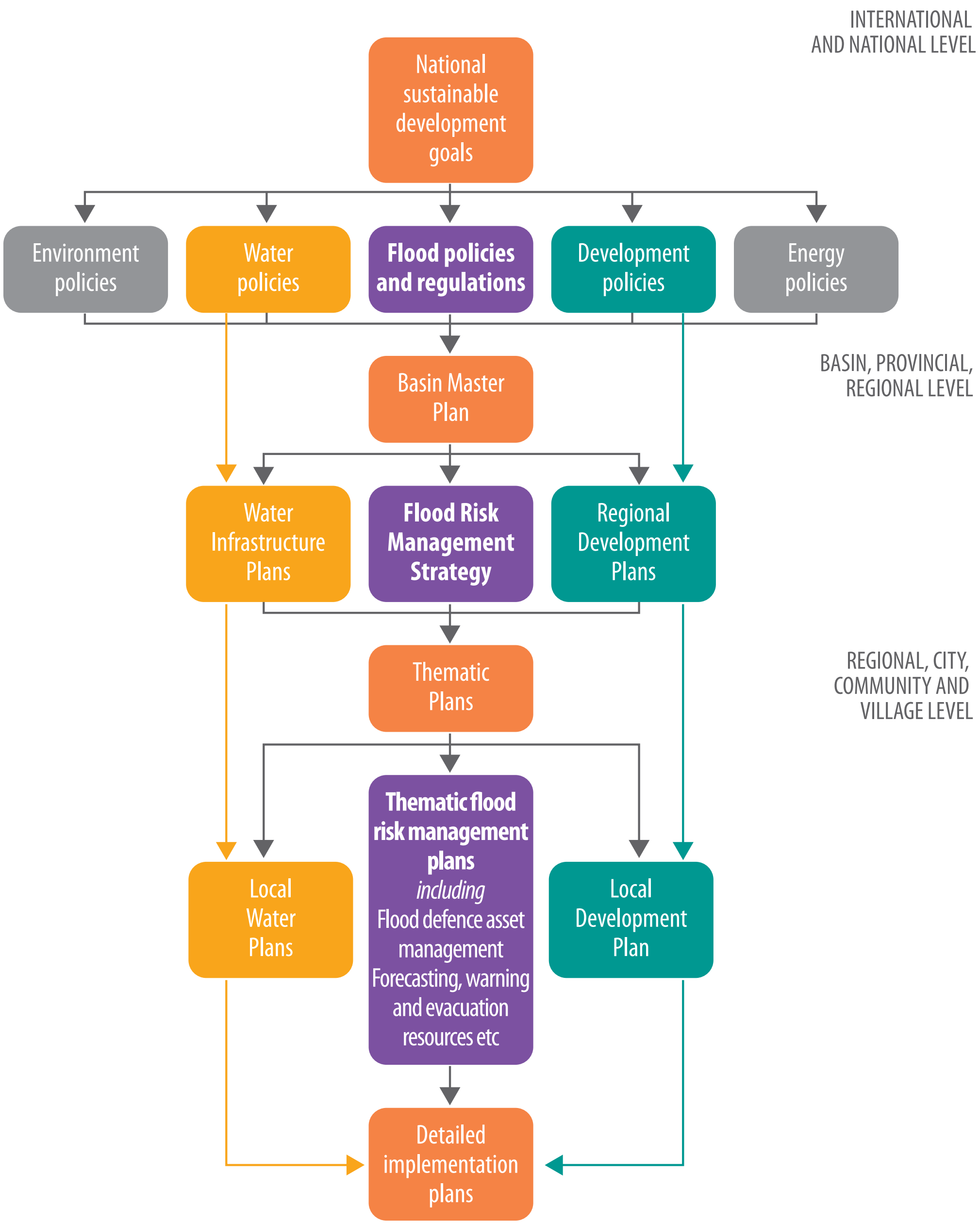
FLOOD EVENTS

Flood events play an important role in shaping society's perception of the risk it faces and the policies that must be implemented to deal with this risk. Major flood events across the globe have triggered government action to address flood issues that might have been long recognized but had not been acted upon because of a lack of public support and a shortage of resources to carry out the work. The consequences of catastrophic flood events arouse public interest and focus government attention on development of approaches to deal with future similar events.

4.3 Bridging the gap between policy, planning and action

At any one time national policies are being refined, strategies developed and local schemes promoted and implemented across a range of sectoral interests (FRM, water resources, development, energy and so on). For government at national, regional and local levels to be effective, they must ensure that the multiple programmes they carry out are appropriately integrated and that work done at one level of government, or in one sector, is in harmony with associated activities in other levels of government and sectors. A simplified view of these horizontal and vertical connections is shown in Figure 31 and discussed in more detail below.

Figure 31: Vertical and horizontal integration of planning and implementation activities is often a chaotic process of integrating policies and plans at various stages of completion

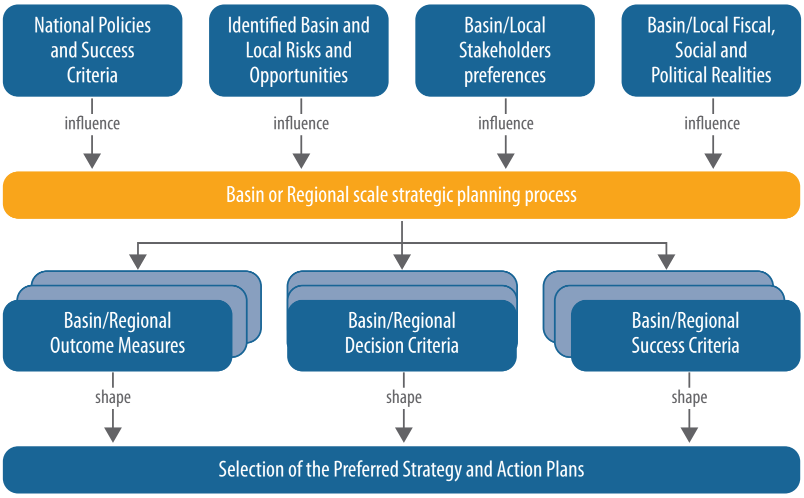


VERTICAL INTEGRATION – LINKING VISIONS AND ACTIONS

Decision-making takes place at multiple levels of government. Basin level decisions, for example, must flow from and take advantage of the guidance at the national level while appropriately reflecting and challenging local plans where they exist. Similarly, local decision-making that leads to detailed plans and on-the-ground implementation must be in keeping with basin and national guidance, while simultaneously recognizing the reality of local needs and ongoing initiatives. When national policies are ignored by lower levels of government, it leads to extreme difficulty when the time arrives for implementation and prioritization of national resources. When national strategies are conceived without consideration of local challenges, they are likely to be ignored.

Strategy planning lies at the heart of this process, and will therefore be guided by the explicit, or if not developed implicit, national policies and desired outcomes as well as more local considerations (Figure 32).

Figure 32: Strategic planning lies at the heart of translating competing demands into meaningful plans and actions



Through the strategic planning process national criteria must be carefully re-examined for their applicability at the basin/local level, and reconciled with local requirements and stakeholders (without losing the underlying meaning). Determination of specific measures for the basin of interest will also be closely tied to the risks and opportunities identified through expert review. For example, the criteria developed in an area subject to frequent flash floods will be substantially different from those considered for an area subject to slow-rise flooding. The underlying philosophy of the measures and their scope will however be similar.

Box 9: Danube Flood Risk Management Plan

The Danube is Europe's second largest river after the Volga, flowing south-east from Germany in the west and eventually emptying into the Black Sea on the Romanian/Ukrainian coast. The basin is regarded as the most transboundary river system in the world, since it includes the territories of nineteen countries.

The Danube River system has seen human impacts from as early as the eighteenth century, primarily as a result of its development as transport route into the heart of Europe. Engineered changes have considerably altered the river, and it is now shorter than its natural length. Some 80 per cent of the original wetland systems have been lost, and many more are now disconnected from the main river. In 2009 the *Danube River Basin District Management Plan* was developed (ICPDR, 2009). The plan contains a vision statement intended to inspire the relevant authorities. In summary, the target for:

- organic pollution is zero emission of untreated wastewaters
- nutrient pollution is the balanced management of nutrient emissions via point and diffuse sources in the entire Danube River Basin District (DRBD) so that neither the waters of the DRBD nor the Black Sea are threatened or impacted by eutrophication
- hazardous substances pollution is no risk or threat to human health and the aquatic ecosystem of the waters in the DRBD and Black Sea waters impacted by the Danube River discharge
- hydromorphological alteration is the balanced management of past, ongoing and future structural changes of the riverine environment, so that the aquatic ecosystem in the entire Danube River basin functions in a holistic way and is represented with all native species and that floodplains/wetlands in the entire DRBD are reconnected and restored
- hydrological alterations is that they are managed in such a way that the aquatic ecosystem is not influenced in its natural development and distribution
- future infrastructure projects is that they are conducted in a transparent way using best environmental practices and best available techniques in the entire DRBD – impacts on or deterioration of the good status and negative transboundary effects are fully prevented, mitigated or compensated
- emissions of polluting substances is that they do not cause any deterioration of groundwater quality in the Danube River Basin District, and where groundwater is already polluted, restoration to good quality is the ambition
- water use is that it is appropriately balanced and does not exceed the available groundwater resource in the DRBD, considering future impacts of climate change.

The connection between the river basin management plan and more specific FRM is then elaborated through the following concerted actions:

- Ensuring a coordinated approach in land-use planning;
- Reactivation of former wetlands and floodplains to achieve increased water retention along with good surface water status. As start-up actions, available data should be collected on, for example, the inventory of floodplains, floodplains that are disconnected from or reconnected to their river, potential flood retention areas and future flood infrastructure projects.
- Prevention of accidental pollution during floods affecting the storage facilities of dangerous substances.
- Preparation of an overview of the implementation of future measures to achieve the requirements of the EU Water Framework Directive.
- Environmental objectives while ensuring appropriate level of flood protection.

Source: ICPDR (2009).

HORIZONTAL INTEGRATION – INTEGRATING ACROSS SECTORAL INTERESTS

In addition to the vertical alignment of FRM policies, plans and action, there must also be close integration of the FRM activities across sectors at all levels. FRM policies must be sensitive to national environmental goals and programmes for development as well as carefully coordinated with other planning activities in the water sector. Since growth in flood risk will be closely tied to the amount and location of development, it is also essential that flood policies work in tandem with development policies and plans. It makes little sense for one part of the government to be attempting to reduce risk while another part is actually increasing the potential consequences of flooding.

Flood risk managers must be fully involved in such development planning. Similar attention must be paid to this horizontal integration at basin, sub-basin and local levels, since effective implementation of FRM plans will depend heavily on synchronization with other sectoral planning approaches, particularly with respect to energy (hydropower construction), agricultural and municipal and industrial water supply, and economic development. The importance of the horizontal integration cannot be overstated, as actions in the floodplain could significantly complement or conflict with other plans. The more closely national flood policies are tied to other national-level policies the more likely it is that the flood policies will be implemented. Experience in the United States has indicated that when policies or laws are narrowly focused and not coordinated with other policies and laws relating to the same geographic region or sector, conflicts inevitably develop. Equally, and perhaps most importantly, the nature of the implementation is heavily shaped by the nature of the financial instruments/incentives used to support FRM. National-level incentives can either promote good practice or detract from it.

Strong horizontal alignment in policy is central to achieving sustainable development. Inconsistencies in the planning process at national and basin level become all too apparent at the local level where actual implementation occurs. If adequate coordination has not taken place at the national and basin level it is unlikely to be possible to coordinate these efforts at the local level. The strong ties that exist within sectoral relationships, and the organizational stovepipes or silos that develop among similar agencies at different levels, will frequently overcome any attempts to work out conflicts at the local level.

Agriculture and food security

Agricultural productivity is directly related to the availability of water to support the growing of crops and the nurturing of livestock. Agricultural areas are often subject to periodic inundation, which in some cases provides nutrient-rich sediment, and in other cases destroys the ability of the area to support agricultural activity. If FRM plans and agricultural development plans are carefully coordinated, true win-win situations can emerge. In the Mexican state of Tabasco, much of which is subject to periodic inundation, large areas of the floodplain are made available for the grazing of livestock, recognizing that as flood season approaches the cattle will be relocated to higher ground and the floodplains returned to functional floodplain. Agriculture flourishes and the chance of flooding downstream is reduced.

Economic development and spatial planning

Effective business planning requires knowledge of the hazards that will be faced in siting facilities and the mitigation steps that can be taken to reduce the hazard. Appropriate residential development similarly requires a complete understanding of the nature and frequency of the hazards that exist so that planners can ensure construction of appropriate facilities at locations where the residual risk is maintained at as low a level as possible.

Ecosystems services

Floodplains are among the most biologically productive areas on earth, and the ecosystems of the floodplain provide numerous services to both nature and humans. Effective coordination among those interested in preserving and enhancing the natural environment and those responsible for FRM can ensure that efforts to provide more protection for human beings does not result in significant losses of ecosystem goods and services. In fact skilful flood risk reduction planning can capitalize on the flood-risk reduction nature of some ecosystem services to reduce the necessity for structural projects.

Energy

Water is necessary for energy production, and energy is necessary to support the production, distribution and treatment of water. The two are inextricably linked. Sound FRM plans will ensure that critical energy facilities are properly sited and adequately protected. The impact of the 2011 tsunami on Japan's energy production received world headlines. Large floods on the Missouri River in the United States threatened nuclear power plants. Effective use of water resources requires that the operations of major dams carefully adjust the amount of storage behind the dam for hydropower, agriculture and flood purposes, to respond to modifications in downstream activity and changes in hydrology and geomorphology. Flood risk planning must recognize these synergies.

Navigation

Inland waterways and ports support domestic and international commerce, and are essential to the continued growth of developing and developed nations. Siting of key facilities must take into account the flood hazards that exist along the waterways. Operators of flood risk reduction systems must consider the impact of their activity on vessels that use the waterways and ports. Plans developed jointly between navigation interests and flood risk reduction managers will avoid potential conflicts during periods of stress, and ensure the effective operation of both systems.

Water supply and quality

Ensuring the availability of water for people, business and agriculture is one of the most important responsibilities of government. Steps taken to reduce the risk of riverine, coastal and pluvial flooding can have significant impacts on water quality. The siting of water and wastewater treatment plants can present a significant additional risk to public health if they are liable to be flooded. Plants must be protected appropriately, or ideally located in a way that takes account of the potential flood hazard. Effective management of flood waters can produce significant supply bonuses during subsequent drought periods. As previously mentioned, careful management of reservoir operations can meet the needs of both FRM and water supply if the plans are well coordinated.

Management of other hazards

A holistic approach to emergency planning and management is preferable to a hazard-specific approach, and the management of flood risk should be part of a wider risk management system, sharing information and the formation of effective relationships across organizations involved in emergency management, and developing building design codes and spatial planning approaches appropriate to all hazards. For example evacuation routes and safe refuges should not be optimized for sole use in the case of flooding but should be suitable for other hazards too. It would be inappropriate to site critical infrastructure out of the floodplain simply to place it at risk from a mudslide, wind or an earthquake. Equally, flood structures themselves may be subject to additional hazards. For example seismic activity can threaten the stability of levees and other flood protection structures and provides an additional consideration in the analysis of risk.

In the United States, FEMA is supporting the state of North Carolina in developing an integrated hazard risk management (IHRM) process that will provide valuable risk information to support all disaster prevention, response and mitigation activities. Recognizing that the state is subject to many hazards, and that information gathered in support of the mitigation of the consequences of one hazard may well be useful in the mitigation of others, the state has embarked on a multiyear effort to identify and communicate risk information concerning riverine flooding, coastal erosion and flooding, dam failure, levee failure, storm surges, landslides, earthquakes, wildfires, high-hazard winds, tornadoes, snow, ice, hail and drought. Maps are being prepared for all areas across the state that identifies the hazards and the systems vulnerable to those hazards. The output of the system will be risk assessments that can be communicated to the public and public officials as well as forming the basis for integrated mitigation activities.

Box 10: Maximizing opportunities and the development of a more integrated approach to FRM

The challenge of achieving a more integrated approach to FRM in practice cannot be underestimated. A recently completed EU research project, FLOODsite, Theme 3, explored the emerging challenges associated with delivering more integrated solutions on the ground, and highlighted the need for improved and more efficient tools and techniques (providing improved functionality to explore risk and richer, more useful and usable evidence on risk). It also identified the need for development across all stakeholders (researchers, practitioners and policy-makers) of a common desire to achieve this integration.

FLOODsite highlighted integrated FRM as an evolution of the sectoral-based current FRM approaches, extending the basic characteristics of FRM to:

- Appropriately reduce the chance of flooding – acting to reduce the frequency, speed, depth or duration of floodplain flows (this could be through local or remote measures).
- Appropriately reduce the resultant harmful consequences should a flood occur – acting to reduce the potential exposure to flooding (through the removal of property from the floodplain for example) or reducing the vulnerability (through floodproofing critical assets, and aiding individuals and organizations in alleviating harm and promote faster recovery).
- Support sustainable economic growth – provide space for prudent economic development to maintain robust local and national economies.
- Support good ecological functioning – any modification of the natural functioning of the coast, river and surface drainage systems should maximize the ecology potential and minimize adverse impacts.
- Promote sustainable development – FRM actions should be integrated with broader sustainability objectives that demand robust solutions. This will enable future generations to have choice in meeting their FRM needs.

Achieving the above, although now widely accepted as desirable, is only now starting to become a reality in practice. The FLOODsite report explores some of the reasons why this is the case, and presents the emerging methods and good practice from around Europe to support the transition from flood defence, through FRM to integrated FRM.

Source: FLOODsite (2009).

4.4 Issues to be addressed at each level of policy and planning

Each level of policy and planning must appropriately support all others. The typical issues that must be addressed at each level, from national policy development through basin strategies and down to regional and local planning, are discussed below.

NATIONAL FLOOD RISK MANAGEMENT POLICY DEVELOPMENT

National FRM policy (either in a single document or, more typically but not desirably, through a collection of polices, legislation and supporting guidance) must address topics that establish national programmes or provide guidance to basin, provincial and other government organizations to support their preparation of basin-level strategies. These policies should provide:

- **A vision for the future.** National policy should describe, in general terms, the expected future conditions of the nation with respect to floods. Fundamental goal-related approaches such as providing 'room for the river' should be identified and clearly stated (see Chapter 3).
- **Defined roles and responsibilities.** High-level definition of the responsibilities of each level of government in the FRM process is essential. Details of these responsibilities can be further defined in other elements of the national policy.
- **Definition of the planning process and its requirements.** Establishment of the planning process and identification of the requirements to be fulfilled in this process by each level of government must be accomplished. Details concerning the information required by the national government to support its decision-making process should also be clearly defined.
- **Decision criteria and priorities.** Except in the most unusual conditions, resources will not be available to carry out all desired or needed activities concurrently. Decisions will have to be made concerning acceptable levels of risk across sectors and geographic regions, and establishing national priorities for funding risk mitigation.
- **Insurance.** National policy should define the extent, if any, of the national government's role in any flood insurance activity (see Chapter 14). When the government decides to participate in insurance, policies should define key factors such as cost recovery, subsidies, the role of private sector, and role of subnational governments.
- **Financial responsibilities.** Defining the scope of FRM financial responsibilities will require close integration with national programme and budget activities. Policies and guidance should provide information on the level of fiscal support to be received by sub-national elements for planning construction, maintenance and operation of proposed facilities and the timing of the provision of such fiscal support.

To be meaningful to those who must execute them, policies should be developed in a collaborative, transparent and science-based environment. This will require identification of areas at significant risk and the primary drivers of future changes in risk. As more information is gathered this initial evidence can be improved. However, before discussion of prioritization of resource allocation can begin, the risks must be identified and understood at same scale as that at which resource allocations are made and responsibility for flood management lies. Typically this will be nationally or regionally. Some elements of national policy may remain static while others will change over time as new information is developed and anthropogenic and natural changes occur.

BASIN-LEVEL PLANNING AND STRATEGY DEVELOPMENT

Based on the policies and guidance provided through national agencies, river commissions, provincial and state governments, and independent municipalities carry out the critical mission of developing FRM strategies and implementation plans. Basin-level strategies and plans should focus on:

- **Recognition of the existing activities and ongoing planning processes.** Throughout the developed and developing world, planning processes are in a state of perpetual change, with some initiatives starting and some coming to an end. Planning is done by a range of organizations and individuals, inside and outside of government. This bottom-up reality provides a critical contribution to the basin plan, and working with these initiative can make the difference between success and failure of the plan.
- **Translating national policy into basin policy.** Translating national FRM policy into basin-level strategies is perhaps the pivotal process in delivering good FRM. The national vision must be translated into a basin-level vision which satisfies long-term needs at that level. Efforts to align the desired outcomes and objectives at a basin level with those

at a national level invariably require a comprehensive and open debate about the influence of regional priorities. It is therefore important that national-level goals and objectives guide, and do not try to prescribe, basin-level strategies. Through close representation of basin leadership in the development of national policies, many potential conflicts (particularly associated with the prioritization of central or federal funding) can be avoided.

- **Identifying hazards and consequences and assessing risk (now and in the future).** Basin-level organizations must identify the unique risks faced in the basin and their relationship to nationally defined risks. The combination of the basin-level risks with national risks forms the risk portfolio, which must become the basis of the subsequent plan development.

- **Establishing the preferred mix of mitigation measures.** Planning must identify those geographic regions within the basin where particular policies apply, and the bases for these distinctions. Particular economic conditions, population vulnerabilities and regional environmental circumstances will all shape the preferred FRM policies; risk approaches enable this to be done in a consistent manner.

- **Outlining an implementation programme.** Response organizations must develop and promulgate the processes and procedures necessary to guide development of implementation plans at the provincial and local levels. These processes and procedures should include specific information that must be developed at the local level and provided to the basin organizations when provincial and local proposed actions must be supported at the basin or national level.

Basin flood planning can therefore be seen to bring together a consideration of the whole river basin, national policies and regulations, and local aspirations and practicalities when managing flood risk, and not just the local measures needed to alleviate flooding at a particular location. In developing the basin FRM strategies, responsible organizations should:

- **Take a systems view.** Many failures in FRM result from approaches that represent a collection of unconnected individual measures as opposed to a basin/catchment-wide system. Frequently, strong FRM systems are undermined by a failure in a small part of the overall network. The devastation brought about by Hurricane Katrina can be attributed in part to this lack of a systems approach.

- **Use watershed boundaries and avoid reliance on administrative boundaries.** Seams in FRM systems develop at administrative boundaries and become potential points of weakness. Transboundary or boundary rivers must be recognized and given special status so that their management is undertaken as a whole rather than through potentially uncoordinated crossover binational and multinational agreements. This does not necessarily imply that there is a need to develop detailed whole river strategies (a daunting task for rivers such as the Ganges, Danube, Rhine, Yellow and other major river systems), but it does imply a need for integrated, transboundary policy development.

- **Investigate and consider the potential impacts of future change in the basin.** Climate change, increased land development, geomorphologic changes in rivers and degradation of existing flood structures increase the risk in the basin. Measures must be identified that will permit adaptation to these changes or mitigation of the consequences of such changes.

- **Foster innovative thinking and radical solutions.** Traditionally, flood alleviation works have been carried out at the locations where flooding occurs. The most common forms of flood protection works are flood embankments and floodwalls that seek to contain the flood flow and prevent water spreading onto the floodplain. However flood embankments and walls can constrict river flows, resulting in higher flood levels, concentrate flood flows in a manner that creates erosion, force deposition of sediment in river channels as opposed to on the floodplain, and lead to an overtopping or breach of the embankments themselves. Innovative solutions that take advantage of natural storage in the floodplain, elevation of at-risk structures, floodproofing and so on should be sought in the development of risk management portfolios. Embankment setbacks and temporary off-river flood storage or conveyance can also provide both economic and ecologic benefits. The operation of floodway systems and backwater storage areas during the 2011 Mississippi River floods dramatically reduced potential damages in the lower Mississippi basin and provided nourishment of lands previously disconnected from the waterway.

- **Make a real difference.** Basin planning can provide a real contribution to good FRM. An example of the effect of channelling a major river and constructing flood defences to protect the floodplains is the Rhine, where channelling and flood protection works carrier out between 1882 and 1955 are now estimated to have caused flood flows near Worms in Germany to increase by about 30 per cent.

REGIONAL AND LOCAL-LEVEL IMPLEMENTATION PLANNING

At a regional and more local level, detailed implementation plans for flood management activities are required. Such plans must be in compliance with national policies and, where available, take their lead from basin-wide strategies as well as the reality of the detail at a local level. Alignment with other sectors must also be finalized. Perhaps the most crucial cross-sectoral decisions are associated with development control, and local governments must pay special attention to control of land use in hazard areas so as to limit the further expansion of risk areas; zoning areas for appropriate development within the floodplain and including making room for the river and blue and green corridors (see Chapter 6).

For FRM processes to be successful, there must be clear agreement between the various levels of government about the meaning and extent of the national policies, the basin-level strategies and the specific challenges faced by regional and local governments in the execution of these policies and strategies. Expertise at all these levels, working together based on a common philosophy of sustainable development, needs to be exchanged through a continuous process of consultation to prevent unintended conflicts, overlaps and importantly gaps.

4.5 A summary – a framework of decisions, data and methods

From national to local decision-making the nature of the information and data available vary considerably. Similarly the parameters of the analysis, the required temporal and spatial resolution, and the granularity of the decisions to be supported (and hence the nature of the uncertainty that is acceptable) reflect the specific challenges faced in each level. Table 11 provides an overview of the types of decisions made, data required, and methods of analysis that might be used at each level.

In Table 11, FRM strategy planning at a basin level is perhaps the most critical component. Around the world, poor FRM is typically a result of constrained thinking and a lack of innovation in the mitigation options considered at this regional level. A strategy planning that takes a long-term\system-scale view, while actively addressing short-term risks, provides the vehicle by which constraints can be removed and robust risk-informed goals and a coherent portfolio of measures developed and implemented.

Table 11: Typical decision levels – content, supporting methods and data

Decision level	Decisions made	Supporting data	Methods of analysis	Example applications
Transnational basins	*As for a single country basin (see below) plus:* ■ data-sharing protocols ■ water sharing agreements ■ operational arrangements during flood and drought extremes ■ making room for water			Danube basin plans Rhine basin plans Red River plans
National based on societal goals and aspirations	National goals and objectives Policy framework National funding prioritization Process and requirements of planning Decision and success criteria Insurance framework Financing frameworks Data-sharing protocols	*Sources:* extreme storm loading conditions. *Pathways:* River and coastal network, topography, notional defence standards and condition. *Receptors:* Property and people numbers/locations, critical infrastructure locations. *Other plans:* findings from regional and local plans.	Simplified broad-scale, yet quantified, models. Discrete scenario-based exploration of future change: ■ climate ■ socio-economic ■ funding ■ Influence of autonomous and planned change ■ impact of flood risk management policy changes.	In the United Kingdom the High Level RASP (Risk Assessment for flood and coastal defence Strategic Planning, Sayers and Meadowcroft, 2005) methods were used to underpin Foresight Future Flooding studies (Evans et al., 2004*a*, 2004*b*) and support the development of long-term policy goals.
Basin (within a single country)	*Translation of the above and below to provide:*	*refinements of the above plus*	*refinements of the above plus*	*refinements of the above*
based on national policy and regional realities	Basin goals and objectives Regional prioritization of investment. Development planning and spatial zonation of the floodplain. Large-scale responses: ■ emergency planning (evacuation planning, warning systems, safe refuges etc). ■ large-scale infrastructure. Trade-offs and synergies with other sectors.	*Sources:* general refinements. *Pathways:* general refinements plus road networks etc. *Receptors:* Demographics, habitat vulnerability.	Increased use of process based models. increased use of continuous simulation and more detailed scenario analysis.	
Regional	*Translation of the above to provide*	*refinements of the above plus*	*refinements of the above plus*	*further refinement of the above*
sub-basin – based on basin strategy, national policies and local realities	Detailed implementation plans for each thematic flood risk management plan, e.g. ■ asset management ■ evacuation planning ■ land use control.	*Sources:* general refinements *Pathways:* general refinements plus geotechnical properties, evacuation networks etc. *Receptors:* general refinements	More detailed models as required	In the United Kingdom the RASP system analysis framework was refined for use in the Thames Estuary 2100 Flood Risk Management Planning studies (Sayers et al., 2006, Gouldby et al., 2008) and used to support optimization (Phillips et al., 2008).

Source: adapted from Sayers et al. (2002).

CHAPTER 5
THE ADAPTIVE PROCESS OF FLOOD RISK MANAGEMENT

5.1 Overview

Flood risk management exists as a combination of policies, strategies and plans – developed nationally, regionally and locally. Pre-existing infrastructure and organizational arrangements combine with the specific local setting to place significant constraints upon, and provide opportunities for FRM.

In contrast to the linear model, based upon a more certain view of the future that is characteristic of traditional flood control decisions, engineers now seek to embed resilience and adaptive capacity into the choices made (see Table 6). Recognition that future conditions may change (perhaps significantly) from those that exist today or that existed when a structure was first designed, underlines the need for a continuous process of monitoring and intervention. The classical engineering control loop of data acquisition, decision-making, intervention and monitoring reappears in contemporary thinking about adaptive management (Willows and Connell, 2003; Sayers et al., 2012*a*). Adaptive FRM is recognized as a continuous process of identifying issues, defining objectives, assessing risks, appraising options, implementation, monitoring and review. Conditions of uncertainty and change imply a commitment to ongoing study of and intervention in the system in question, in the context of constantly evolving objectives.

All flood risk management plans (FRMPs) differ in detail and the specific actions they include, but the same cyclic process, as summarized in Figure 33, is relevant to all. Each stage in this common process is discussed in turn below.

5.2 Define objectives over time and space scales of interest

Understanding flood risk and how best to manage it over a range of time and space scales underpins good decisions. Traditional planning activities have all too often adopted a time and spatial scale that is simply too short (often no more than twenty or thirty years) and too small (a single community or reach) to promote innovative strategic thinking. Typically such approaches are constrained by immediate demands which are often seen to promote the continuation of the status quo and undermine the strategic nature of the plans developed.

An important first step is therefore to outline the whole system of interest (Figure 34) and, in particular, to explain how activities will transition from the short to long term and vice versa (that is, how the demands of today will be met in a way that is supportive of achieving longer-term goals). For example:

- **Long-term and large-scale** (the basis of strategic planning) – by adopting a timescale of 75 to 100 years or more and a space scale that spans whole catchments, basins or even nations, the constraints of the existing structures (organizational and physical) can be challenged and new innovative and ambitious approaches sought. Adopting such an approach enables the strategic direction to be set, unencumbered by local and present-day political issues. Such an approach was successfully applied through the Foresight Future Flooding Studies (Evans et al., 2004a, 2004b) and is now a routine component of the planning in the England and Wales through the Long Term Investment Strategy (Environment Agency, 2009b). In United States, the

Mississippi River Commission has begun to develop a 200-year vision for water resource development in the Mississippi River basin as a whole (USACE, 2010).

- **Short and medium-term and system scale** (critical action planning) – Under certain circumstances such as post-flood recovery, it may be necessary to move immediately to restore elements of a flood damage reduction system damaged by a flood event. Failure to repair levees or damaged flood walls in the face of the potential for similar floods in the immediate future could result in catastrophic losses should a flood occur. However, in moving forward with such short or medium-term actions, every effort must be made to take into account how the short-term plans might best fit with potential long-term actions, and plans that would foreclose future options should be avoided. To the maximum extent possible, real estate acquisitions and recovery work should provide flexibility for future FRM activity. Where pre-flood planning has taken place, it may be possible in a post-flood recovery situation to move immediately to initiation of longer-term FRM options such as conversion of frequently damaged lands into natural flood storage areas.

Figure 33: Flood risk management takes place as a continuous cycle of planning, acting, monitoring, reviewing and adapting

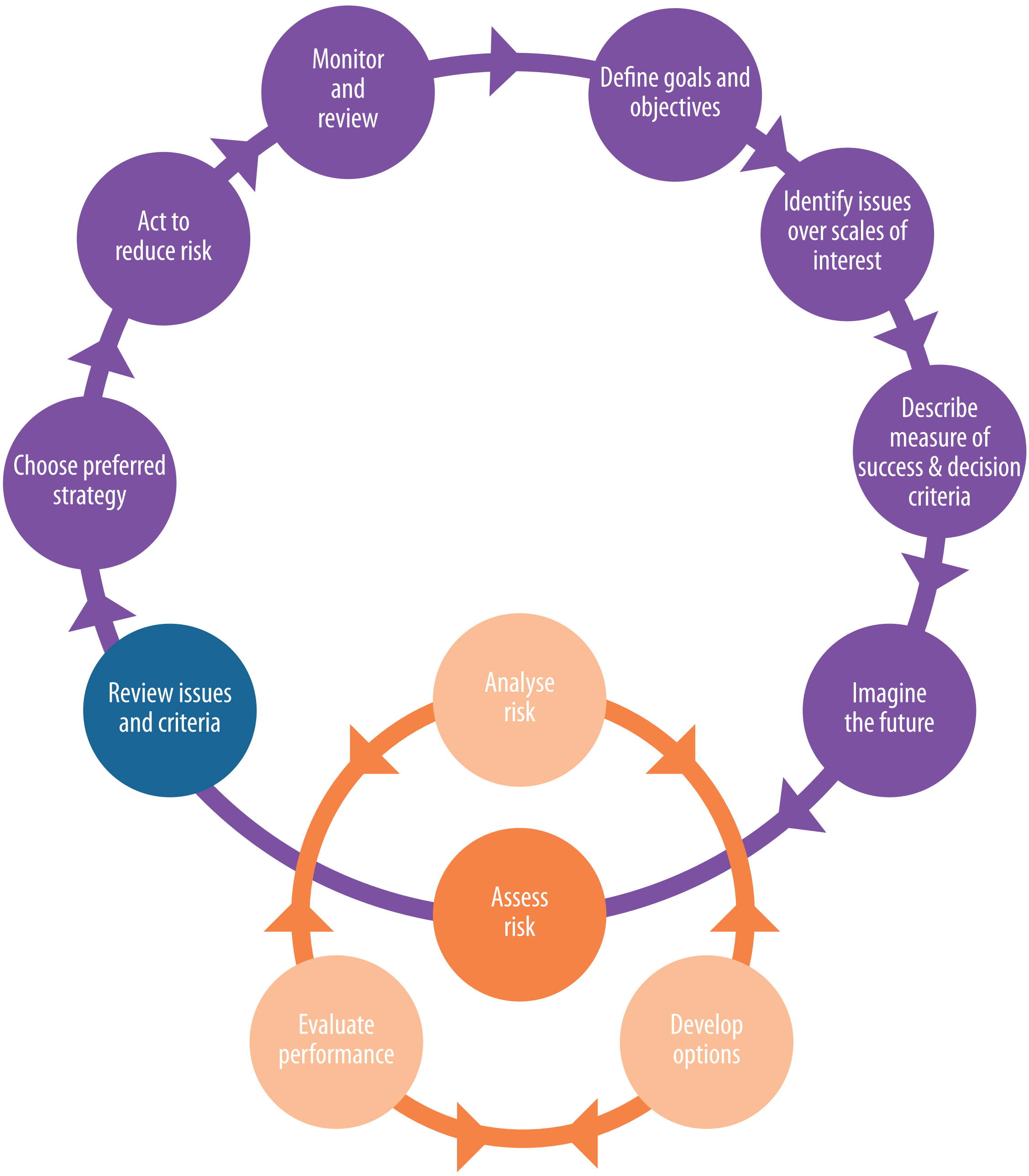
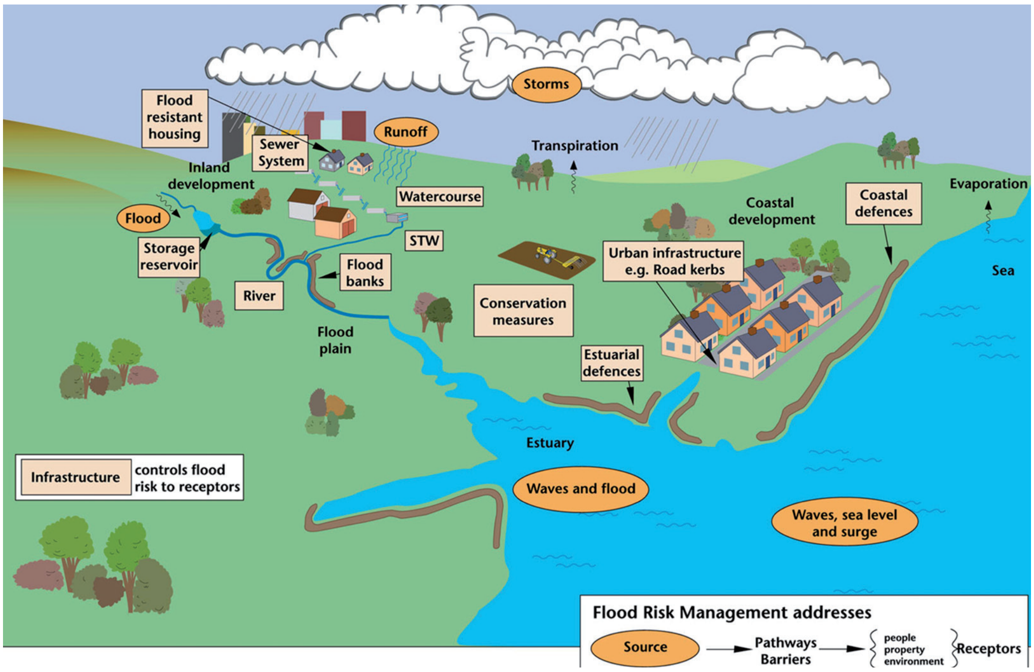


Figure 34: Identifying an appropriate spatial and temporal scale of the decisions and supporting analysis (based on a whole systems view) is critical to good management



Source: courtesy of Mervyn Bramley.

5.3 Identify issues – perceived risks and opportunities

An expert-based review of the perceived risks and opportunities as well as an understanding of how these might change within the timescales of interest remains an important first step in the risk management processes. To be meaningful, the process of identifying risks and opportunities must be comprehensive and wide-ranging, including structured consideration of the available evidence on all aspects of flood risk, analysis of how risks might change in the future, and identification of opportunities to deliver wider multiple benefits. This stage in the process is a powerful force in shaping the subsequent analysis and focus of action, and therefore must:

- **Include an appropriately comprehensive view of the sources of flood risk and drivers of change.** Typically floods result from hydro-meteorological events that increase river flows or lead to marine storms (surge and waves), but these are not the only sources that might be important. Attention must also be given to floods resulting from ice jams, sheet flow and stormwater runoff (pluvial flooding) as well as issues such as land subsidence (caused by groundwater abstraction and drainage, a process that has visibly influenced the flood risk in towns from Venice to Bangkok – and is still a close and real danger in many places, such as Jakarta).

  Without consideration of all the important aspects that influence flood risk, strategies can be poorly developed and risks falsely stated. How these sources might respond to changes in climate, upstream development, construction on the floodplain, structures that interfere with the flow regime, sediment deposition or evolving channel morphology are all important questions that should be explored at an early stage in planning. In each case, estimates of the impact of potential changes (using available quantitative evidence where possible and qualitative evidence where necessary) must be made and taken into account in identifying the perceived risks and opportunities. The initial estimates can then be refined progressively as new evidence and more information is gathered.

- **Actively seek to highlight potential opportunities.** It is easy to reduce flood risk in isolation. It is more difficult to do so in such a way that promotes wider benefits to society and ecosystems in an efficient manner. If potential win–win opportunities are highlighted early in the process, including maximization of opportunities for wider benefits through wetlands, blue corridors, recreation, land management and so on, the chance of delivering coordinated multifunction responses can be dramatically increased.

Box 11: The Napa River Project: finding opportunities

Floods have been part of the history of California's Napa River since settlement began in the mid-nineteenth century. Disastrous floods in the middle of the twentieth century spurred interest in developing a flood control project to protect the city of Napa, a major community in the Napa Valley, one of California's major wine-producing districts, but initial proposals to develop a structural flood control project were rejected by the community. Responsible for a 35 per cent cost share of the project, Napa sought a project that represented a balance between structural protection and enhancement of the wetlands and riverine system that runs through the middle of the community. The project, as designed, has a geomorphically based channel design and will provide 100-year flood protection, a meandering river, community access to the river and enhancement of the natural and beneficial functions of the floodplain. The project has been recognized nationally for its opportunistic approach to dealing with the flood issue.

The Napa River passing through the city of Napa. Note the use of the river area for community recreation

Source: USACE (2011*b*).

5.4 Describe measures of success and decision rules

Flood risk management is fundamentally concerned with outcomes. The criteria for success must be described through clearly identified goals and objectives, and specific outcome measures as well as a clear process of decision-making.

Chapter 3 provides insights into the development and use of well-defined decision and success criteria. These provide the background for the development of criteria more directly relevant to the basin or system of interest and the particular challenges faced, including:

- **Setting goals:** reviewing and refining higher-level goals in the context of local circumstances. This does not provide an opportunity to move away from the national goals, but rather provides for an elaboration of them.
- **Setting objectives:** the way in which goals are translated to economic, ecosystem, and social objectives for the area under consideration shapes the nature of the plan developed, and the choices made. An ability to synchronize multiple objectives and deal with the evitable conflicts that may arise among these objectives remains an ongoing challenge; but if what is desired is spelled out, this can be open and transparent.
- **Defining outcome measures:** the translation of objectives into quantitative outcome measures creates the specificity required to develop comprehensive plans (see Chapter 3).
- **Determining success criteria:** the political, economic and social realities will always influence the level of ambition in the desired outcomes, and which outcomes will be considered a success, but should not do so without challenge. Decision-makers frequently choose to establish success criteria from two standpoint: first, plausible optimism – defining outcomes that are considered realistic to attain under ideal conditions – and second, satisficing outcomes – defining minimum outcomes that represent non-negotiable impacts and risks and must be achieved in order to meet fundamental societal expectations.

The criteria developed through this process enable the performance of alternative strategies to be compared and FRM actions prioritized.

5.5 Determine decision rules

A clear process of decision-making and associated rules provide the means to evaluate the performance of one strategy against another transparently. Such rules are at the heart of the planning and evaluation process, and enable all stakeholders contribute to:

- **Defining the criteria of interest.** What makes a difference in the basin or watershed under consideration? Areas with strong agricultural activity will focus on criteria that measure the ability to maintain the viability of this agriculture. Urban areas will focus on criteria dealing with public safety and property loss. It is important that the selection of criteria be accomplished in a transparent manner and that the results of the selection are shared with those affected by the action.

- **Agreeing how impacts are measured.** A clear and accepted means of measuring impacts is a central component of strategy development. Various approaches are available, including monetized and non-monetized benefit–cost and multicriteria scoring and weighting (see Chapter 3). A summary of criteria typically used are outlined in Table 12.

- **Agreeing how multiple criteria will be combined.** The analysis model can be either computer-driven or the product of a tabletop game in which participants develop the effectiveness scores with the assistance of computer-aided analytical tools. Critical in either case is the assignment of the relative weights of each of the desired outcomes. Is loss of life more important than loss of property, and if so by what factor? Assignment of weights can be accomplished by decision-makers in a Delphi or other decision-support process, or through processes that involve stakeholders in establishing the weighting factors. Failure to assign weights implies equal weighting of all outcomes, which is typically not the desired situation. The output of the model is a relative ranking of each of the strategies against each of the scenarios.

- **Agreeing how decisions will be made given uncertainty in future outcomes.** Future conditions in a basin or a watershed will inevitably be different from the present conditions, but determination of the specifics of change is difficult. Nevertheless, ignoring potential changes is not an option. Plans must be assessed based on their ability to operate under a variety of conditions. Decision-makers must examine alternative futures and determine which are the most logical to be used for the region under consideration. While economics will certainly play a role in determining what futures are affordable, it would be unconscionable to select a less costly alternative and marginally effective approach when it is clear that a more expensive alternative is required to deal with the most likely future.

- **Agreeing how investments will be prioritized.** It is not realistic to expect that all demands for funding can be met immediately.. Therefore decisions must be taken on which requests and actions have priority. Such decisions should be based on a thorough analysis of the risks attendant to each approach under consideration. Areas with the highest level of risk should receive priority.

Table 12: Typical criteria used in comparative analysis of alternatives

Basic criterion	Description
Benefit–cost ratio	Provides a measure of economic efficiency through the ratio of the present value of all of the streams of benefits over the present value of all of the streams of costs
Net present value	Provides a measure of economic efficiency difference between the present value of all of the streams of benefits and the present value of all of the streams of costs
Nonmonetary risks and impacts	Provides a measure of the wide benefits and costs (that are not appropriate for monetization) of proposed action on a wide range of desirable outcomes. Often includes ecosystem services and loss of life.
Robustness	Measures the ability of the strategy/system to perform under a range of plausible futures
Sustainability	Measure of how a strategy promotes long-term economic prosperity, social well-being and ecosystem health.
Fairness	Measure of the way decisions are made and implemented – ensuring the most vulnerable are protected and no group is disadvantaged by the choices made (without appropriate compensation)
Whole-lifecycle costs (capital, operations and maintenance)	Resources required for continuous and adequate maintenance and upgrade of any measures, structural or nonstructural, put into place and the security of these resources.
Adaptive capacity and flexibility	Can the strategy or system to be modified and adapted to cope with future conditions without significant cost?
Carbon mitigation	Description of the net carbon use associated with a strategy (traditional flood control/defence approaches are carbon intensive; use of wetlands can have significant positive benefits and these are increasingly central to flood risk management choices)

5.6 Imagine the future – Develop scenarios of change

> Illustrating the future by means of scenarios is a way to overcome human beings' innate resistance to change. Scenarios can thus open mental horizons that allow the individual to accept and understand change, and so be able to shape the world. This approach may therefore help in seizing new opportunities ahead as well as avoiding undesirable effect or misconceived action.
>
> (Bertrand et al., 1999)

Uncertainty characterizes FRM decisions. By exploring different future scenarios, an understanding of what the future may look like and, importantly, how different strategies play-out in those futures, can be developed. Good scenario development is not straightforward, and demands a combination of expert dialogue support by quantified evidence. Some of the basic rules in good scenario development are outlined below:

- **Open minds to future change.** Experts must think laterally about change and not simply project forward existing trends. A comprehensive view of the potential drivers that might influence future flood risk needs to be considered and discussed. It is through this process that the status quo can be challenged and space given for innovation.

- **Distinguish autonomous from purposeful actions.** Autonomous developments (that is, all future developments that are not purposefully influenced by FRM measures and related policy instruments) and purposeful FRM actions must be clearly identifiable. Without this distinction benefits can be misattributed to FRM activities and resources unnecessarily invested (McGahey and Sayers, 2008; Klijn et al., 2009). Scenarios must also recognize the degree to which FRM is likely to influence future change. For example from a flood risk point view it would be an attractive future to permit no development within the floodplain, but this is likely to be impractical to achieve and not within the remit of flood risk managers alone to deliver.

- **Be internally consistent and evidence based.** Not all the combinations of future change are possible or plausible. Consistent scenarios are transparent in recording their assumptions and applying these consistently to each component of the scenario – the climate, demographic, morphology and so on.

- **Be capable of quantified analysis.** At the core of the scenario analysis lies a system flood risk model for estimating the severity and consequence of flooding, and a cost model for computing the different costs of FRM options. To be meaningful, risk analysis must reflect the performance of the whole system of sources, pathways and receptors and how each component of risk is influenced by change (Figure 35). If a whole-system risk model is used alongside quantified scenarios of change, alternative strategies can be appraised and used to support expert selection of the preferred approach.

Figure 35: Examples of factors that can influence future flood risk and scenario development

Factors influencing future increases in risk

Source
Climate change

Pathways
Land management change (e.g. agricultural practice)
Land use change (e.g. urbanisation leading to a change in run-off, loss of natural buffers)
Channel and nearshore change (e.g. vegetation, loss of beach sediments)
Deterioration of infrastructure

Receptors (exposure and vulnerability)
Development of the floodplain
Lack of awareness/complacency

Factors influencing future transfer of risk

Source
None

Pathways
None

Receptors (exposure and vulnerability)
Increased or decreased ability of insurance
Ownership of flood infrastructure
Legal responsibilities and requirements centtre

Factors influencing future decreased in risk

Source
Climate change

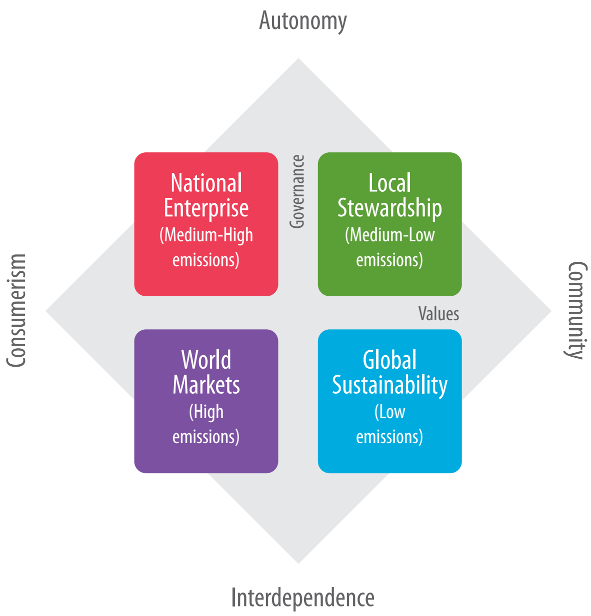
Pathways
Land management (e.g. run-off storage and attenuation)
Improved vegetation and morphology management
Flood control/defence infrastructure
Improved building construction and property scale protection

Receptors (exposure and vulnerability)
Relocation
Improved forecasting, warning and emergency planning
Widespread awareness and preparedness

Various methods exist to help develop meaningful future scenarios (see www.foresight.gov.uk). Scenarios can be considered as discrete futures or a continuous spectrum of futures. Each approach has its own advantages and disadvantages in the context of supporting FRM policy, strategy and engineering design, as follows:

- **Discrete storylines.** A small number (up to four or five) of contrasting scenarios are developed. This approach is widespread in the field of socio-economic scenarios (e.g. the IPCC (2000/2007) Special Report on Emissions Scenarios and the UKCIP 2002 (socio-economic scenarios, Hulme et al., 2002), where a set of narrative storylines are developed based on a small number of distinct worldviews. The performance of possible management actions is then assessed in the context of each discrete future, and actions that perform well in a wide range of futures identified. This approach is most useful for policy analysis which needs to be nuanced with respect to a wide range of attributes of the future, many of which may not be quantifiable. The approach is attractive in that it involves a small number of futures, so it is readily communicated. It has been used in the UK Foresight Future Flooding studies (Evans et al., 2004a, 2004b) and Schelde estuary planning (Klijn et al., 2009). In both cases, scenario analysis was used to explore high-level FRM policies and to successfully influence national policy (Figure 36). For example, in England and Wales it shaped the development of Defra's (2005) Making Space for Water strategy and the subsequent Floods and Water Management Act, 2008.

Figure 36: Four discrete scenarios were used in the UK Foresight Future Flooding project



Source: Evans et al., (2004a, 2004b).
Note: The vertical axis shows the system of governance, ranging from autonomy, where power remains at the local and national level, to interdependence, where power increasingly moves to international institutions. The horizontal axis shows social values, ranging from consumerist to community-oriented.

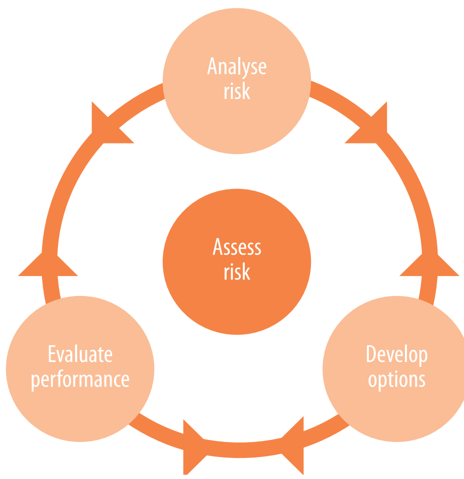
- Continuous scenario space: The disadvantage of the discrete storylines approach is that it deals with a relatively small number of scenarios. Moreover, the narrative basis requires further elaboration before it can be used to generate quantified inputs for decision analysis. An alternative approach, promoted most effectively by Lempert et al., (2003) is to explore the performance of alternative policies with respect to a continuous multidimensional scenario space. The dimensions of this scenario space are identified to represent the main uncertain variables in a decision. Analysis of option performance with respect to this scenario space helps to identify options that perform acceptably across a wide range of possible future conditions. This type of analysis offers advantages for engineering design in comparison with a discrete approach, as it provides the basis for quantified analysis of specific engineering alternatives and associated design characteristics (crest level and so on).

Once developed, using either approach above, the multiple futures underpin the assessment of risk and the selection of robust and flexible strategies (see below).

5.7 Assess risk

To assess risk the performance of alternative management strategies must be compared against set criteria and be based upon an appropriately comprehensive understanding of the probability and consequences as well as the associated uncertainties. Risk assessment therefore proceeds as a cyclic process of refinement until the assessment is considered fit for purpose in the context of the decision(s) being made. The most important aspects of this cycle are shown in Figure 37 and elaborated below.

Figure 37: The risk assessment cycle of analysis and evaluation



DEVELOP OPTIONS – DEVELOPING ALTERNATIVE STRATEGY PLANS AND ACTIONS

The specific mix of measures and instruments in a portfolio will be a function of the features of particular localities, and will continue to be adapted as knowledge is acquired and the reality of the future becomes known. Although there is no blueprint for the combination of measures and instruments that constitutes the best approach to managing flood risk, there is a common understanding of those that will, almost universally, form part any portfolio at any location (Figure 38).

Figure 38: Key components of any portfolio of measures and instruments to manage flood risk

1. Actions to raise **AWARENESS** of the chance of flooding
2. Policies and instruments to limit **exposure** and **AVOID** potential consequences
3. Measures to reduce **vulnerability** and **ALLEVIATE** the potential consequences
4. Measures to reduce the **probability** of floods and **PROTECT** people and property
5. Measures to **ASSIST** in the process of recovery
6. Policies and instruments that promote the development and implementation of portfolio-based and comprehensive **STRATEGIES**

Source: adapted from INTERREG EC Flood Resilient Cities, http://www.floodresiliencity.eu

The activities presented above act together to promote good FRM as follows:

Actions to raise awareness of the chance of flooding

Risk-based management strategies require a much richer understanding and communication of both the risks posed and the interactions between potential interventions and the change in risk. Awareness informs not only individuals (the public, stakeholders, investors and decision-makers) but also engineers and flood risk managers. Awareness leads to better understanding of :

- risk
- the nature and associated probabilities of potential floods
- the primary, secondary and tertiary consequences of flooding.

Policies and instruments to limit exposure and avoid potential consequences

The most reliable means of reducing risk is to reduce exposure and avoid development in areas subject to flooding. This is, of course, easy to say but often very difficult (if not impossible) to do (because of the pre-existing infrastructure, livelihoods, community issues and so on). Good spatial planning can however act to reduce risk through:

- removing critical infrastructure (hospitals, power stations and so on) from the floodplain
- promoting water-sensitive developments.

(There is more detailed discussion of this in Chapter 9).

In the United States, federal agencies are required by Presidential Executive Order to avoid, where possible, placing critical infrastructure in the 500-year floodplain, and where this is not possible, to protect these facilities against the impact of a flood.

Measures to reduce vulnerability and alleviate the potential consequences

Closely allied with activities to raise awareness and reduce exposure, early warning systems and the construction of safe havens (such as structurally sound taller buildings and purposefully elevated land areas) within the floodplain also provide a legitimate, and effective, means of reducing loss of life during major events. Embedding safe havens in the planning process and developing dual roles for buildings – as safe havens as well as their primary function – offers an important contribution to developing urban resilience. (This is discussed further in Chapter 11).

Measures to reduce the probability of floods and protect people and property

Structural measures, implemented as part of a portfolio, will continue to have a significant role in managing risk by acting to reduce the chance of flooding. If planned well, flood retention areas, flood storage systems, levees, dams, tsunami barriers and geo-embankments all form legitimate parts of FRM strategy. Many cities combine structural and nonstructural responses – for example Shanghai, London, and many cities in the Netherlands and New Orleans are protected by barriers and levee systems together with a variety of nonstructural measures. Measures to reduce the probability of flooding do not, however, all need to be large in scale. Small-scale actions are equally important, for example actions at the individual property level.

Applying more advanced asset management and risk-based thinking to the design and management of flood protection systems, as a subset of the overall response, has started to become more common. Approaches based on whole-life considerations, factoring in asset deterioration or emergent faults in construction, and how repair will be managed and financed throughout the life of the structure, are now all central considerations. Even so, maintenance remains the Achilles' heel of such structural approaches. Changes in organizational structures and priorities often result in a lack of resource support from central administrations to provide continued and adequate inspection and maintenance. These aspects are discussed further in Chapter 10.

Measures to assist in the process of recovery

To avoid long-term impacts, and widespread outrage, communities must be reinstated as quickly as possible in the aftermath of a flood. This is often dependent on the speed with which critical infrastructure can be recovered and reinstated, and people can be returned to their homes, or permanently relocated. It also depends heavily on the resilience of the governance structure and the pre-disaster planning in the community. Any redevelopment that takes place must be done in a planned manner, and opportunities should be taken to avoid repeating historical mistakes and to ensure fairness in redevelopment. Insurance has a key role to play here, and opportunities for betterment in terms of flood resilience should be sought. (Insurance is discussed further in Chapter 14).

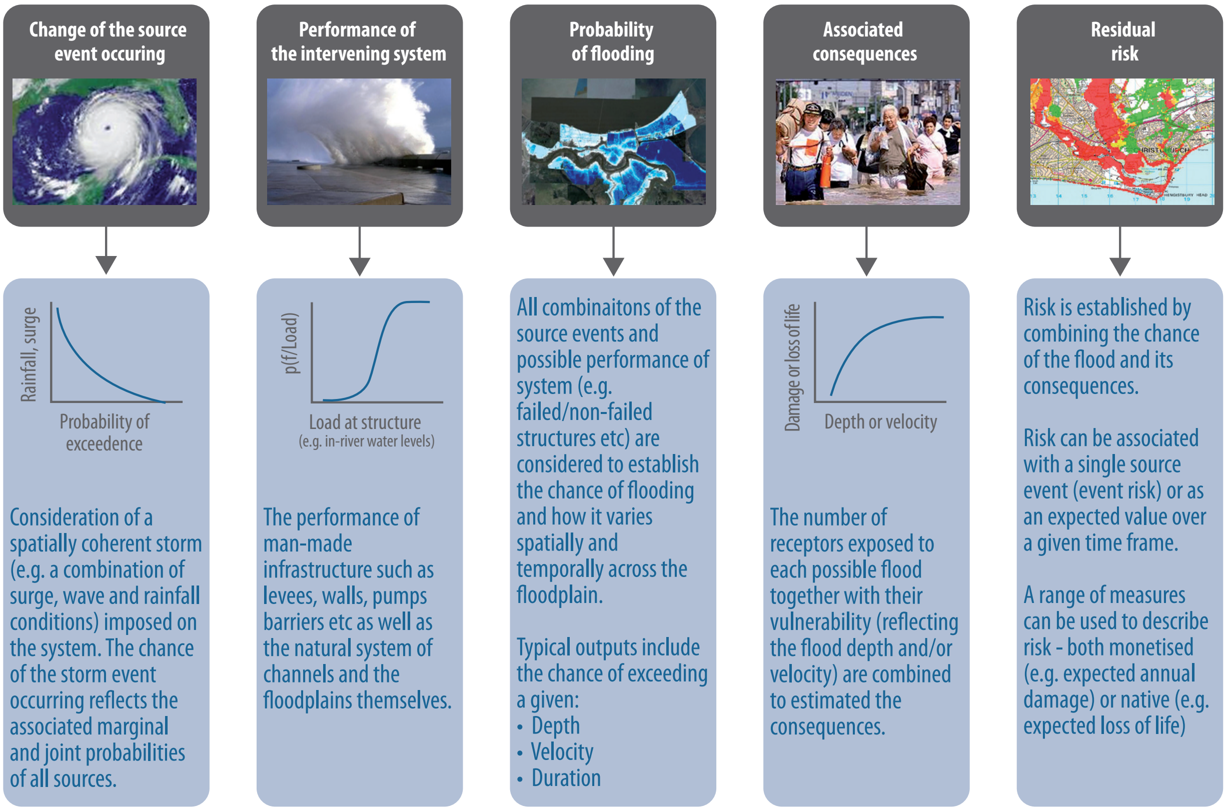
Policies and instruments that promote the development and implementation of portfolio-based and comprehensive strategies

To help ensure that the characteristics of good FRM (see Chapter 2) are embedded in the management strategies actually developed at a basin, regional or local level, it may be necessary to provide incentives to local decision-makers. For example, often the perceived additional costs associated with developing more adaptive solutions (which are often associated with greater short-term costs) can be a barrier. Therefore incentives such as grants and subsidies for the uptake of adaptive risk-based strategies and/or partnership working and cost-sharing can promote use of these approaches. Equally, mandating the publishing of hazard and risk maps, and making such maps a statutory consideration for planners, can help force better spatial planning decisions.

ANALYSE RISK AND UNCERTAINTY

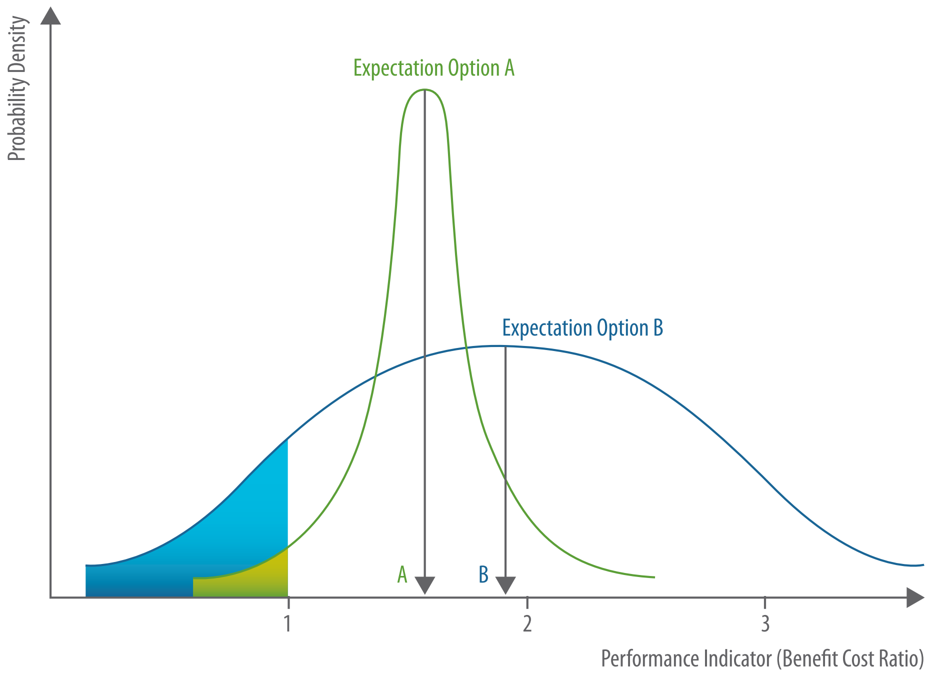
The analysis in support of the decision-making process must, first, analyse the change in risk, and second, identify the associated uncertainty in that estimate. The analysis of risk must appropriately reflect the performance of the whole system (Figure 39). This does not however imply that great detail is required throughout (Box 12).. The goal of the analysis should not be to eliminate uncertainty, a practical and philosophical impossibility, but to understand it and be clear on its importance in terms of the decision being made. The detail with which any aspect is resolved (that is, aspects such as the data and modelling effort) will therefore vary reflecting the particular demands of decision being made, and can be considered of sufficient detail when the decision would remain the same regardless of the recognized uncertainty within the evidence. If this is satisfied then no further refinement of the analysis is required.

Figure 39: The framework of whole-system risk model that underpins a credible analysis



Source: adapted based on Sayers et al. (2002) and Link and Galloway (2009).

Figure 40: Risk profiles associated with two alternatives. Option 1 has a greater expected BCR than Option 2, but is also more likely to realize a BCR of less than 1.



Source: Sayers et al. (2002).

Box 12: The need for completeness – although not equal detail – in the analysis of risk

The importance of considering a range of storm conditions

Traditional approaches (for example standards-based approaches) typical consider one or two design conditions (typically 1:100 or 1:200 years) and highly simply the performance of the defence infrastructure (often assuming it to either not exist or work perfectly to the design standard, then instantly fail when it is exceeded). Assessment based on such simplified assumptions at best provides limited data, and more importantly can misguide users into poor investment or planning choices. Risk analysis provides a much more honest discussion with the user, and hence supports risk-informed judgements. The discipline of risk management provides insight into the way flooding occurs and how flood risk may be efficiently reduced. This insight can be utilized in the later stages of option identification and evaluation.

Representing the intervening systems

In describing the probability of flooding it is important to recognize that the majority of urban centres around the world lie within natural floodplains and are defended from flooding by a system of defences, control structures and dams. Assessing the performance of these structures under stress is a vital component in assessing the probability of flooding. For example, the breaching of flood levees in New Orleans made a significant contribution to the severity of flooding. London and Rotterdam are protected from flooding by many infrastructure works. The Taihu basin, China lies in the delta of the Yangtze and is protected by a heavily engineered system of dykes and sluices. Failure to include the performance of this intervening system in the analysis of flooding can significantly mislead and misdirect priorities. Various tools are now starting to emerge to represent this combined system more formally (see for example the Modelling Decision Support Framework: McGahey et al., 2007, and the US Hydrologic Engineering Center's Flood Risk Management models (HEC-FRM): Dunn and Deering, 2009).

Reflecting all consequences

To estimate risk, the consequences associated with flooding must also be described. Estimates of flood depths, velocities and duration need to be combined with quantified representations of harm to establish the likely risk to people, property and environment. In many countries the assessment of economic property damages is fairly mature (Rowsell et al., 2010, Floodsite Task 9); however methods to assess risk to life or environmental habitats or species remain in their infancy (pioneering work in such assessment was accomplished for the post-Katrina Risk and Sustainability Report (IPET, 2009). Regardless of the methods available, an approach that assesses only those risks that can be quantified in certain terms must be avoided, and all potentially significant and important impacts must be included. Without a comprehensive view, FRM measures might be developed to reduce risk to unimportant receptors, simply because they can be measured.

EVALUATE PERFORMANCE AGAINST DECISION CRITERIA

Evaluation provides the evidence on which to base the selection of the preferred strategy. Making the 'best' choice relies upon an ability to assess the performance of alternative strategies against predescribed decision criteria (see Section 5.5). This is usually done by comparing the performance of (several) 'do something' options against a baseline (or reference) option (usually a consistently described 'do nothing' reference case enabling the value of 'doing something' to be assessed). The assessment must be based on an analysis over the time and spatial scales of interest, and consideration of whole-life costs and benefits as well as risk profiles (Figure 40).

In addition to considering the ability of a given strategy or measure to meet given performance criteria, decision-makers must also evaluate the broader issues of practicality and implementation feasibility. Typically all of these factors are brought together in an evaluation table. As an example, consider the use of evacuation as a nonstructural measure. Table 13 illustrates some of the outcome criteria related to evacuation. In actual analysis, evacuation would be judged against all outcome measures being considered, and, where possible, estimates of actual costs, either total or per capita (or per structure), would be included.

Box 13: The need for a comprehensive evaluation of impacts

The focus on economic BCA has frequently been criticized as neglecting the multitude of nonmonetizable benefits. Various attempts have been made to establish a common currency of risk (based on monetarization) using contingent valuation of noneconomic impacts (including human life). However, much debate continues. In the United Kingdom preference is currently given to maintaining the expression of harm in the native parameter of that harm (people, habitat and so on) where appropriate, and utilizing monetarized descriptions where it is practical to do so. A committee of the US National Academies recently reported that:

> Benefit–cost analysis should not be used as the lone criterion in deciding whether a proposed planning or management alternative in a . . . planning study should be approved. A more appropriate role for benefit–cost analysis is to serve as a primary source of information concerning the benefits and costs of project alternatives, and the groups who gain most from a project. This separation of the role of benefit-cost analysis from its use as a mechanistic decision criterion would reduce the pressure on Corps analysts to seek a high degree of precision, which does not always reflect a similar degree of accuracy.
>
> (NRC, 2004)

Currently, US flood damage reduction studies do not consider the value of life in the conduct of analyses. However, the US Congress recently directed that public safety be included as a component of project analyses.

Table 13 Example of an option evaluation table to improve evacuation in the event of flooding

Measure/desired outcome	Reduction in loss of life	Reduction in property loss	Protection of critical infrastructure	Costs	Social challenges	Other factors
Evacuation	Reduces to near zero	Minimal impact structure loss; some reduction in personal property loss	Minimal impact	Relocation process; temporary lodging; structure rebuilding; individual compensation	Can only be used infrequently; high social disruption	Minimizes damage to the natural environment

5.8 Choose a preferred strategy – making a robust choice

Determining what to do would be a straightforward given perfect information and objective outcomes to be achieved. In reality, however, uncertainty in both information and the outcomes to be achieved complicates this process. An underlying desire to maintain the flood risk systems' ability to perform acceptably (that is, avoiding catastrophic failure, limiting residual risk, maximizing environmental gain, and avoiding waste of resources) in the context of the widest set of plausible futures drives the need for a change in thinking – and a desire to make 'robust' choices.

Developing risk management strategies in the context of these severe uncertainties demands a new way of appraising alternative strategies. Various useful and useable tools are starting to emerge, including:

- **Defining robustness in the context of a range of future scenarios given a set of plausible futures.** There is a range of formal robustness methods, including robust-satisficing, robust-optimization and hybrid approaches (elaborated further in Chapter 8). Such approaches try to ensure that a range of minimum performance criteria is satisfied (for example safety-related or legislative, perhaps relating to protection of habitats or maximum loss of life) while maximizing the return on investment (assessed for example by net present value).
- **Flexibility through using multi-staged decision pathways.** In a changing world, a linear model of FRM strategy development is no longer valid, and multistaged adaptive approaches are required (Table 14). In this context, adaptive management provides an opportunity to modify both the strategy and components of the strategy as the reality of the future becomes known and/or predictions of the future change. The concept of decision pathways, based on a progressive approach to decision-making, where decisions that foreclose further choice are avoided or delayed as long as possible, is shown by way of an example in Figure 27.
- **Building adaptive capacity decisions.** Uncertainty not only impacts on strategy planning, it fundamentally influences the way specific components of the strategy are developed – promoting resilience and adaptive capacity in all measures and instruments.

Fundamentally, however, a 'good choice' ensures that the course of action taken is better than all others, taking into account all important economic, social, environmental and technical issues for a full range of options. Identifying the preferred strategy typically relies upon a process where:

- the complexity of choice is simplified through initial screening
- the impact that different strategic choices have on risk and the associated investment, is well understood and uncertainties acknowledged
- this understanding is shared by stakeholders.

Table 14: Example responses to manage uncertainty

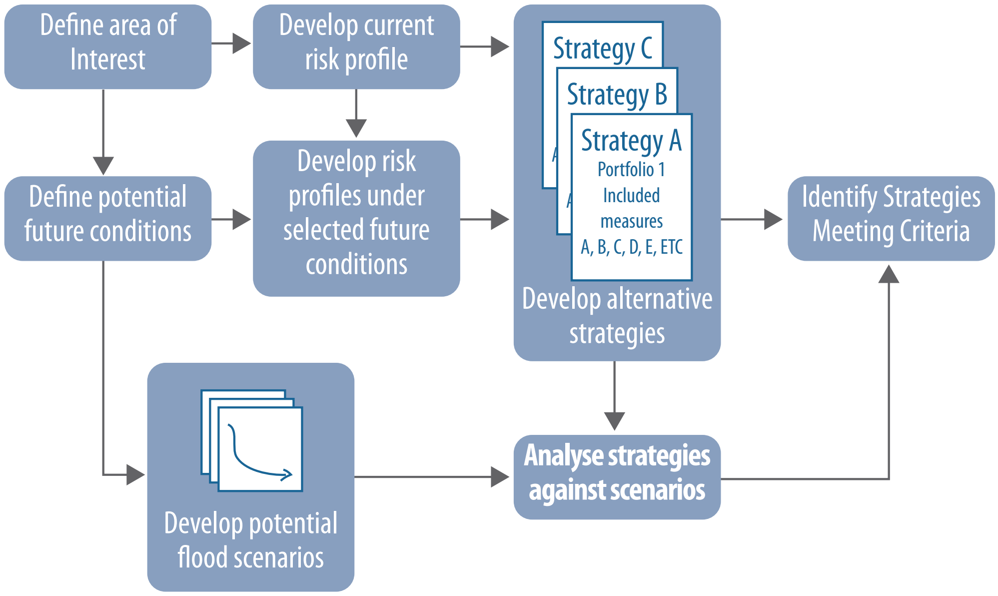
Practical responses to manage uncertainty	Description
Monitor and decide	Monitoring places a central role on adaptive planning – enabling approaches to be changed as the reality of the future becomes known
Increase knowledge	Research and development offer significant opportunities to reduce uncertainty and target risk management more specifically
Avoid	Avoiding exposure to flooding through development control provides a robust means of managing uncertainty
Seek robust approaches	Seek to implement approaches the work acceptably well in a wide range of plausible futures
Seek resilient approaches	That embed an ability to cope with floods and continue to perform
Develop self-regulating systems	Allow room for natural systems to change with climate change – for example natural systems such as dunes and wetlands will naturally migrate and change as appropriate
Insure	Transferring risk to third parties
Develop 'Fail-safe' systems	Plan for failure, limiting the opportunity for risks to cascade and escalate through the community
Overdesign	Embed an appropriate degree of overdesign – this will cost more but can be useful for critical aspects
Build in redundancy	Relying on a portfolio of measures for management, rather than a single measure, provides redundancy in the management system

5.9 Development and selection of the best portfolios

Given the large number of measures and instruments that are available for use in reducing risk, the determination of which measure to use is a challenging task. At its simplest level, a single policy response could employ only nonstructural measures to the maximum extent feasible. More normally many more complex responses are possible, and the fittest of these, often in seemingly infinite combinations, must be identified.

Group-based expert elicitation provides a powerful means of identifying a number of most promising alternatives, which can then be assessed and compared to identify their relative effectiveness in terms of the desired outcomes and other impacts they produce under a variety of future storylines, including hypothesized extreme future floods and historical floods (Figure 41).

Figure 41: Expert judgment coupled with system risk models (both qualitative and quantitative) play a central role in evaluating the performance of different portfolios of measures against a range of possible future scenarios

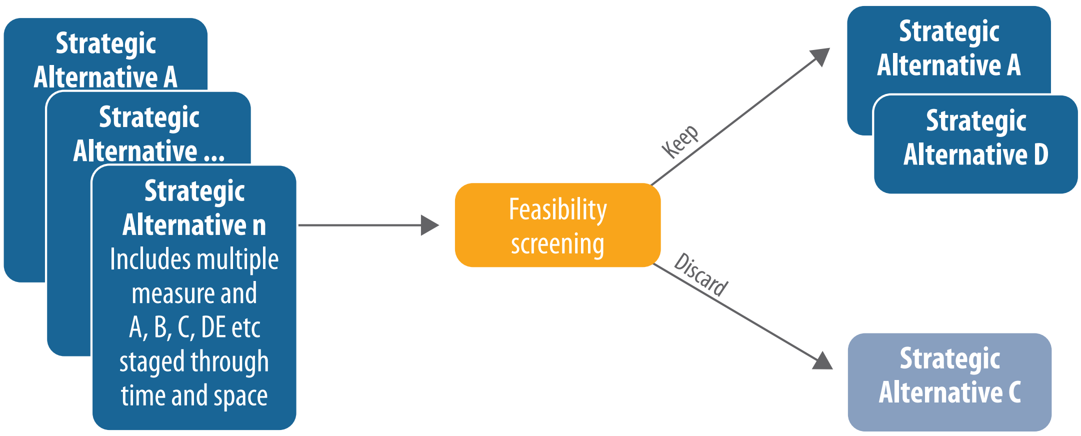


The system risk model can vary from an expert review through to numerical simulation using process-based models or more conceptual serious gaming technologies. Critical in either case is recognition that system risk models provide only the evidence to the decision-makers – not the decision itself. The results from the analysis of multiple futures and strategies can highlight a series of optimal strategies for a given level of expenditure and against different criteria (economic, loss of life and so on - see for example Woodward et al., 2010). There is, of course, no unique optimum, and the preferred choice relies upon assignment of the relative weights of each of the desired outcomes. Is loss of life more important than loss of property, and if so by what factor? Assignment of weights can be accomplished by decision-makers in a Delphi or other decision-support process or through processes that involve stakeholders in establishing the weighting factors. The output of the model is a relative ranking of each of the portfolios against each of the scenarios. The scoring process may provide a basis for discarding certain portfolios as nonresponsive to the objectives. It might also indicate that none of the portfolios are satisfactory and that new portfolios must be developed.

5.10 Ensuring implementation

Once strategies are identified that meet the basic criteria, these portfolios must be screened for feasibility of execution (Figure 42). During this process, alternative strategies are examined more closely to determine the feasibility of their use under the physical and social circumstances existing at the time of the screening. A common mistake is to throw out options that challenge the status quo as being infeasible. This must be avoided and challenged to ensure the most innovative approaches are retained. Some strategies will however be screened out. For example, is it feasible to rely on insurance? Is there sufficient room for construction of a major levee or floodwall in an existing urban area? Are adequate resources available to fund the projects? During this step, engineering, environmental and social professionals and decision-makers must work together to identify and accurately record reasons for declaring a particular measure not feasible. Decisions must also be made on whether the elimination of one or more measures reduces the viability of a particular strategy as a whole, so that it should not be considered further.

Figure 42: Screening for the feasibility of implementation



5.11 Act – to reduce risk and deliver outcomes

To reduce risk and to prevent risk from increasing inappropriately, actions must be taken. In the context of an uncertain future it may be appropriate to implement the first stage in a multi-stage strategy, or act in one area but not another. Action may also require a long lead time in periods of national policy change or planning decisions. Implementing the strategy will undoubtedly require a change in behaviour from many stakeholders, from the way engineers develop detailed designs to the way homeowners behave, and the way planners make decisions (Table 15).

5.12 Monitor – performance and change

Once an FRM plan has been implemented and nature has been given the opportunity to operate against this plan, it will be possible to evaluate the plan's performance. Success criteria were defined early in the planning process and action should have been taken, concurrent with the implementation, to establish a programme to monitor achievement of the success criteria and to identify shortfalls and potential problems.

Immediate action must be taken to address deficiencies in the plan that threatens the integrity of the FRM system. However, adequate time must be allowed for a complete evaluation of plan performance. Moving too rapidly to adjust the plan in reaction to a single event negates the concept of whole-life evaluation. A sound plan will have been developed to deal with a variety of situations, and a shortfall in addressing one situation might not reflect the performance of the system over the spectrum of situations.

Quite frequently, in the implementation of an FRM plan the focus is placed entirely on construction of structural measures and execution of nonstructural activities, and little attention is given to development of the monitoring systems needed to assess plan performance. The situation frequently becomes worse after implementation, when monitoring falls to the bottom of the priority list in organizations that are short of funding.

Table 15: Desired changes in behaviour and information, and tools that would support these changes

Target audience	Behavioural change desired (examples only)	Information and tools (examples only)
Homeowners	Buy flood insurance. Elevate/floodproof home.	Information provided through the US National Flood Insurance Program. Height of potential flooding. Information on state assistance with floodproofing. Calculator of household damage at various depths of flooding.
	Elevate/floodproof home.	Information on state assistance. Technical specifications. Articulation of financial benefits. Calculator of household damage at various depths of flooding.
Individuals living in an areas with levees and raised watercourses	Develop emergency plan.	Examples of emergency plans. Height of potential flooding. Evacuation routes. Checklists for what to take and timeline.
	Evacuate when requested.	Marked evacuation routes. Email alerts. Checklists for what to take. Articulation of consequences of staying.
	Observe levee for problems.	'Levee watch' programme.
	Support levee safety programmes through resources (taxes) for operation and maintenance.	Inspection reports. Levee system assessments, stating consequences associated with deficiencies.
Levee owner	Maintain reliable levees, repairing and rehabilitating as necessary. Inform the public if the levee is in danger of failing or being overtopped.	Inspection reports and assessments. Make deficiencies public. Better understanding of liability. State programme enforcement.
Regional and local governments	Develop and maintain robust levee safety programmes.	Information regarding number of people at risk. Estimates of damage to critical infrastructure and economic impact. Need for compliance with regulatory levee safety programmes.
Technical societies	Explain how levees are designed to work and limits of their use.	Current standards and information on where problems with these standards are occurring. Review of proposed new standards.
	Lobby for funding required for levee infrastructure upgrades.	Existing lobbying programmes. Existing education and public awareness programmes sponsored by societies.
Developers, land agents and homebuilders	Promote floodproofing in new construction and renovation.	Long-term benefits to clients and customers, and the sustainability of the community as a whole.
Media	Reporting on levee safety programme creation and progress. Educating public about levee issues. Developing a cadre of levee experts.	Information about compliance. Educate the public about potential consequences of levee failure. Statistics on what is protected by levees.
Schoolchildren	Increase geographical understanding of students protected by levees, and awareness of benefits and risks. Encourage parents to know how to evacuate, and practice (similarly to fire drills).	Education programmes. Field trips. Incorporate into history and geography curriculum.
Insurance organizations	Provide financial benefits to those who take steps to mitigate damage through raising buildings, floodproofing, preparing emergency plans.	Mitigation measures that can be provided to customers.

Source: adapted from NCLS (2009).

5.13 Review – re-evaluate and reconsider

When review of the performance of the system indicates the need for change, flood risk managers must clearly describe the situation to higher-level decision-makers, indicating to them that such needs for adjustments are part of the cyclic execution of FRM. Given the uncertainties connected with natural systems, the materials used in construction of structural measures, and public reaction to nonstructural measures, the need for such adjustments is normal. Decision-makers must then agree on the next actions.

Once a decision has been made that adjustments will be made in the plan in order to meet the success criteria, or it is determined that the success criteria themselves must be adjusted, the FRM cycle begins anew.

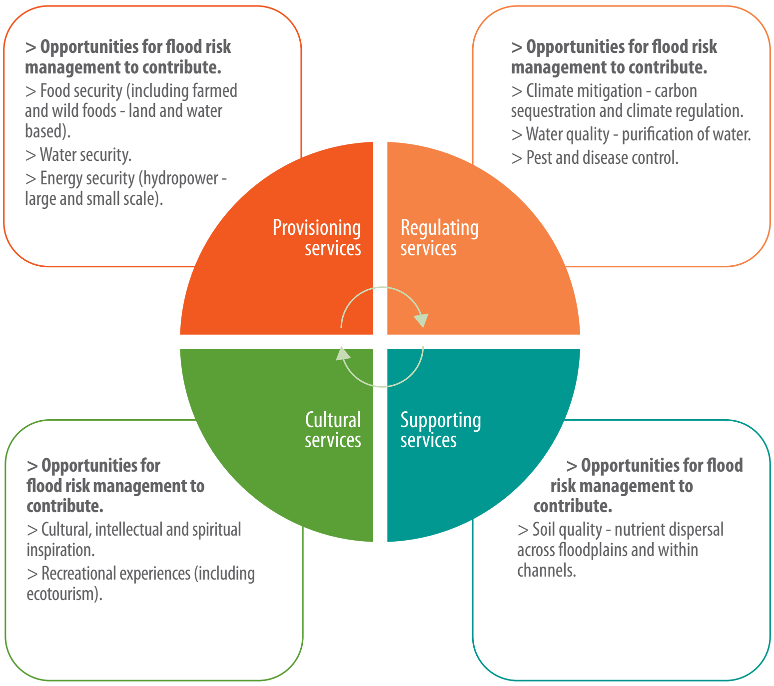
CHAPTER 6
SAFEGUARDING AND PROMOTING ECOSYSTEM SERVICES THROUGH FRM

6.1 Introduction

Complex ecosystems underlie river and coastal systems and are fundamental to the well-being of society as a whole. Colloquially, ecosystem services have been described as 'the benefits of nature to households, communities, and economies' (Boyd and Banzhaf, 2007). The Millennium Ecosystem Assessment (2005) defined them as provisioning, regulating, cultural and supporting services, and examined how changes in ecosystem services influence human well-being. Human well-being in this context is assumed to have multiple components, including security, which encompasses secure access to natural and other resources, personal safety, and security from natural and human-made disasters. Therefore, security from disaster is a primary constituent of human well-being, which in turn is intrinsically linked to ecosystem services.

If implemented well, FRM can have a major positive influence on services provided. If done poorly, it can have a dramatic and devastating effect (Figure 43). This chapter reviews some of the practical approaches to safeguarding and promoting the environment through the use of 'soft path' measures (such as land use changes, wetland storage and floodplain reconnection) and 'hard path' measures (such as bypass channels and controlled storage), while simultaneously delivering effective and efficient flood risk reduction.

Figure 43: The four characteristics of a healthy ecosystem and mutual opportunities with flood risk management



6.2 Options for delivering flood risk reduction and promoting ecosystem services

The use of natural or green infrastructure for flood storage and enhancement of other natural features in the floodplain provides not only an effective method of mitigating floods, but also a cost-efficient method of reducing the need for major structural projects. The use of green infrastructure is aligned with the shift in thinking from flood defence to modern-day FRM. Embedding an environmental ethic in FRM means both taking advantage of natural systems to reduce flood risk, and ensuring that any measures adopted minimize adverse impacts on the environment.

Green infrastructure represents the use of natural processes to carry out functions that have in the past been linked solely with the built environment. Green infrastructure is especially appropriate for use in FRM as floodplains have a natural storage capacity and slowly release floodwaters, reducing peak flood flows downstream. Working with natural processes in FRM means protecting, restoring and emulating the natural regulating function of catchments, rivers, floodplains and coasts (Environment Agency, 2010). Central to the idea is working with the river (and flooding) rather than against it. Many of the world's floodplains and upland areas were once filled with wetlands and swamp forests. Where they are available or where they can be restored, they can be used effectively to reduce flood damages.

A focus on green infrastructure does not negate the need for physical infrastructure; 'soft' and 'hard' approaches can complement one other. Harnessing opportunities for reducing flood risk through natural processes can extend the life of structural defences and in addition reap multiple other benefits due to the synergies among different ecosystem services. Moreover, natural options generally require less investment and maintenance than built defences, providing a cost-efficient method of reducing the need for major structural projects. There are also growing concerns about the ability of existing flood management structures to cope with impacts of climate change. In many parts of the world the intensity, duration and variability of rainfall events is projected to increase, which will necessitate either the costly improvement of existing structures, or consideration of alternatives. In this context, green infrastructure represents an opportunity for climate change adaptation. A number of examples of using green infrastructure for FRM are discussed below.

RIVER WETLAND AND WASHLAND STORAGE

Floodplain wetlands can play an important role in flood mitigation, acting as 'natural sponges' for floodwater storage and regulating flow. This flood attenuation function occurs both on large floodplains in the lower parts of the river where large hollows and depressions can store excess water, and in upland areas where the rivers begin. Due to the multiple ecosystem services derived from wetlands, restoring, protecting or creating wetlands will provide other benefits, such as erosion control, improved water quality, aquifer recharge, stabilization of micro-climate and recreational value.

Box 14: Sustainable wetland restoration for flood risk management on the Yangtze River, China

The Yangtze is the longest river in Asia, and third longest in the world, rising in the high mountains of Tibet and meandering 6,300 km before reaching the East China Sea. Intensive land reclamation for agriculture and urban development led to the loss of large areas of the natural floodplain during the twentieth century and first decade of the twenty-first century. Wetlands and natural lakes have become disconnected from the river, disturbing natural processes and causing the loss of their natural flood retention capacity. Flood risk has been further heightened by large-scale deforestation in the river basin.

The Chinese Ministry of Forestry developed a National Wetland Conservation Action Plan which was completed in 2000. This Action Plan serves as a guideline for the conservation and wise use of wetlands, with an aim of extending the area of wetlands under protection. One restoration programme in Hubei province involved opening sluice gates to reconnect the Zhangdu, Hong and Tian Zhou lakes and their wetlands to the river. An area of 448 km^2 of wetland was restored, providing storage for up to 285 million m^3 of floodwaters.

The restoration of wetlands is part of a broader conservation and sustainable river basin management plan which includes addressing unsustainable fishing and agricultural practices. As well as providing key flood mitigation by allowing natural seasonal flooding, the project has led to significant improvements in water quality, and benefited migrating fish and wildlife populations. Successful demonstration projects have stimulated government investment and commitment to expanding and replicating wetland restoration work throughout the central Yangtze region.

The occasional provision of flood storage on land used for agriculture or other rural land is also a potentially important FRM option, enabling these lands to act as wetlands to provide flood mitigation to downstream areas. In some countries there is an ongoing shift in land use in some floodplain areas from predominantly agricultural production to types of land use that need less protection against flooding, simultaneously providing floodwater storage and enhancement of biodiversity and amenity, carbon storage (on peatlands for example), and potentially providing alternative sources of income to land managers (Morris et al., 2008). Here 'natural processes' are harnessed to support FRM in the catchment.

In this context, the term 'washland' is often used to denote flood storage areas typically isolated from the main river by some form of natural or designed hydraulic control, used during times of high flow to attenuate flooding downstream in the catchment. The degree of attenuation depends on the volume of storage provided (relative to the magnitude of flows), the degree of control over the timing of filling, and the rate at which water can be evacuated after the event in preparation for subsequent events.

From a flood management perspective, the potential contribution of a washland or a wetland area depends not only on its capacity to store flood water, but often more critically, on the ability to control intake from and release back into the main river system. In general, a greater degree of control requires a greater degree of engineering intervention but also allows a greater degree of flood attenuation (Morris et al., 2005). Maximum flood attenuation is achieved by delaying the flood peak as much as possible – which requires both control over the timing of the filling of the storage and knowledge of the flood hydrograph (Förster et al., 2008).

Where land in the floodplain is to be used for temporary flood storage, the options for land use depend on the frequency, duration and the seasonality of flooding and the level of the soil-water table, regulated by the level of flood protection and land drainage respectively. High levels of protection from flooding and the control of field water levels to avoid waterlogging are required to support arable farming in floodplain areas. Less intensive land uses, such as wet grassland and woodland, can tolerate lower standards of flood protection and land drainage. They also tend to be associated with provision of nonmarket goods and services, such as nature conservation, amenity and carbon sequestration.

COASTAL AND ESTUARINE WETLANDS STORAGE AND ENERGY DISSIPATION

Coastal ecosystems and their natural features such as mangroves, sand dunes, barrier islands and shingle ridges retain water and dissipate wave energy, acting as a buffer against tidal waves, storms and coastal flooding. Lagoons and salt marshes can divert and withhold floodwaters. These natural functions can be promoted by restoration activities such as salt marsh regeneration and dune and shingle ridge naturalization. Managed realignment involves removing or setting back 'hard' coastal defences, allowing tidal flooding and the recreation of salt marsh or mudflats which act as natural flood buffers. One benefit of natural systems over hard flood defence structures is that they often show remarkable resilience. A resilient system is one that can absorb disturbances or reorganize itself in order to retain its character and ecological functioning (see Table 16 and Box 15).

Table 16: Relative importance of different wetland types for natural hazard regulation

Coastal wetlands	Inland wetlands
Estuaries and marshes	Permanent and temporary rivers and streams
Mangroves	Permanent lakes, reservoirs
Lagoons, including salt ponds	Seasonal lakes, marshes, swamps, including floodplains
Intertidal flats, beaches and dunces	Forested wetlands, marshes, swamps, including floodplains
Kelp beds	Alpine and tundra wetlands
Rock and shell reefs	Springs and oases
Seagrass beds	Underground wetlands, including caves and groundwater systems
Coral reefs	

Box 15: New Orleans, Louisiana, USA: Coastal wetland restoration provides a critical component of the protection

New Orleans was first settled in 1717 by the French. At that time it served as an inland port for commerce to the New World and was relatively protected from hurricanes and coastal storms by a vast coastal wetland extending from New Orleans into the Gulf of Mexico. It has been estimated that every kilometre of wetland extending into the Gulf was capable of reducing the height of hurricane storm surges by 1–2 cm. Human actions, which included construction of levees on both sides of the Mississippi River from New Orleans to the Gulf and extensive channelization to support the oil and gas industry operating along the coast, resulted in an annual loss of 6500 to 10,000 ha of wetlands each year. Hurricane Katrina alone caused the loss of 31,000 ha of wetlands. Losing these wetlands was the same as losing part of a structural flood control system.

As part of the of the task of providing protection for New Orleans, the oil and gas industry along the coast, and the thousands of residents who populate the region, federal and state governments are undertaking a major coastal wetland restoration project, the total cost of which will exceed $20 billion. Where these wetlands can be restored, they can be used effectively to reduce flood damages. In addition to providing great benefits for flood mitigation, when the floodplains and coastal areas are restored, they also provide many other beneficial functions. This makes the use of wetland areas for flood mitigation even more important. Natural and beneficial functions of the floodplain can be enhanced by effective use of the floodplain and the flows that move through it. At the centre of these restoration efforts will be the construction of diversions of Mississippi River sediment and freshwater from the river into the wetlands to restore the processes that initially created the Mississippi delta. These diversions will provide for marsh reestablishment, the strengthening of natural ridgelines, and the building or restoration of barrier islands.

LOCAL SCALE – RUNOFF QUANTITY AND QUALITY CONTROL

On a local scale, sustainable urban drainage systems (SUDS) have been proposed as a means to manage runoff and increase storage. Urban areas face particular challenges for FRM because of the extensive transformation of natural land surfaces into impervious surfaces, and the limited space available. SUDS are designed to mimic natural drainage processes, and examples include retention ponds, detentions basins, filter strips on vegetated land, green roofs (see Box 16), swales and infiltration trenches. Structures are being built with below-ground temporary detention areas with nearby storage ponds such that new development does not cause an increase in the runoff in the downstream flows. At the same time these detained waters provide ecosystem goods and services in various ways to the local environment.

Stormwater transfer to groundwater via seepage drains is also a possibility (as used in Male, the Maldives, where groundwater is sparse). Such approaches do not come without significant difficulties however, particular in terms of the negative environmental impact they may have in term of groundwater contamination.

Box 16: Local runoff management

Managing the run-off from building through green roofs and below-ground storage

Around the world new buildings are being constructed with green roofs – roofs with natural vegetation that will capture rainfall and hold it on the building – and local below-ground storage. Once established, the roof vegetation can reduce the peak flow as well as total runoff volume, storing water which is released back into the atmosphere by evapotranspiration, providing a space-efficient means for mitigating urban flooding. As well as absorbing rainfall, green roofs provide wildlife habitat, help lower urban air temperature, insulate buildings, reduce noise and air pollution, and offer aesthetical appeal. This quiet revolution is spreading throughout cities in Europe and the United States. In some countries financial incentives are offered to encourage the uptake of green roof technology, and some cities have even made it a legal requirement (for instance, in Germany and Switzerland).

Chicago's City Hall building – the first municipal building in the United States to host a green roof

Source: Image from http://teachers.egfi-k12.org/lesson-green-roof-design/

Planting bamboo helps protect villagers against monsoon flooding in Assam, India

Nandeswar village is located in the Goalpara district of Assam, India. The region experiences severe flooding during the monsoon months from June to September. Local communities plant bamboo along channel embankments to prevent them from being breached and to protect bridges and roads from damage. Planting bamboo along paddy fields and fish ponds also prevents soil erosion and stops water from flooding low areas during peak flooding days.

Source: UNISDR (2008).

CATCHMENT-SCALE RUNOFF MANAGEMENT

The way in which land is used and managed interacts with hydrological processes in the river basin, presenting opportunities for reducing flood risk through catchment management. Central to this approach is the conception of the river basin as a dynamic and interconnected environment, where actions in one place can have consequences elsewhere. For example channelization and levees, while providing isolated local protection, can speed up the flow and cause flooding downstream. Catchment-scale management addresses the cause of flooding at source. It requires a detailed understanding of the natural processes that influence the generation and conveyance of floodwaters. Land use and management is then strategically planned to facilitate natural flood regulation services. For example upland forestry is well recognized for its role in reducing flood flows; it intercepts rainfall, increases infiltration, reduces soil erosion and increases evapotranspiration. Further downstream, vegetation along a river bank increases the roughness of the channel, which slows the flow of floodwaters. Other techniques include managing hill slopes, restoring wetland features, enhancing soil condition and controlling erosion, reconnecting floodplains, restoring river channel meanders, and managing large woody debris in rivers. Crucially, any individual measure must be considered in relation to the whole catchment, and all other flood mitigation measures.

Practices that reduce soil compaction and improve soil structure can modify runoff by enhancing the infiltration capacity of the soil and thus facilitate the movement of water into and through the soil profile, often increasing sediment yield into the river systems too. These practices include low livestock stocking rates, grazing management to avoid damage to soil surfaces, use of field machinery with low ground pressure tyres to avoid compaction of soils, avoidance of field operations under wet conditions, soil improvement measures including conservation tillage, and field drainage using either pipes or temporary 'mole' drains.

Practices that influence the degree of flow connectivity, that is, the rate at which water from fields discharges into watercourses, include those concerned with restraining flows in fields and on the boundary of fields. In-field measures which 'break' the slope include contour ploughing, artificial bunding and retention ponds. Field boundary features include hedgerows, stone walls, field margins, buffer strips and woodlands. These are particularly effective if combined with measures to improve infiltration. For example, in the Nant Pontbren catchment (mid-Wales) shelterbelts were established in selected pastures of land used for sheep grazing. Infiltration rates were up to sixty times higher in areas planted with young trees than in adjacent grazed pastures (Carroll et al., 2004). It was suggested that tree shelter belts could reduce flood peaks in this catchment by up to 20 per cent (Wheater et al., 2009).

Table 17 contains examples of mitigation measures to control runoff on agricultural land as a pathway, classified by broad response themes.

Table 17: Measures to control flood generation from agricultural land

Response theme	Specific measure	Examples
Water retention through management of infiltration into the catchment	Arable land use practices	Spring cropping (versus winter cropping), use of cover crops. Intensification, set-aside and arable reversion to grassland.
	Livestock land practices	Lower stocking rates, reduced poaching, restriction of the grazing season
	Tillage practices	Conservation tillage, cross-slope ploughing
	Field drainage (to increase storage)	Deep cultivation and drainage, to reduce impermeability
	Buffer strips and buffering zones	Contour grass strips, hedges, shelter belts, bunds, riparian buffer strips
	Machinery management	Low ground pressures, avoiding wet conditions
Water retention through catchment-storage schemes	Upland water retention	Farm ponds, ditches, wetlands
	Water storage areas	Washlands, polders, reservoirs
Managing connectivity and conveyance	Management of hillslope connectivity	Blockage of farm ditches and moorland grips
	Buffer strips and buffering zones to reduce connectivity	Contour grass strips, hedges, shelter belts, bunds, field margins, riparian buffer strips
	Channel maintenance	Reduced maintenance of farm ditches
	Channel realignment	

Source:adapted based on Lane et al., (2007), O'Connell et al., (2004).

BLUE CORRIDORS

The term 'blue corridors' relates to the use of strategically designed urban flood routes that direct flood flows through urban areas to temporary storage areas (parks and other green spaces within the floodplain but remote from the river course). Typical interventions range from major re-engineering of the urban environment to direct flow waters, through to more subtle modification of existing infrastructure to modify the path of flood flows and create preferential flow routes – for example the use of 'flood bumps' to direct flood flows along specific highways/roadways away from higher-impact areas to areas of low impact.

Box 17: The effects of clearing naturally forested in the Comet River catchment in Central Queensland, Australia

Siriwardena and colleagues (2006) present in their research the effects of clearing naturally forested areas for grass and cropland in the Comet River catchment in Central Queensland. The Comet River has a large upstream catchment of approximately 16,400 km^2 and ultimately drains to the Fitzroy River. The native vegetation of the catchment was predominately acacia, eucalypt and softwood scrub trees. This vegetation was largely cleared during development in the 1960s, with cover being reduced from approximately 80 per cent to 38 per cent. The map provides an overview of the Comet River catchment and land use.

Siriwardena et al (2006) examined flows during two similar long-term climatic periods, one representing the pre-clearing period from 1920 (hydrologic year) to 1949, and the other representing the post-clearing period from 1971 to 2000. The stream flow recording gauge recorded flows for both periods.

Overall, they found that while rainfall for the post-clearing period increased over the pre-clearing period by 8.4 per cent, the total runoff increased by 78 per cent. The maximum runoff during the pre-clearing period was 82 mm whereas the maximum flow post clearing was 121 mm. (However there are questions regarding the accuracy of the gauge at high flows). The trend established by examination of the flow rating curves indicated a significant change in flood flows, though less so at greater return intervals – a finding consistent with other studies.

Source: WWF (2011).

6.3 Safeguarding the environment – minimizing environmental impact

Interventions within the river system with a view to reducing flood risk can either be done in a way that is detrimental to the environment (often unnecessarily), or be sensitive to the natural processes and minimize impact. Traditional 'hard' flood control measures such as levees, reservoirs, dams and channelization have significantly altered the natural environment. Any action that modifies a flood regime should be considered carefully in terms of its potential impact on ecological and morphological processes. Such an assessment should provide key input to the decision-making process when options are being evaluated.

Box 18: Ecosystem degradation and flooding, Viet Nam

Urbanization, the increasing impacts of climate change and the effects of rapid population growth, globalization and industrialization have all contributed to devastating catastrophes in Viet Nam's recent history, including the floods of 1999 in the central Thua Thien Hue province which claimed 325 lives and caused damage estimated at US$120 million. Additionally, the degradation of ecosystems, through deforestation and the conversion of traditional agricultural land to residential areas, has exacerbated the impact of floods, prolonging inundation in lowland areas and creating more flash flooding in upland areas.

The linkages between urbanization, economic development and disaster risk are manifest in Thua Thien Hue province. Impacts traverse the natural and social environments. Deforestation in the highlands has not occurred in isolation from urban demands for timber, the relocation of people from one region to another and the push for agricultural land to increase crop production and export income. Spatial linkages have not been reflected in environment and disaster management policies for the province. In addition, limited stakeholder engagement in the process of formulating disaster and environment management plans has undermined and weakened the connection between provincial levels and local communities. As a result the policies and programmes designed for disaster risk management have been considered impractical.

In order to successfully mitigate impacts of disasters it is now recognized that hydro-meteorological disasters are an integral component of the challenges of sustainable development and environmental management, and not just a matter of planning for emergency aid and humanitarian assistance. This perspective links not just the rural–urban continuum but poverty alleviation, stakeholder empowerment, and the allocation of public and private functions and responsibilities.

This integrated approach also requires an assessment of trade-offs and the need to understand the implications of forgoing short-term economic benefits for long-term environmental and social sustainability.

Source: Tran and Shaw (2007).

MAINTAINING SEDIMENT AND MORPHOLOGICAL DYNAMICS

Sediments are part of the complex relationship between landform (morphology), natural processes and flood risk. The distribution of sediment and the flood regime are important determinants of the channel and floodplain morphology. The disruption of natural sediment dynamics has implications for future flood risk, yet this is frequently overlooked in flood management. Developing environmentally sensitive flood management measures requires a comprehensive understanding of sediment transfer and its relationship with river system morphology. Deposition of sediment can increase flood risk by raising the level of the river bed. The problems caused when sediment transportation is impeded by dams are well documented, and the difficulties imposed by sedimentation cannot be illustrated more dramatically than by the case of the Yellow River in China (Box 19).

Box 19: Sediment management in the Yellow River, China

The Yellow River has the greatest sediment load of any river worldwide. It transports a mean annual load of 1.6 billion tons of yellow sediment each year which originates from the expansive Loess Plateau, giving the river its colour and its name. Only 25 per cent of this sediment is carried to the sea, with the rest deposited on the riverbed. As a result the bed of the river has risen an average of 5 to 10 cm each year, causing the river to change its course several times, and to increase the risk of flooding. These dynamics are vital for the ecological health of the river while at the same time they pose extraordinary challenges for the river's management. Dykes have had to be periodically strengthened and raised, as the Yellow River Conservancy Commission attempts to artificially constrain movement of the river. The dynamic and ever-changing nature of the river means it is impossible to use historic hydrological data to predict future flood risk. Unless these natural large-scale processes are given space, it is unlikely flood risk management will be successful in the long term.

In 2002 the Yellow River Conservancy Commission implemented the Water-sediment Regulation Scheme which allows the controlled release of floodwaters from reservoirs to transport sediment. Soil conservation practices in the middle reaches have also demonstrated some success in reducing erosion in the Loess Plateau, with activities ranging from reforestation and planting of grass, and establishment of pasturelands, to the construction of terraces and sediment-retaining dams.

Source: Wang et al. (2007), WWDR (2009).

MANAGING HABITATS AND PROMOTING BIODIVERSITY

Traditional flood control measures such as channelization and the construction of levees reduce habitat complexity and oversimplify the river corridor, thereby having a negative impact on biodiversity. With due consideration of these environmental implications, the challenge of modern FRM is to manage conveyance in a way that simultaneously promotes habitats while achieving the desired reduction in flood risk.

Perhaps the most crucial consideration when designing flood management measures is the importance of maintaining system connectivity. This includes maintaining:

- longitudinal connectivity (between upstream and downstream reaches)
- lateral connectivity (between river and adjacent side channels and floodplains)
- vertical connectivity (between surface water and groundwater).

These dynamic interlinkages crucially underpin ecosystem processes, and are typically disturbed by traditional engineered flood defences. For example, levees and channelization disrupt lateral connectivity. This engineered disconnection of rivers from the floodplains reduces productivity and exchange of nutrients, having a negative impact on habitat and species biodiversity. It also removes the system's natural capacity for flood attenuation and increases the risk of flooding downstream.

Dams and reservoirs can also be significant barriers to connectivity. By storing floodwaters and then releasing them slowly to attenuate flooding downstream, dams can provide a significant constraint on the transfer of sediment, nutrients and organisms. Older and poorly designed dams are coming under increasing scrutiny for their impacts on the environment. Altering the natural distribution and timing of flows has far-reaching effects on the ecological integrity of the riverine ecosystem. The physical barrier or the reduction of flow caused by dams severs the longitudinal connectivity of the river, inhibiting the migration of fish and other species. The need to incorporate sufficient environmental flows is a vital component when considering the operation of dams. This means ensuring a flow regime which keeps the river system functioning in a desired condition, a requirement that relates not only to the percentage of total flows released, but also to the temporal variability of outflow. The storage of water in reservoirs can cause alterations to temperature, affecting the productivity of aquatic species adapted to specific conditions. Another major issue of concern is the obstruction to the natural movement of sediment and organic material. The build-up of sediment reduces the flood storage capability of the reservoir and prevents vital nutrients from reaching ecosystems downstream. An excess of nutrients and sediments can cause eutrophication, leading to algal blooms and deoxygenation of the water. The reduction in sediment transfer downstream impacts river and estuarine morphology, and therefore species habitat.

Maintaining adequate flow in the river, and allowing water levels to remain high downstream of dams and other controls, is fundamental to maintain species, including fish yields (van Zalinge et al., 2003).

Various strategies can mitigate these negative impacts of dams on the river system, for example:

- selection of sites based on an understanding of the river basin and ecosystem functioning
- operational rules which include the release of flows to simulate the natural and historic flow regime
- sediment bypassing devices and fish passes which maintain to some extent the lateral connectivity of the river
- upstream catchment management which reduces nutrient loading in reservoirs.

Box 20: Incorporating principles of ecosystem connectivity into flood management

The Yolo Bypass, California, USA

The Yolo Bypass is a 240 km^2 leveed floodplain designed to protect Sacramento and other communities in the California Central Valley from flooding by conveying excess floodwaters from the Sacramento River. It was constructed from 1910 to the 1930s in response to several severe floods. The bypass conveys up to 80 per cent of the Sacramento River's floodwaters during major flood events, and fills completely during wet years. Below Sacramento city, the Sacramento River channel has a maximum design flow of 3,100 m^3/sec, which compares with the Yolo Bypass's capacity of 14,000 m^3/sec.

In addition to providing effective flood protection, the land is used for agriculture during the summer, and large areas of wetlands provide critical habitat for bird and aquatic species. When the bypass floods it functions as an important spawning ground, rearing nursery and migration corridor. Allowing the floodplain to be inundated, rather than disconnecting it from the river, has resulted in a whole host of environmental benefits. The biological value of the bypass for native species is particularly important since much of the historic floodplain has been lost to development, levee construction and river channelization. The Yolo Bypass demonstrates how carefully designed structural approaches to flood management can be adapted to sustain and support natural processes in aquatic and wetland systems.

Source: Sommer et al. (2001).

The Thale Noi Elevated Causeway, Songkhla Lake, South Thailand

The 14.5 km Thale Noi elevated causeway was built around 2000 after a lengthy public debate. Its socio-economic benefits were clear but so too were the potentially devastating environmental implications if the new causeway intersected the lake system with its vulnerable wetlands and valuable fisheries. As a result connectivity was preserved by choosing an elevated causeway instead of a less expensive road embankment.

Courtesy of Prof. Dr Chatchai Ratanachai, Prince of Songkla University

Box 21: Setting aside space for ecosystems: the Great Lake of Tonle Sap, Cambodia

The Great Lake of Tonle Sap is connected to the Mekong by the Tonle Sap River, which reverses its flow over the year, reflecting the seasonal water level variation (of 6–9 m). In the process, the Tonle Sap basin stores some 20 per cent of the Mekong floodwaters. The flow pattern is of regional significance. It moderates the peak flow (and flooding) and augments the dry season flow in the downstream parts of the Mekong, moderating the intrusion of saline seawater into the Mekong delta, with its intensive cultivation. The active floodplain of the Great Lake provides homes for many floating villages and a valuable fisheries. It was constrained by elevated national roads in the early 1990s, linking provincial towns around the lake; but a 14,800 km^2 area was left within the confines of the roads, forming the Tonle Sap Biosphere Reserve.

The Great Lake of Tonle Sap

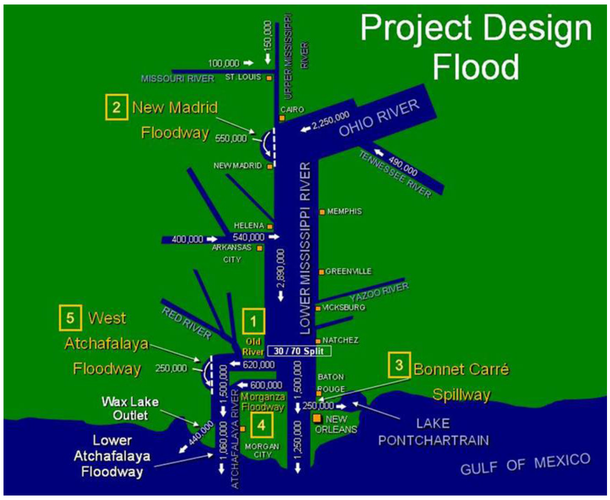
UTILIZING BYPASS CHANNELS AND DETENTION AREAS TO LIMIT STRUCTURAL INTERVENTIONS

Following the disastrous Mississippi River flood of 1927, the US government determined that the previously used 'levees only' policy for protection the people and property alongside the lower Mississippi River was no longer valid and that new approaches should be put in place. Rather than using levee raising as the sole means of dealing with the major floods that would be faced in the years ahead, the engineers determined that they would use a combination of levees, upstream storage behind new dams, floodways to divert large volumes around critical areas, and periodic storage of floodwaters on agricultural lands.

Over the following thirty years, four floodways were established to divert waters around a narrow section of the Mississippi near its junction with the Ohio River, and nearer the mouth of the river, reduce the flood flows that would pass New Orleans.

Where other tributaries joined the Mississippi, levees were constructed to reduce backwater flooding for large floods but at a level that would permit their overtopping under major flood conditions to provide flood storage (Figure 44). In 2011, the magnitude of the flood approached the design level. All four floodways were put in to service and successfully passed the floodwaters around the designated areas (Mississippi River Commission, 2011).

Figure 44: The Lower Mississippi River design flood indicating use of floodways to relieve pressure on stressed areas



Source: Mississippi River Commission (2011).

The use of floodways and detention areas is not new, and has, for example, been part of China's strategy for FRM for over 4000 years. As flood volumes increased it was no longer possible to keep raising levee heights and width. Today there are ninety-seven flood storage detention areas in China covering a total area of over 28,000 km^2 with a flood storage capacity of 102 billion m^3. Twelve of the storage areas are operated by the national government and have a flood storage capacity of 22 billion m^3. Between 1950 and 2001 the storage areas were put into use over 400 times, with one, Dujiatai flood diversion, used nineteen times. The multiple flood discharge and storage areas along Huaihe River have been used over 200 times since 1950 (Liyun, 2007).

Each time these areas in the United States and China are put into use, the ecosystems in the affected lowlands benefit from the flood flows.

Table 18: Summary of impacts of structural measures on various river corridor processes and possible mitigation measures to deal with these impacts

		Impacts on the environment	Possible mitigation measures
Dams and reservoirs	Flow regime	Reduced seasonal variability of flow, i.e. low flows increased and high flow decreased. Increased flow fluctuations at hourly and daily timescales. Change in frequency and timing of floods (impacts depend on reservoir capacity and dam design and operation).	Managed flow releases by reservoir operation, leading to seasonal variability of flow. Multiple and/or depth-selective intake structures for maintaining the natural seasonal temperature regime of released flows in reaches below dams, as well as water quality. Allowing for fish passage over weirs and dams in both directions. Appropriate sediment bypassing devices. Bypassing large woody debris.
	Sediment/ channel structure	All sediment but the wash load fraction is trapped in the reservoir. Reduced sediment downstream leads to possible accelerated bed degradation and bank erosion in the reach immediately downstream of a dam. Possible changes in bed material composition and channel pattern downstream of the dam (e.g. from braided to single-thread). Encroachment by riparian vegetation, decreasing the channel's conveyance capacity. Possible coastal erosion.	
	Water quality	Constantly cold water released from deep layers of the reservoir reduces the temperature variability of downstream river water. Possible accelerated eutrophication, as a result of the reservoir incorporating and trapping nutrients. Deeply plunging spillway releases can cause bubble-disease in fish because of nitrogen dissolution in water. Water turbidity is decreased, which can lead to increased primary productivity. Reservoir will export plankton downstream, changing availability of food resources (most impacts on quality depend on a reservoir's retention time).	
	Habitat / biodiversity / natural resources	River species largely replaced by lake species in reservoir. Native river species reliant on natural flow regime will disappear downstream of the dam. Changes in thermal regime affects many species, e.g. invertebrates. Short-term flow fluctuations (dewatering) result in stranding of organisms, particularly with hydropower dams. Most silt and organic matter is retained in the reservoir, instead of fertilizing floodplains. This also has ecological effects in the river, estuarine and coastal ecosystems. Floodplain structure is changed, as flooding is reduced or eliminated. This displaces some riparian trees and animals. Dams sever the longitudinal connectivity of the river, which impedes or hinders the passage of fish and invertebrates along the river course, and also of some terrestrial animals along the river corridor. Exotic species can displace the locally adapted natives because of dam operations reducing extreme flows (both low and high), and/or extreme environmental conditions (e.g. high turbidity).	
Detention / retentions basins	Flow regime	Little impacts on natural flow regime, if the basin is designed only for storing floodwater to reduce flood peaks downstream. Reducing temporally peak flood flows.	Artificial wetlands or permanent ponds can help in creating new habitat for many aquatic and terrestrial species, if the mitigation measures satisfy flood management objectives. Detention basins should be designed so as not to affect the flow and sediment regimes in the main channel.
	Sediment / channel structure		
	Water quality	Increased temperature, decreased dissolved oxygen and eutrophication etc., if water is stored during low-flow season or in permanently wet basins. Little impacts on river water quality if the basin is used only during flooding.	
	Habitat/biodiversity/ natural resources	The basin can help in creating habitats for many aquatic species (plants, fish, invertebrates etc). by serving as an artificial wetland. Little impact on river biodiversity if the basin is used only during flooding.	
Bypass channels	Flow regime	Little impact if the bypass channel is used only during flooding for bypassing. Reduced river flow, stage and velocity in the bypassed reach if the water diverts flows permanently into the bypass channel. Increased flooding downstream, as waters are rushed through the bypass channel, leading to faster travel times.	Managed flow by design or operation to attain a new dynamic equilibrium under the altered flow and sediment regimes. A bypass channel can be planned in conjunction with a detention basin downstream of the bypass channel, in case the altered flow largely increases flooding downstream.
	Sediment/channel structure	Possible aggradation in the bypassed reach, if the bypass takes only flood water but does not allow for intake of its share of bed load into the bypass channel.	
	Water quality	Little impact on river water quality in the original channel.	
	Habitat/biodiversity/ natural resources	Little impact on biodiversity in the main channel.	

		Impacts on the environment	Possible mitigation measures
Embankments	Flow regime	Higher water stages and velocities at above-bank full flows. Flood peaks increased downstream.	Embankments should be planned in conjunction with other structural measures such as dams and detention basins, as well as nonstructural measures. Spacing of embankments should allow for the morphological lateral movement of the river. Embankment designs should minimize the disruption in lateral connectivity by setting balanced standards of protection based on economic and environmental criteria. Setting embankments farther back from the river channel depending on land use conditions Removal of embankments separating floodplain from river in combination with land use planning, if the floodplains are not occupied by human development.
	Sediment/channel structure	Loss of connectivity between river and floodplain. Loss of pool and riffle patterns and other heterogeneities in channel form. Increased erosion possible (both local scour and overall degradation). Possible sedimentation downstream, of material eroded in embanked reach.	
	Water quality	Loss of exchange of nutrients and carbon with floodplain.	
	Habitat/biodiversity/ natural resources	Loss of floodplain refuges and spawning areas for river species. Loss of floodplain forests (timber, fruits, medicines). All floodplain structures, processes and species needing frequent inundation are affected. No more silt deposition on floodplain. No more habitat creation on the floodplain.	
Channelization	Flow regime	Increased channel slope, flow velocity, lower stages, reduced residence time, leading to increased flooding downstream (faster travel times and lower peak attenuation).	Use of natural and permeable materials, i.e. soft revetments, instead of concrete revetments. Maintaining or reintroducing coarse woody debris as far as possible.
	Sediment/channel structure	River bank and bed erosion (scour and degradation). Sedimentation problems downstream. Total loss of heterogeneity in channel form.	
	Water quality	Reduction in nutrient and pollution assimilation capacity of river channel. In small (narrower) streams, increased temperatures. Increase in fine sediment load.	
	Habitat/biodiversity/ natural resources	Loss of river habitat diversity, bankwaters and refuges; loss of native river species. Loss of instream and riparian vegetation. Loss of organic material input Lowering of floodplain water tables, affecting riparian vegetation and floodplain wetlands.	

Source: WMO (2006).

6.4 Summary conclusions and recommendations

Significant synergy exists between the demands of good FRM and the delivery of health ecosystem services. From an FRM perspective, innovative implementation of 'soft path' approaches (structural measures implemented with the aim of working with the natural processes) offers many advantages including:

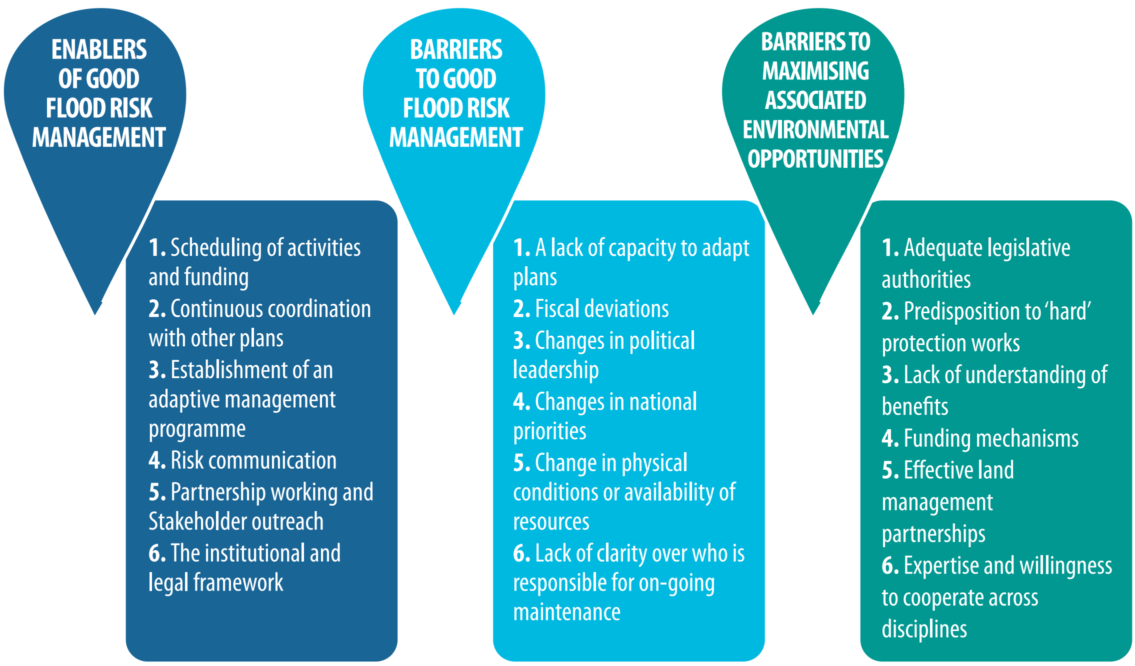
- **Influence on flood flows:** although soft-path measures may have a more limited impact on major event flood flows, they can be highly influential in modifying lower and more moderate events. Such events can be crucial in their contribution to the expected risk (a value typically dominated by events occurring more frequently than every thirty years).
- **Sediment yield:** modifications to land use have a major impact on sediment yields and subsequent channel morphology/health and reservoir siltation.
- **Land use management and land management:** land use management focused towards spatial planning – the creation of preferential flood routes, urban development and so on – has a significant role to plan in limiting exposure to flooding. Effective land management through good soil husbandry, site management and so on can also play a role. In particular, rural land management, mainly involving agriculture, forestry and areas of nature conservation, can contribute to ecosystem health through modification in flood generation and the storage of floodwaters in floodplains. Such interventions essentially slow down and/or retain potential floodwaters. They involve land within and beyond the areas liable to flooding. While the efficacy of measures to reduce runoff and retain water from rural and farm land can reasonably be estimated at the field scale, there is considerable uncertainty regarding the likely impact of these interventions on flooding at the larger subcatchment and catchment scales. Here, many event and context specific factors are important.
- **A desire to be innovative:** combining FRM and ecosystem service has the potential to deliver many benefits. However delivery is not straightforward, and requires innovation and a willingness to develop whole system-thinking and work collaboratively to develop portfolios of responses.

CHAPTER 7
IMPLEMENTING FLOOD RISK MANAGEMENT – BARRIERS AND ENABLERS

7.1 Introduction

The successful implementation of a strategic approach to FRM requires close coordination and cooperation with all parties involved in the FRM and other related government and nongovernmental activities. The best strategy is of little utility if it cannot be implemented. The barriers that prevent the delivery of good FRM and the enablers that promote its implementation are summarized in Figure 45 and discussed in this chapter. Early attention must be given to administrative matters that can facilitate successful implementation. Similarly, potential problems must be identified and dealt with before they become 'roadblocks' to successful implementation. This chapter outlines activities that have proven to be important in enabling successful implementation, as well as those factors that can become barriers to implementation of good flood risk, and specifically barriers to maximizing environmental opportunities.

Figure 45: Enablers and barriers to implementing good flood risk management



7.2 Enablers to implementation

Successful leaders and managers recognize activities that facilitate effective operations and take steps to ensure that they are given continuous attention. Review of the practice of FRM has identified the following enablers.

SCHEDULING OF ACTIVITIES AND FUNDING

Implementation begins with the development of detailed schedules to indicate the order of implementation of the multiple measures contained in the selected portfolio. The schedules must reflect the feasibility of accomplishing the work within the specified time, the impact of the work of one measure on the work on other measures, and the availability of funding. Funding availability most often becomes the principal driver, and it is imperative that the implementation plan clearly identifies the timing and amount of the funding stream that will be made available to support the effort. A well-developed strategy or portfolio with intermittent funding is an ineffective strategy or portfolio.

Gaps in budget allocation can cause delay and inefficiency. For example, in a Flood and Water Bill that was being considered by the UK Parliament, confusion existed over who would pay for the ongoing maintenance of new flood defence schemes and, in particular the SUDS constructed as part of new developments. This confusion continued to hinder the development of integrated and imaginative FRM solutions and will need to be solved. This issue of who pays, and specific flood-related taxes, has been around for many years.

CONTINUOUS COORDINATION WITH OTHER PLANS

FRM plans are among many that exist within governmental structures, and they must be carefully coordinated with these other plans. National policies for FRM as well as national, basin and local strategies must be integrated carefully with other planning efforts. Because of the time involved in developing and executing FRM plans, it is not unusual for parallel plans such as agriculture and navigation plans to experience change. Unless there is continuous exchange of information among the different planning agencies, it is possible for efforts that once were in synchronization to suddenly become in conflict. At each step in the FRM process there must be passage of information to those agencies most affected by the flood planning. Similarly, flood risk managers should expect proponents for other sectors to inform them of changes in their planning that might impact on the structure of FRM plans.

Box 22: St Petersburg: a consistent and continuous budgetary approach and allocation is needed for efficient implementation of major FRM plans

After 30 years, a giant construction effort to protect the beautiful city of St Petersburg from catastrophic flooding is drawing close to completion, after a major gap in construction during the 1990s that threatened to lead to the plan being aborted and huge resources wasted (see photo).

The Russian city is under threat from sea level rise. At the worst projection the city would be flooded to a depth of 5.15 m. Up to 3 million of St Petersburg's 5 million inhabitants would be directly affected, and some of the world's most precious monuments would be swamped at unimaginable cost. Water and sewage treatment plants, schools, hospitals and the city's metro would also be inundated, and the people remaining after the waters had receded would be facing a humanitarian crisis comparable to that of New Orleans in 2005.

But after an extraordinary effort by the Russian government, some help from European funding and a major effort by Russian and international civil engineering experts, the city is seeking to establish flood defences, in the form of constructing a curving flood barrier that embraces the shallow waters of the Neva Bay.

The project is something of an epic in scale and timeframe. The 25.4 km barrier consists of eleven embankment dams, six sluices and two navigation channels each with floodgates. The dimensions are massive. Each of the pair of floating steel gates that closes like a door to shut the main navigation channel measures 122 m long by 23.5 m high by 4.7 m wide.

But this is not just flood defence. In the spirit of multifunctional FRM, the barrier also doubles as a motorway, the latest link in the St Petersburg ring road. It will carry a six-lane highway that crosses one navigation channel via a bridge that lifts 9 m to allow shipping underneath. It passes beneath the main navigation channel in a 2 km long, 26 m deep tunnel.

Such complex multipurpose plans have required the close cooperation of spatial planning, water resources, navigation, environmental and other agencies, both in and outside government, and at all levels of decision-making. The result should be a more sustainable project giving better value for money than a flood defence scheme alone could provide.

Multisector funding – St Petersburg's integrated flood defence and highway project

Source: New Civil Engineer (2009).

ESTABLISHMENT OF AN ADAPTIVE MANAGEMENT PROGRAMME

No implementation plan will remain static. Schedules will change and funding programmes will be modified. In addition, physical and political changes in the implementation area and the nation as a whole will affect the execution of the FRM programme. Better data and information will become available. A successful FRM process includes a robust adaptive management programme.

At the heart of the adaptive management programme is a monitoring effort that continuously looks for and reports on changes in the hazard, structures and programmes that have been created in support of the flood risk reduction effort. Political support, public interest, funding schedules, and construction and implementation delays must also be observed closely. This monitoring effort must be formally established and operate on a scheduled reporting basis so that leaders understand both when changes occur and when things remain as planned. As flood risk reduction measures go into service, both structural and nonstructural, there must be continuous monitoring of their performance. Any deviations need to be examined closely and reported to programme leadership together with recommendations for adjustment. Changes in programmes that interact with FRM must also be observed, and actions that could impact on flood risk programme reported to leadership with recommendations for necessary action.

When significant changes occur, it will be necessary to re-evaluate the strategy and, using the processes described above for the original strategy development, identify changes that need to be made to move the programme back on track. Necessary support and approval for these changes will have to be obtained from higher-level government and, as appropriate, changes will need to be implemented.

RISK COMMUNICATION

Government leaders and the public do not support FRM if they do not believe there is a risk. Immediately following a major flood event, there is considerable discussion of the need to take some action, but very rapidly, as conditions return to near normal, support for taking action often wanes. Implementation of flood risk strategies requires the cooperation of the public in the execution of many of the measures, especially evacuation and use of individual home protection systems. If those in a flood hazard area do not believe that they are at risk as a major flood approaches, they are less likely to respond to any directions to leave the area, putting them in danger and creating problems for those responsible for fighting the flood. Much of the loss of life in recent world events can be traced directly to the inability of leaders to either understand the potential risks or communicate those risks prior to the floods to those in the affected areas.

Communicating risk is a complex operation that requires the full involvement of professionals in the field. Policy-makers often demand absolute information about floods, and fail to recognize the uncertainties that exist. The public at large do not understand the systems that have been put in place to reduce their risk, and assume that if there are problems someone will tell them what to do, excusing themselves from accepting any responsibility for self-protection, or better, education. Before Hurricane Katrina, most residents of New Orleans assumed they had absolute protection from floods, and political leaders were reluctant to dissuade them from this erroneous view. The recent identification in the United States of thousands of miles of substandard levees that were placing thousands of people and billions of dollars of property at risk caused a brief stir. But because national and local leaders did not have the resources to deal with the problem or were not willing to reprioritize use of resources, they downplayed the threat , and in some cases chastised those who are identifying these risks.

Effective risk communication requires full use of all methods of communication. Education in schools and businesses, community activity, social networking, risk mapping and other tools all begin to deal with the challenge of convincing individuals to change their behaviour and gain understanding of flood risk. Static and interactive flood map use in Europe and the United States is gradually informing the public and their officials of the actual risks faced. Ineffective communication can jeopardize the trust that should exist between government officials and the population at large, and destroy support for FRM strategies in the political and public environment.

PARTNERSHIP WORKING AND STAKEHOLDER OUTREACH

Implementation success hinges on attainment of cooperation from and the education of all parties involved in the FRM process. This involves structured outreach and risk communication. Without such partners, beyond those traditionally involved in flood defence, the more comprehensive approach of FRM cannot be implemented. There are many examples of partnership arrangements that provide added value to all those involved – supporting the achievement of multiple goals and objectives.

Those who live and work in flood hazard areas are the most affected by flooding, and believe that they should be part of the decision process to determine what measures are used to reduce their risk. Public officials in affected areas, although not directly involved in the FRM effort, also see the need for consultation with those implementing FRM. Use of nonstructural means such as land use control, evacuation and early warning requires the full cooperation of those on the ground. All too often plans are developed without this consultation, only for those responsible for implementation to discover that the works they have put in place are ineffective. Initiation of outreach to the public at the beginning the FRM process and continuous maintenance of this outreach effort will do much to provide public support for the decisions being made and the resources needed to carry them out. New planning methods such as shared vision planning provide opportunities for increased public participation in the development of consensus approaches to difficult issues of land use, right-of-way clearance and relocations. Environmental issues frequently arise because FRM planners do not understand the fragility of regions or species that would be affected by FRM measures. The greater the involvement of the public in the initial planning, the less likely it is that such problems will arise during implementation.

THE INSTITUTIONAL AND LEGAL FRAMEWORK

Four interdependent and interlocking elements provide a necessary institutional framework for effective FRM:

- a framework of law that assists FRM
- institutions that are responsible for FRM at a variety of levels and scales and are accountable for their actions
- a clearly articulated policy that defines the 'direction of travel'
- transparency in decision-making.

A legal framework that assists FRM

In all countries the law establishes the role of the state and of individuals or agencies. It allocates powers such as the power to raise revenue through taxes or levies (specifically related to the provision of flood management activities), and assigns property rights, obligations and duties. All of these provisions are important to making clear 'who does what, why and how' in FRM. Without a clear set of laws, there is confusion and muddle. It also is necessary to have an appropriate legal framework in place for effective spatial planning for flood risk areas, since this spatial planning is likely to be an essential ingredient of successful FRM.

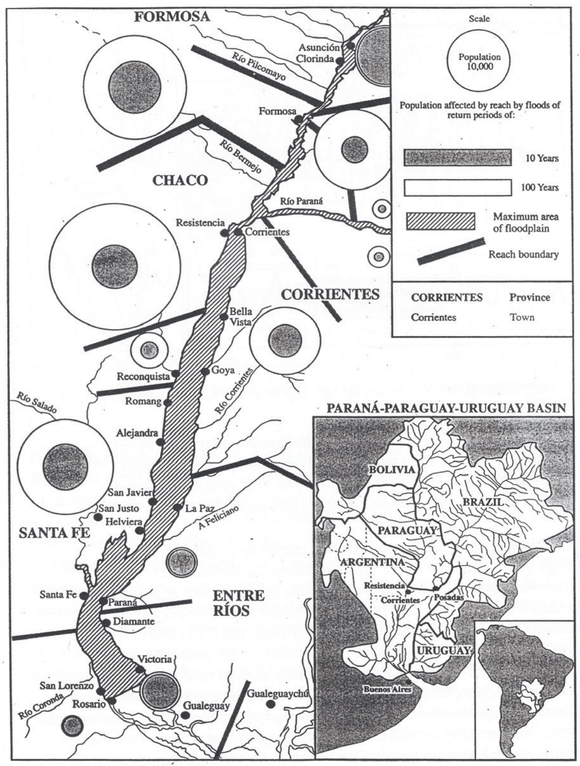
The law regarding FRM also sets aims and targets. For example a Floods and Water Act (2010) considered by the UK Parliament aimed 'to provide greater security for people and their property from the risk of flooding and coastal erosion, better service for people through new ways of delivering a and greater sustainability by helping people and their communities adapt to the increasing likelihood of severe weather events due to climate change, encouraging sustainable technologies, protecting communities and the environment better from the risk of flooding'.

But FRM does not just require flood-related law. Sustainable FRM requires rules for the development of flood risk areas, and hence synergistic spatial planning law. Legislation is often needed to allocate responsibilities for flood emergency response, for insurance arrangements, for the ownership of rivers and their banks, and a host of other government and private-sector functions.

Box 23: Argentina – increased development leading to increased flood risk

The frequency of major floods in Argentina appears to be increasing rapidly (Penning-Rowsell, 1996). At the same time, human vulnerability to flood hazard is gradually rising because of economically induced population movement to the river valley floors and to the coast. The World Bank has assisted the Argentine government through the 1990s and onwards in promoting more sustainable flood alleviation strategies, based on the control of land use in floodplain areas.

Many circumstances have made the implementation of such an approach highly problematic. A principal difficulty has been that the rivers, river banks and floodplains of Argentina at the time were poorly defined in law and inadequately mapped, making the enforcement of spatial and land use planning rules contentious and drawn-out.



Flood risk in Argentina continues to grow, in part because of a deficient legal system

Institutions that are responsible for FRM at a variety of levels and scales and are accountable for their actions

FRM cannot be left solely to the private sector and to markets. Government support and guidance is required, and this is best delivered through institutions of the state or its agencies specifically charged with those functions.

There is no one 'correct' or perfect arrangement. Countries may have dedicated FRM agencies, or have that responsibility as part of a public works department, or a water resources agency, or an environment agency (as in England and Wales). Many countries still operate with distributed responsibilities. For example, in the United States, for historical reasons, the principal agency for the design and planning of flood defence activities is the USACE, with the National Oceanographic and Atmospheric Administration providing weather and climate information, and FEMA responsible for emergency response, and flood mitigation and insurance. The development and promotion of FRM activities, however, is often bottom-up from the local political administrations. This fragmented approach (and the frequent disconnect between national policy-making and local implementation) worked well under the paradigm of flood defence but has presented barriers to the implementation of integrated FRM. Each arrangement has its advantages and disadvantages, but one organization has to be designated to carry a lead role, and have the powers and budgets that are necessary for effective implementation of government FRM policies.

A clearly articulated policy defining the 'direction of travel'

FRM involves many different stakeholders in many parts of society. There can be confusion and inefficiency if everyone is not pulling in the same direction. National/federal or regional governments must set out their policy frameworks in areas where public goods are at stake and resources are raised through general taxation (as in most countries). It is then for agencies of the state, such as basin authorities, and parts of the private sector (for instance, in insurance or the media), to move their activities in the same general direction.

There will be debate and disagreement over policies and their aims, and hence it is for governments, with full stakeholder involvement, to decide on behalf of the society what policy to pursue and how it should be implemented. In 2004, the United Kingdom conducted a consultation exercise on *Making Space for Water* (Figure 46). A resulting document (Defra, 2005) laid out the first UK Government response and offered a strategy. This strategy aims to implement a more holistic approach to managing flood and coastal erosion risks in England. The aim will be to manage risks by employing an integrated portfolio of approaches which reflect both national and local priorities, so as to reduce the threat to people and their property; and deliver the greatest environmental, social and economic benefit, consistent with the government's sustainable development principles.

Figure 46: The UK Government's 2005 policy statement on Making Space for Water (Defra, 2005) sets out a clear direction of travel in FRM

Transparency in decision-making

Flood risk management decisions affect many people for many years, whether the decision is to protect them or not to do so. The decisions may affect the land on which people work and the properties in which they live; they may well also influence the flood risks that they face, including risk to their lives. In addition, public money is being used to fund FRM plans and works. The public supports decisions on these matters when the decisions are understandable and made in the open.

To be properly accountable in these circumstances, the organizations and agencies making these decisions (including central/federal governments) need to have clear and transparent procedures and processes whereby those decisions are made, so that all can see what was decided, why, and how the decisions were arrived at. Such decisions should not be made behind closed doors or by a small unaccountable elite, and the general public should be made aware of the decision-making process and how they might influence this if they feel the need to do so.

7.3 Barriers to implementation

Just as 'enablers' facilitate the execution implementation plans, other activities present barriers to this implementation. Experience in dealing with FRM in a variety of circumstances points out factors that can slow or stop implementation:

A LACK OF CAPACITY TO ADAPT PLANS

Frequently, those involved in the execution cannot deviate from what was originally planned, being constrained by funding streams, expectations and so on. As a result, adapting to the realities of the future as it unfolds becomes difficult, and the final outcomes differ considerably from those outcomes originally envisaged (even though the original plan was implemented faithfully). It is important that as the need to make change arises, changes are in fact made.

FISCAL DEVIATIONS AND BUDGET OVERRUNS

Rarely does the size of the plan funding stream increase. It is more likely that the annual funding support plan for the project will be decreased to accommodate other regional or national priorities. Each of these funding changes requires a revaluation of the planning schedule and identification of those projects in measures that should be delayed or accelerated to best meet priority FRM goals. Simply decreasing all elements of the programme equally in the case of fiscal reduction does not provide for optimum FRM. Major projects are prone to simple budget overruns – this can lead to incomplete projects or later change in the scope of a strategy, often undermining the outcomes from even the most well-considered plan.

CHANGES IN POLITICAL LEADERSHIP

Frequently those who are most supportive of a particular set of measures change positions or leave regions and are replaced by others who either do not understand the FRM process or have a different view of what should have priority. It is imperative that as such changes occur in personnel, there is a concerted effort to inform new decision-makers of how the current strategies were developed and the challenges that will be faced in making significant changes to these strategies.

CHANGES IN NATIONAL PRIORITIES

Inevitably the world situation and domestic challenges will cause there to be significant shifts in priorities at the national level. Need for support to agriculture or manufacturing may shift priority for implementation of flood risk reduction projects and measures. A major natural disaster might not only cause changes in the flood hazard, but result in large resettlement or the need for new development that will cause modification of existing flood strategies.

CHANGE IN PHYSICAL CONDITIONS OR AVAILABILITY OF RESOURCES

Faster sea level rise, increased storm activity, geomorphologic changes in river configuration and failure of older infrastructure can significantly affect implementation. Initial choices of measures and portfolios will have been made on the basis of information existing at the time of the decision, and when significant changes occur, there needs to be a revaluation of these choices a determination of what changes need to be made. As was seen during world shortages of steel and cement, international market conditions can create shortages of critical materials or stretch out their availability. Again, efforts must be made to revaluate what each of these changes means in terms of the FRM activities as a whole, and where appropriate, adjustments should be identified, vetted and implemented.

LACK OF CLARITY OVER WHO IS RESPONSIBLE FOR ONGOING MAINTENANCE

While there is typically widespread support for capital investment in new FRM projects, support for ongoing maintenance and operation activities is frequently overlooked and the actual activities are neglected, leading eventually to system failures. Without clarity and fairness within the legal instruments that set out who pays for operations and maintenance activities (based for example on general principle of the beneficiary pays), integrated and effective FRM is difficult to achieve.

7.4 Barriers to maximizing environmental opportunities

The provision of FRM and promoting ecosystem health are not mutually exclusive goals, but closely interrelated activities if the activities are done well. There are however a number of specific barriers that influence the degree to which FRM utilizes the potential synergies with ecosystem services and vice versa. Some of these are discussed in more detail below.

LEGISLATIVE AUTHORITIES

Often management of the river basin is governed by a range of legal requirements and organizations with a range of roles and responsibilities. In this context flood risk managers often have limited legislative requirement to deliver specific environmental gains, other than to act responsibly towards the environment. This lack of clear legal direction is often reflected in limited consideration of environmental issues and a use of approaches that are based on minimizing the impacts of a chosen approach, rather than setting out to deliver environmental gains through FRM at the outset.

COMPREHENSIVE ASSESSMENT

A firm scientific understanding of the ecology and morphology of rivers and their floodplains, and their interaction with interventions, is an essential prerequisite for delivering environmentally sustainable FRM. Flood risk managers may need to seek technical expertise in order to fully understand environmental implications and opportunities when identifying, evaluating and choosing measures to adopt. Despite the widespread acceptance of the notion of sustainability, in practice economic appraisals often neglect environmental aspects.

PERCEPTION AND DESIRE FOR 'HARD' WORKS

The hard engineering flood control paradigm is deep-seated and mindsets can be difficult to shift. Trained flood defence engineers may find the ideologies embedded in their training questioned, and equally the public may have greater faith in the protection provided by hard works rather than natural systems.

NEED FOR A SOUND EVIDENCE BASE

A paucity of empirical evidence of the benefits of green and blue infrastructure contributes to a lagging confidence in the approach. There are also greater uncertainties involved in use of green approaches than for hard engineering measures. This highlights the importance of research and demonstration projects. Creating a robust evidence base needs to be coupled with public awareness-raising and communications efforts to help strengthen the case for green infrastructure approaches.

FUNDING AND PAYMENT MECHANISMS

Flood risk reduction is normally one of many benefits derived from natural infrastructure approaches, and these benefits are closely linked to water and environmental management. This presents opportunities for strategic funding packages with collaboration between different funding organizations, but also creates a more complicated and multi-actor arena where roles and responsibilities are not clearly defined. Where changes in rural land management are promoted as part of the FRM portfolio, compensation to reward the provision of services by land managers forms an important aspect to ensure take-up and longevity of the washlands.

NEW LAND MANAGEMENT PARTNERSHIPS

Rural land management interventions will call for new collaborations amongst interested parties at the landscape scale, not least land managers themselves. They will also require appropriate arrangements to compensate and reward land managers for FRM services rendered.

Box 24: The economic value of green infrastructure for flood risk reduction

Determining the economic value of services provided by natural ecosystems is not straightforward, and as a result these benefits are often ignored or underplayed in decision-making processes. Governments tend to favour investment in physical infrastructure over intangible assets. Nonetheless, analyses suggest that the value of flood management services derived from natural infrastructure can be considerable:

- In the Luznice floodplain in the Czech Republic, flood mitigation services through water retention are valued at $11,788 per hectare.
- Forest protection in the upper basin of the Vohitra River basin in the Mantadia National Park, Madagascar, has reduced flood damage to crops, with benefits amounting to $126,700 in 1997.
- The Muthurajawella Marsh near Colombo in Sri Lanka covers an area of 3068 ha and forms a coastal wetland together with the Negombo Lagoon. Its value in terms of flood attenuation has been estimated at over $5 million per year.
- The Dutch Wadden Sea is an estuarine environment of 270,000 ha in the Netherlands. It is located between six barrier islands and the Dutch coast, and comprises extensive tidal mudflats, salt marshes, wet meadows, sandbanks, reclaimed polders and dune systems. Its flood prevention services are estimated at $189,000,000 per year.

Sources: various in World Bank (2010), WWF (2004).

AVAILABILITY OF LAND FOR RESTORING NATURAL INFRASTRUCTURE AND OPPORTUNITY COSTS

In already intensely developed floodplains, restoring the natural functioning of floodplains and rivers may involve politically charged land use decisions. For example, the need to use land for wetland restoration or managed realignment may face competing demands from agriculture or urban development. Land on floodplains 'protected' by structural defences is often high in value, requiring costly acquisition, compensation or incentive schemes.

EXPERTISE AND COOPERATION NEEDED FROM MULTIPLE DISCIPLINES

In order to maximize environmental opportunities, dialogue between different disciplines is imperative. A holistic catchment approach to FRM requires a collaborative effort between multiple sectors, including those responsible for water resources, environmental protection, land use planning and forestry, and establishment of links between other plans and policies. The complexity and the number of stakeholders that a catchment approach necessarily entails are a major obstacle to its realization.

SEPARATION OF BENEFITS AND COSTS

Frequently, in dealing with ecosystem goods and services, there is a separation between those who must pay the costs for use of natural infrastructure and those who receive the benefits. Where land is used for flood storage, the owners and users of the land receive no compensation for having their land flooded and serving to reduce downstream flood damages, while the beneficiaries who are spared flood losses pay nothing for this ecosystem service.