



GIWP



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

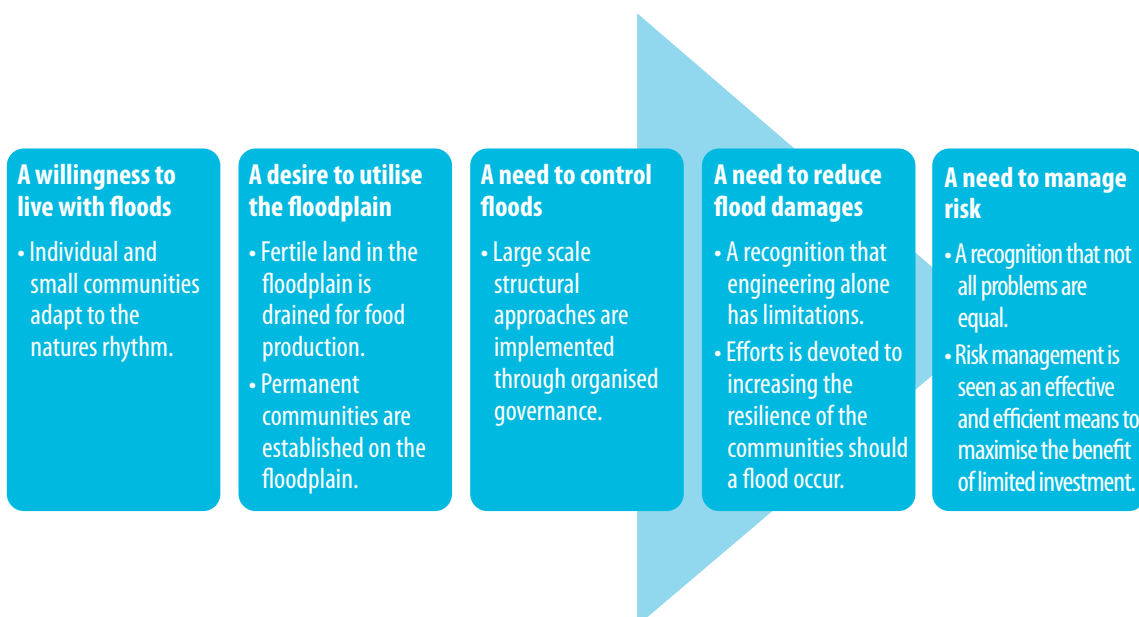
The earliest civilizations recognized the need to live alongside floods; locating critical infrastructure on the highest land

(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.

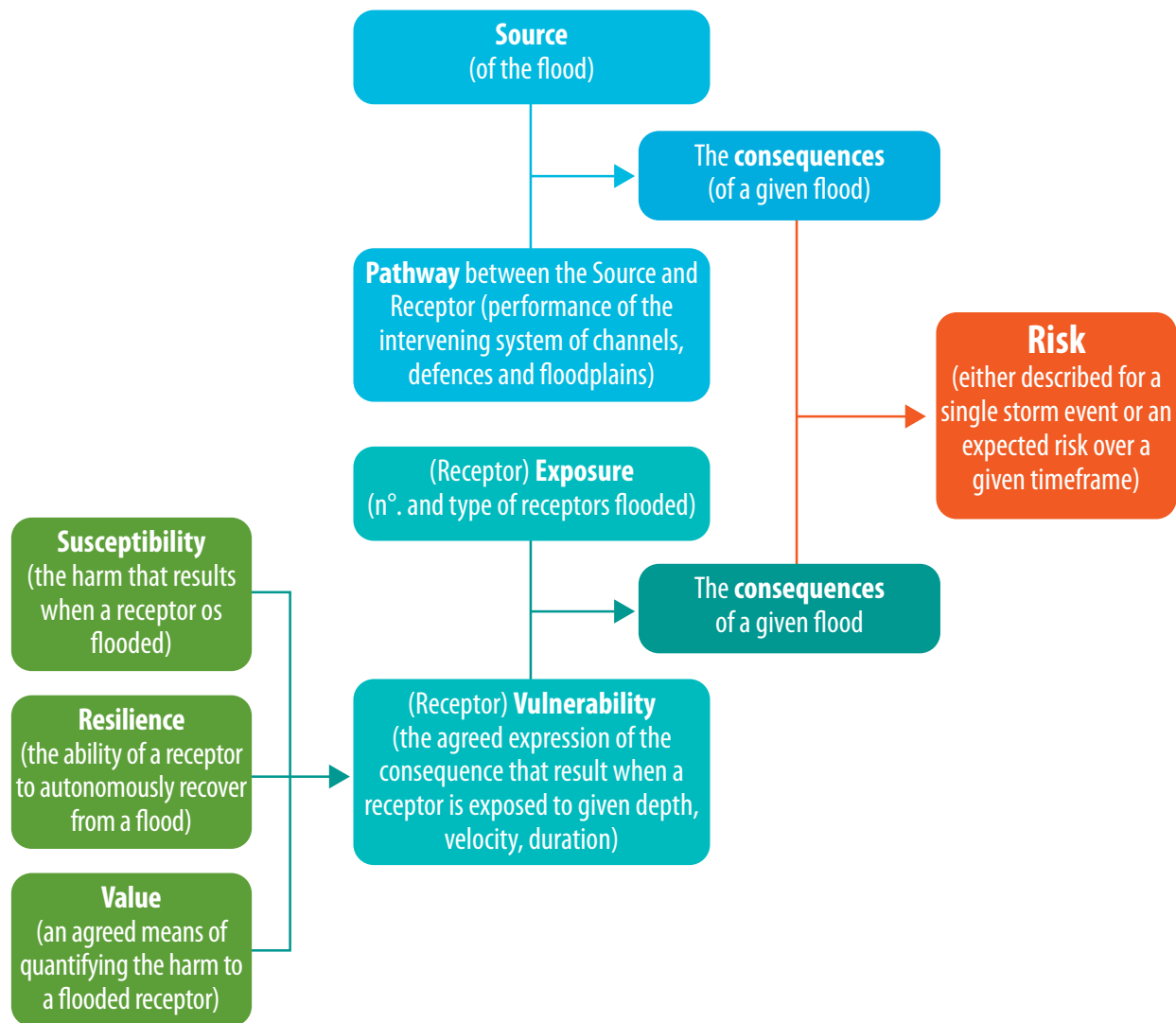
All of these dimensions are subject to change, through either autonomous pressures or purposeful intervention. Traditionally the focus has been on reducing the probability of flooding through extensive structural defence systems such as those found in the Rotterdam in the Netherlands, New Orleans in 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.

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).

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

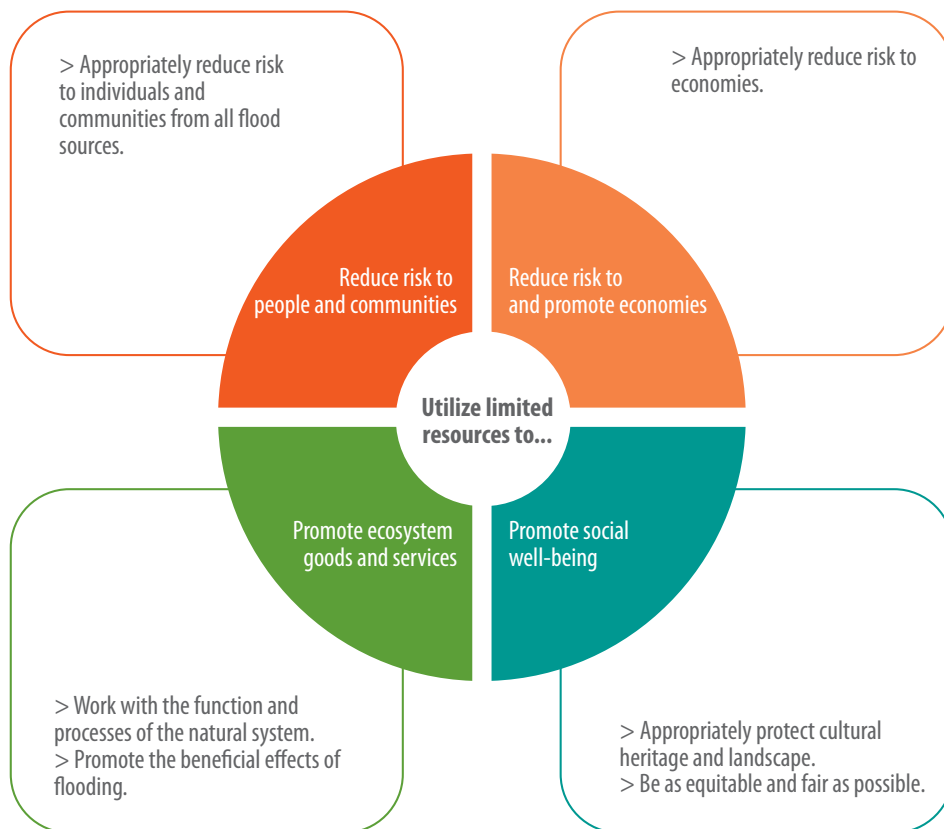
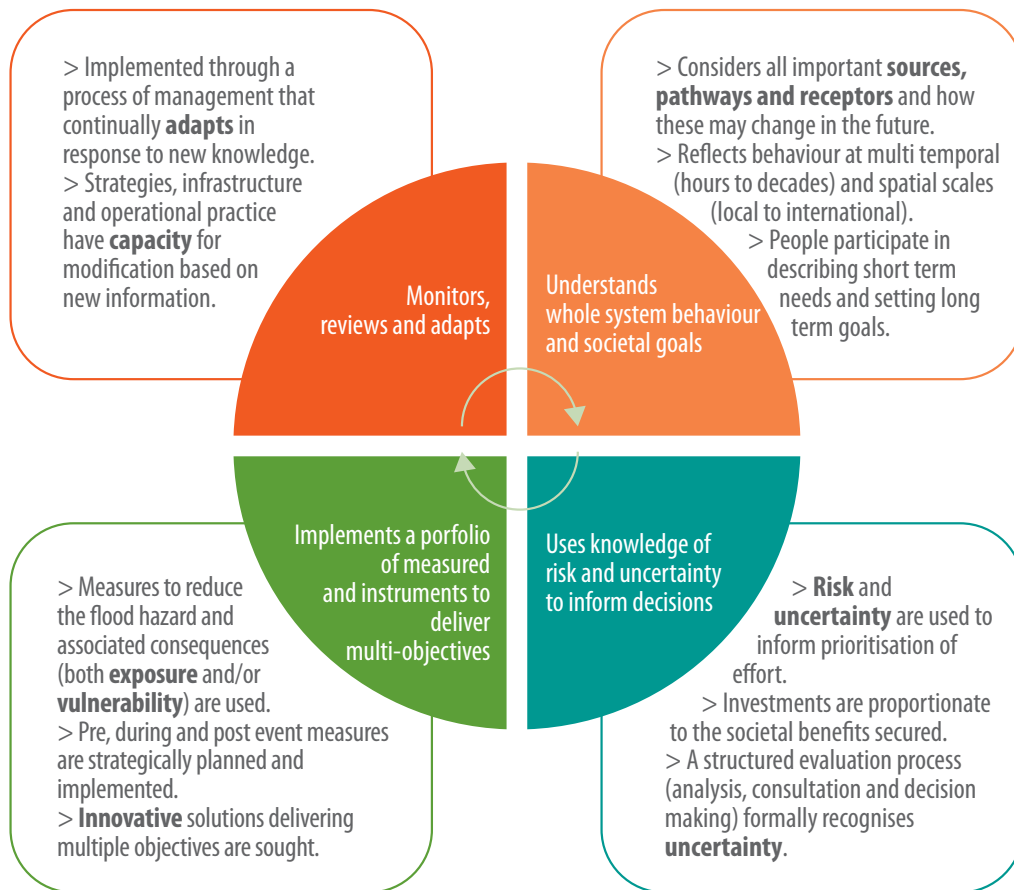


Figure 4: The characteristics of good flood risk management



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

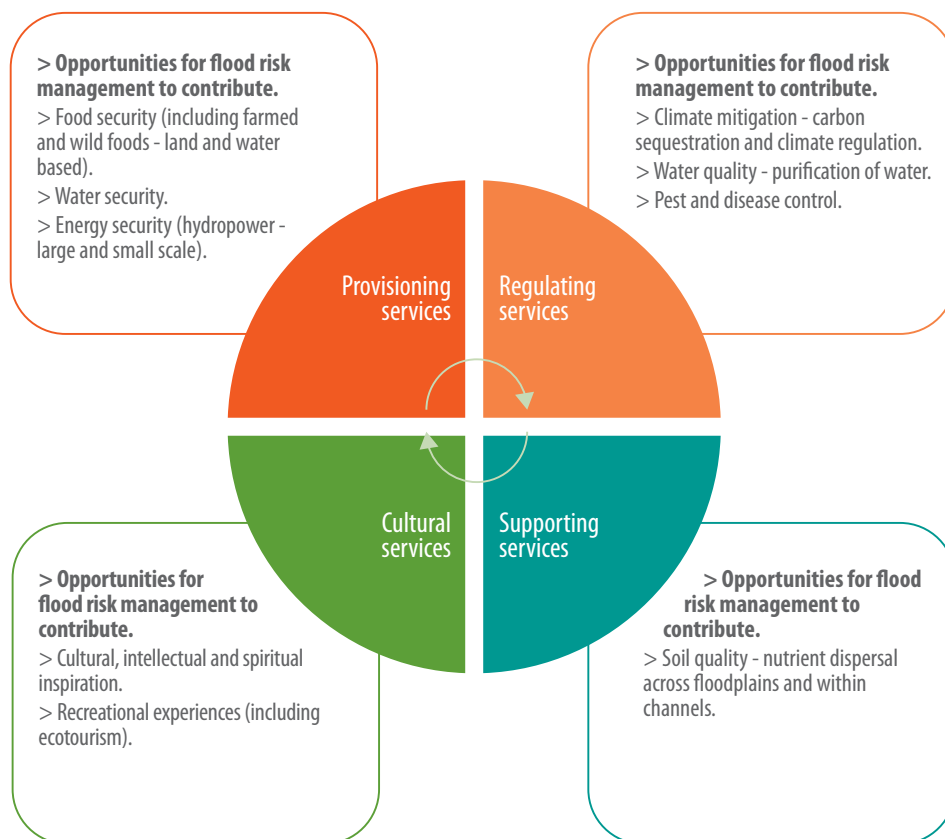
Stages of strategy development	Traditional (certain) model of strategy development and decision-making	Adaptive (uncertain) model of strategy development and decision-making
<i>Deciding what to do</i>	Predefined system of goals, objectives and desired outcomes. Defined set of activities and resource demands.	Emerging pattern of goals, objectives and desired outcomes. Flexible configuration of resources and priorities.
<i>Deciding how to do it</i>	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.
<i>Understanding the external and internal influences</i>	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 overlooked (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

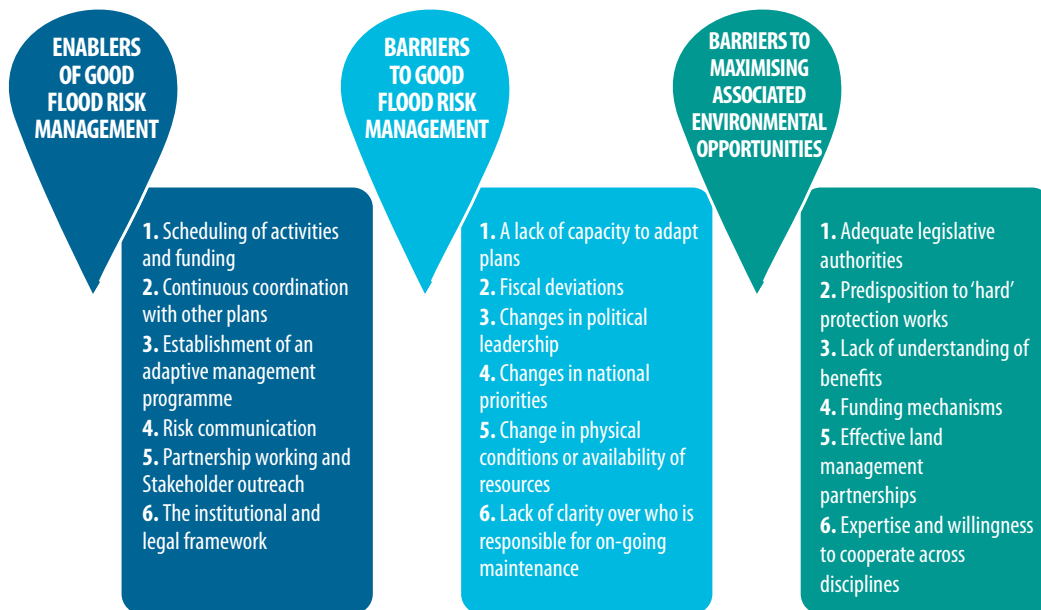
For nearly 300 years, those living along the Mississippi River have experienced the devastating effects of floods. Over time, governmental and public organizations have attempted to provide increasingly high levels of flood protection. Some of these efforts have been very successful; others have failed.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

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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 kept 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

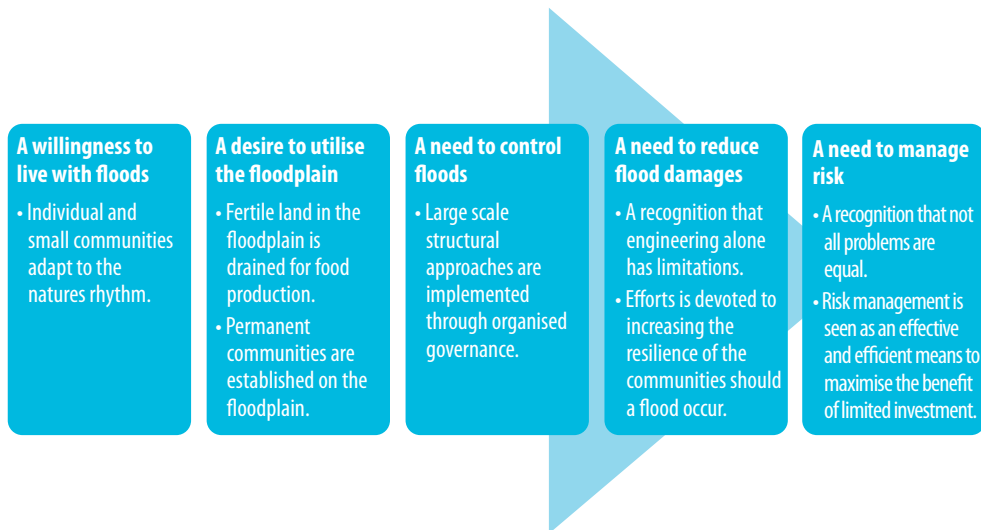
HISTORICAL DEVELOPMENTS AND EMERGING TRENDS

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 1185 (Davidson, 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.'

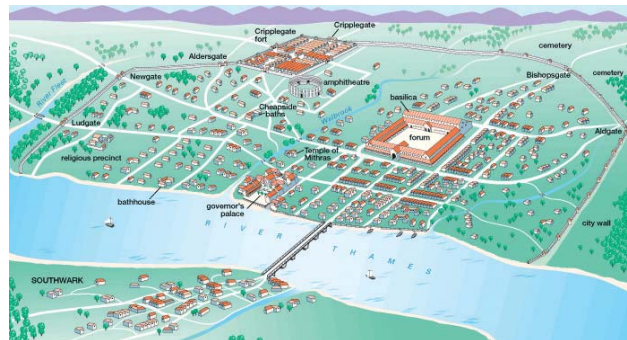
Some of the primary drivers for using floodplains and the engineering responses they prompted are discussed below.

► **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

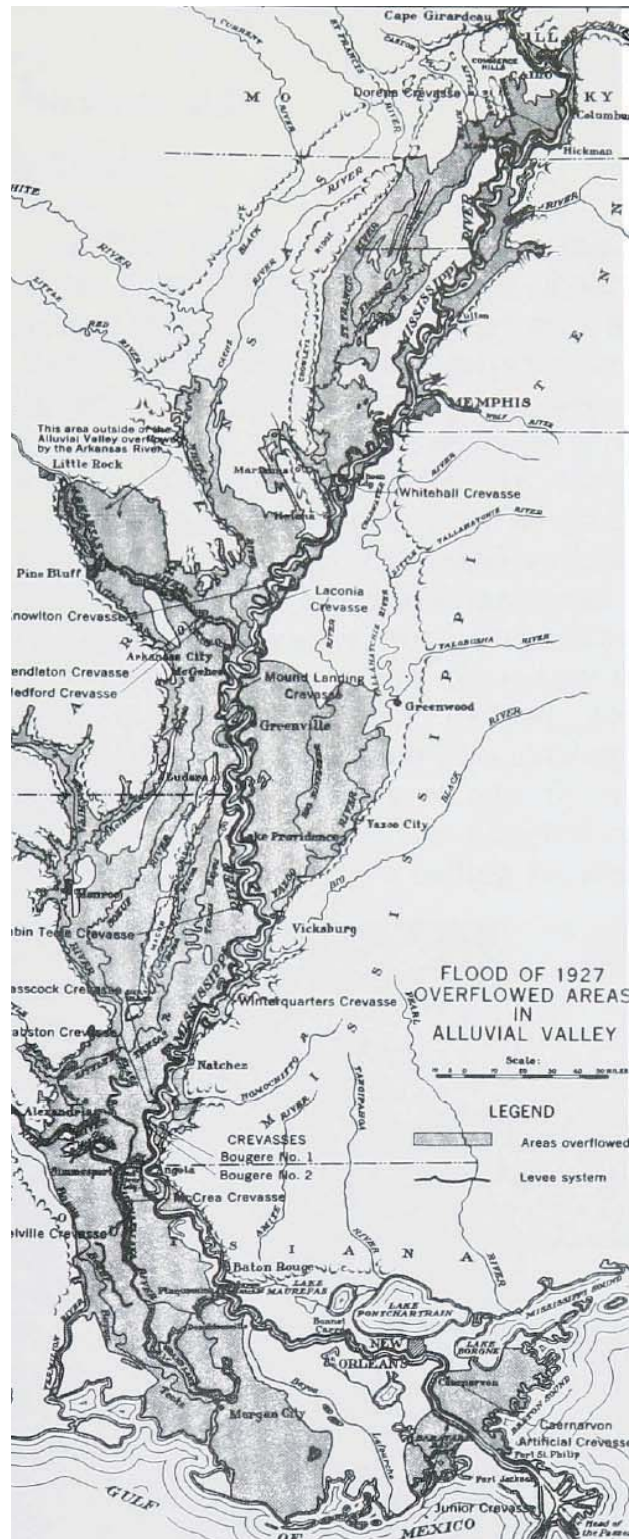
floodplains inherent in this legislation set the tone for the treatment of the floodplain environment that would continue in the United States over the next century, and reflected practice across much of the western world.

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

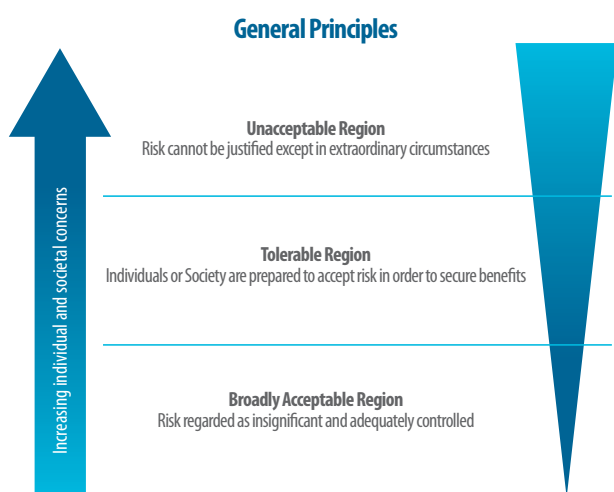
Until the latter part of the twentieth century, risk management was focused primarily on insurance activities and financial markets. Recognition that many unknowns influenced the success of trade led to the development of new methods that could provide better insight into the risks and how best to share 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

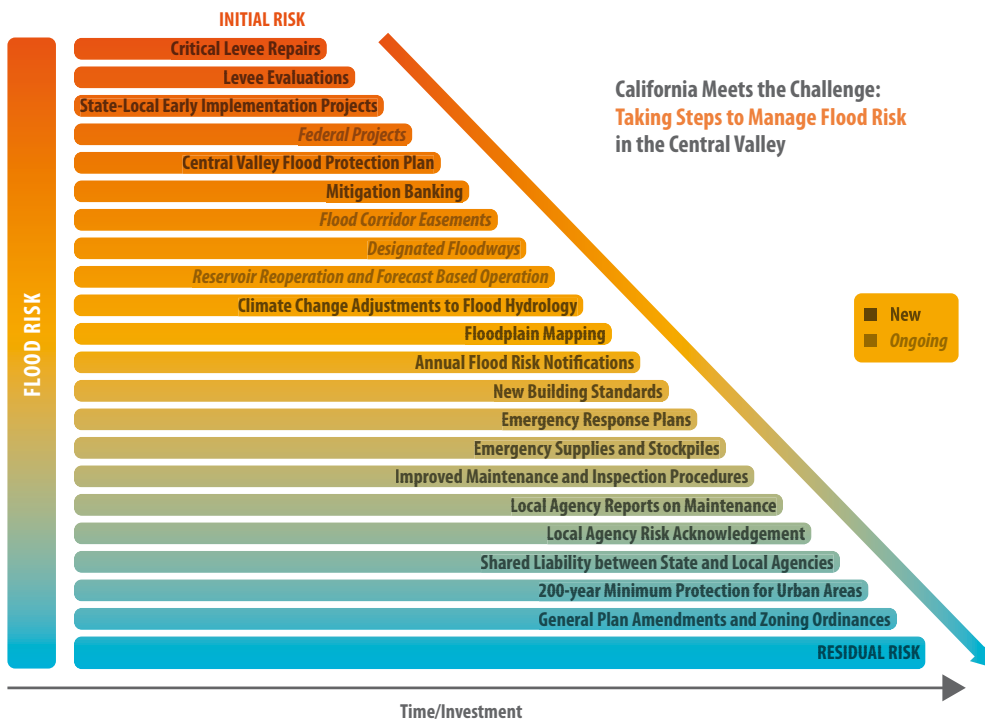
reinforced this view across the United States. Hurricane Katrina hit the Gulf Coast of the United States in June 2005, taking over 1900 lives and creating damages and costs to those in the area and the nation that may well exceed \$100 billion. Five years after this event much of New Orleans still had 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

Flood SAFE CALIFORNIA



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 m³/s (compared with the designed-for maximum flood of 85,000 m³/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:

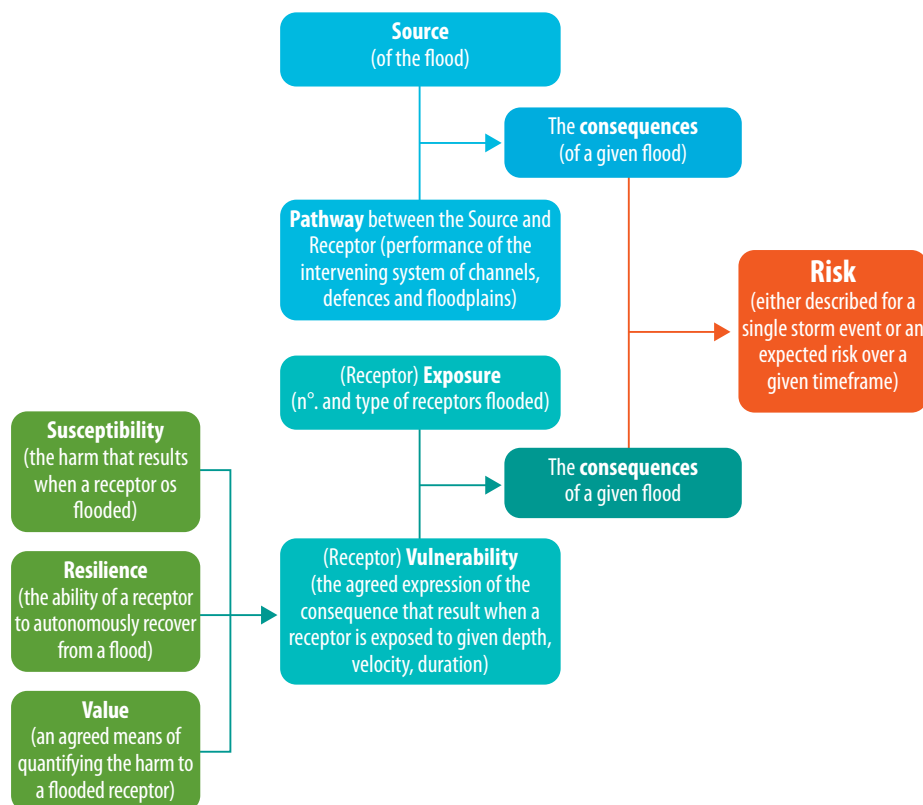
- ▶ The **probability of occurrence** of inundation. This reflects both the probability of the occurrence of the initiating event (the **source** of the flood such as rainfall or a marine storm) and the probability that flood waters will reach a particular location in the floodplain, taking account of 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

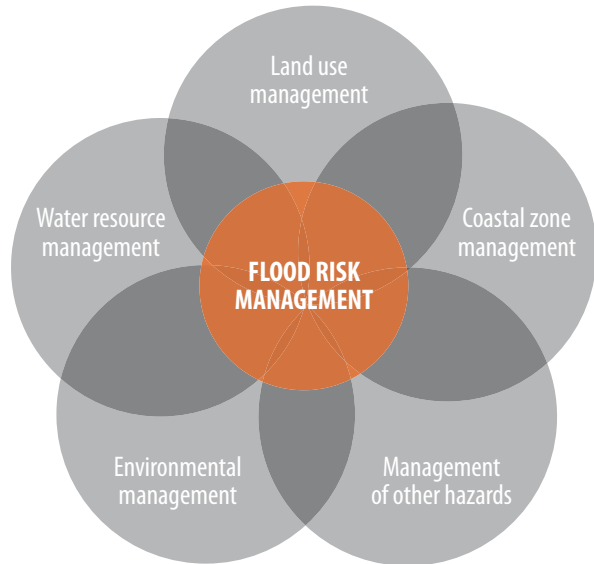
Risk cannot be eliminated totally. It is impossible to remove all risks, and it is said that there are only two types of levee, those that have failed and those that will fail. There will always be a future flood event that threatens and overcomes the most robust of defences. State-of-the-art warning 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



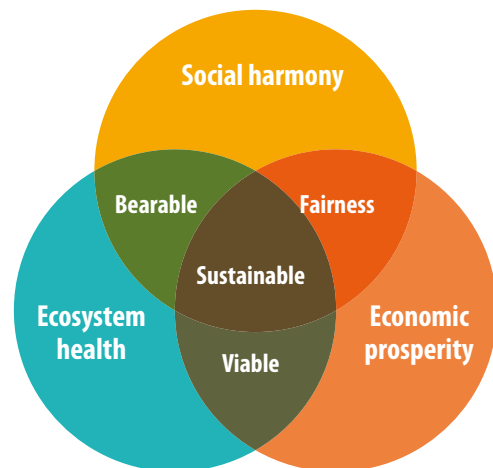
Box 4: Three pillars of sustainable development (the Brundtland Report)

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

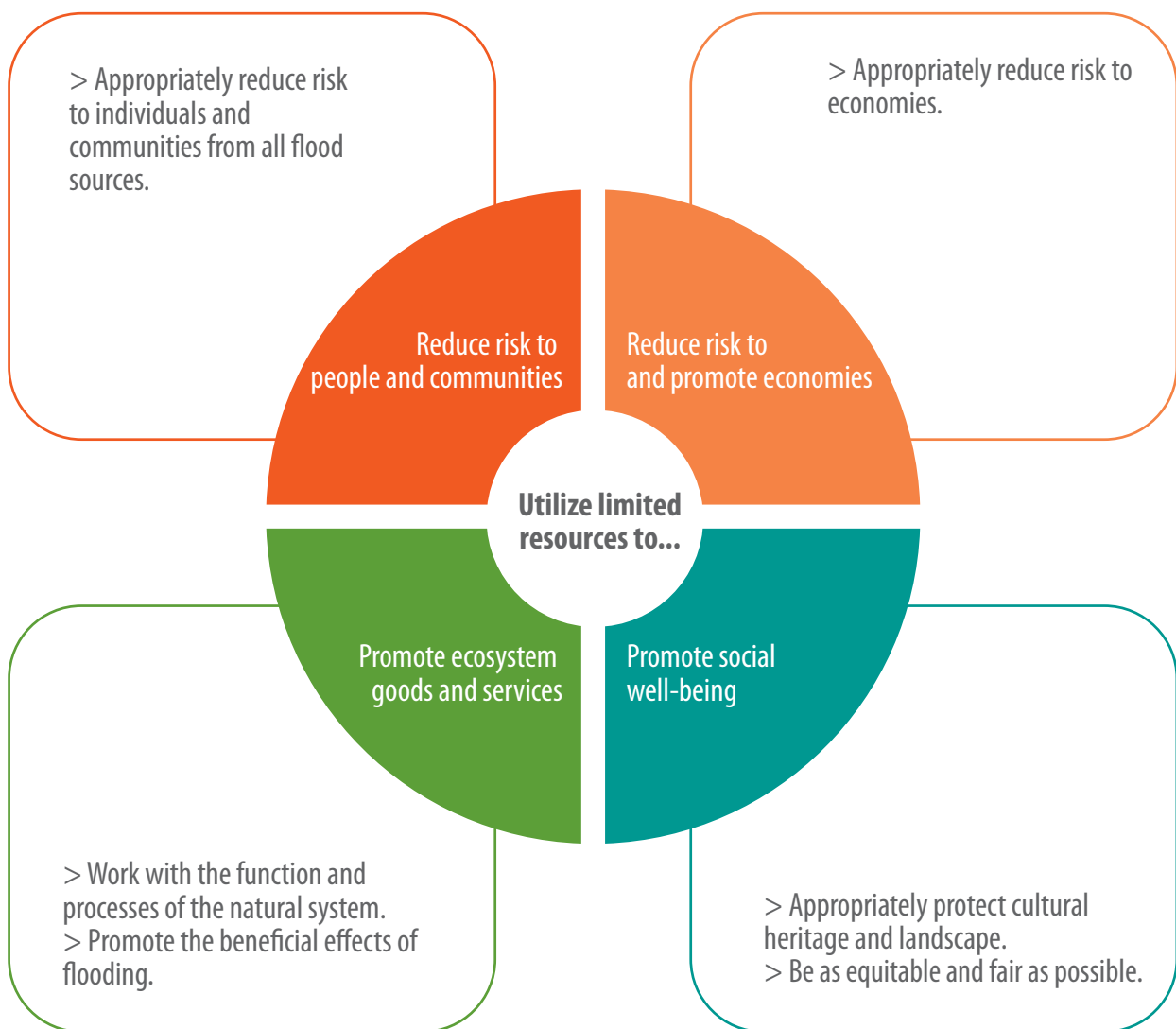


Table 3: A paradigm shift – from flood control to flood risk management

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.

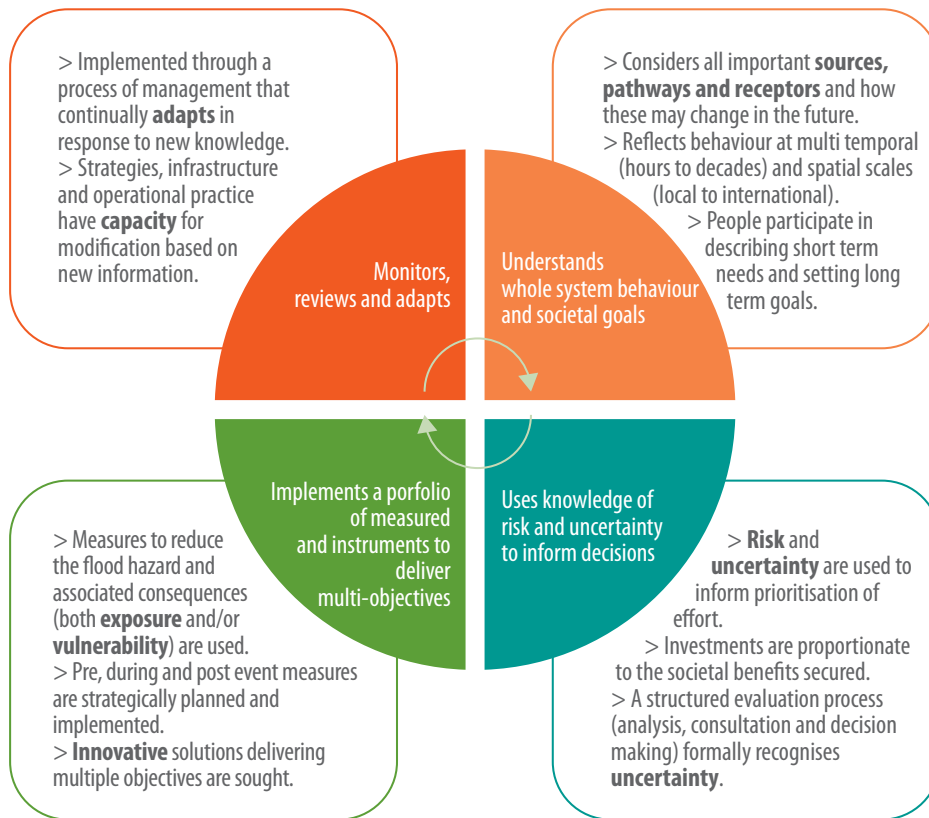
2.4 Characteristics of good flood risk management

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

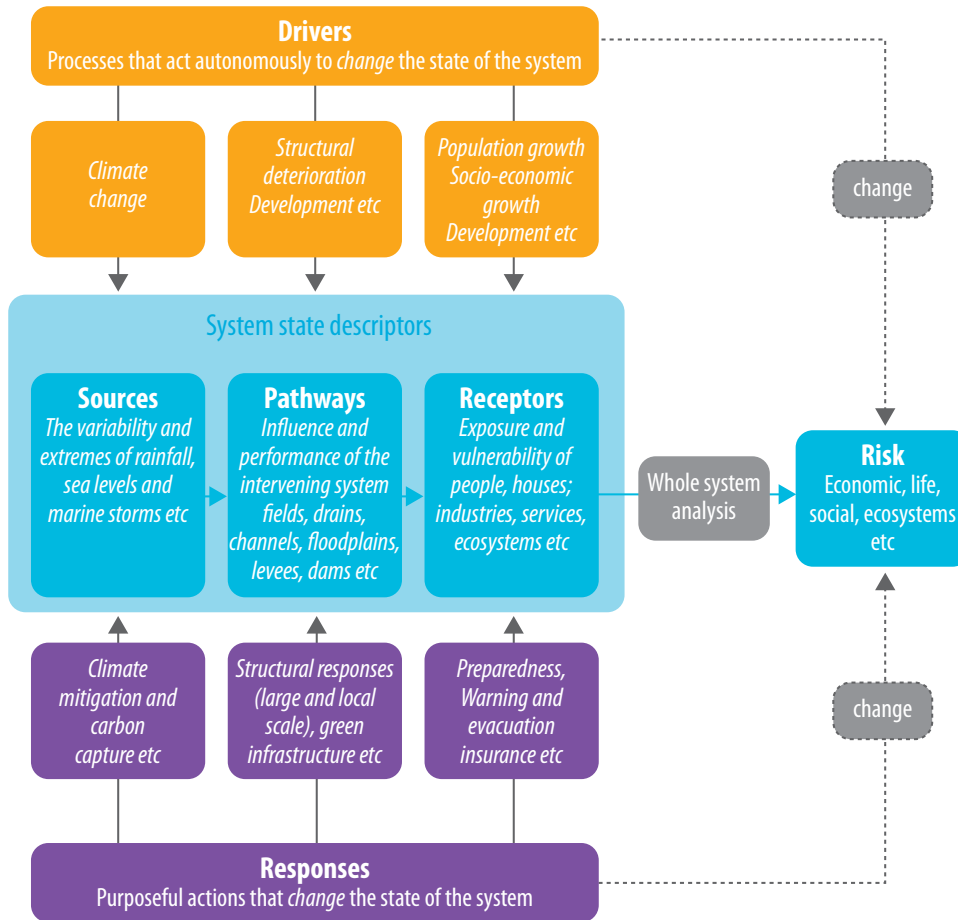
An appropriate understanding of the whole flooding system (that is, river basins, subcatchments, coasts and communities) in a way that accounts appropriately for all of the external drivers of change (such as climate and demographic change) as well as the potential management responses (structural, nonstructural 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.

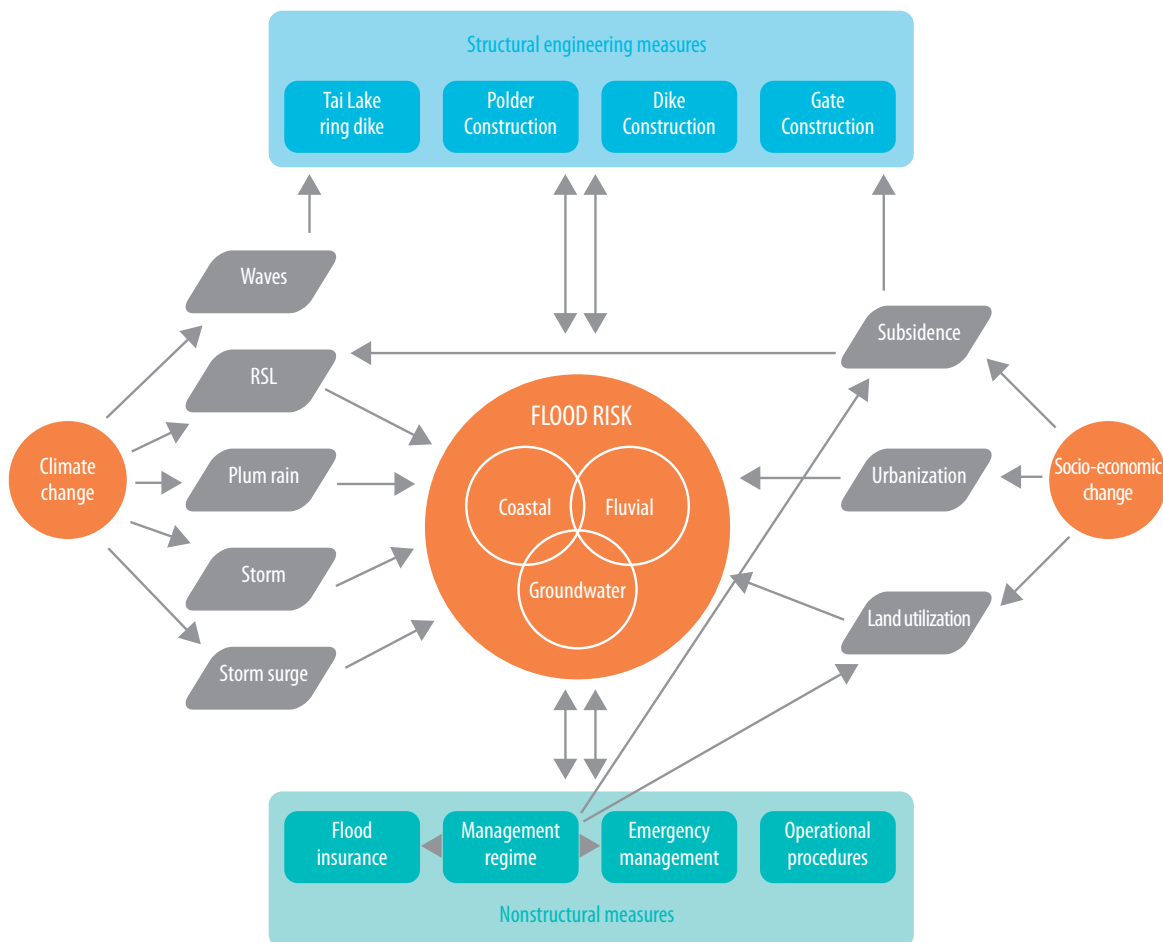
Box 5: Understanding the whole-system behaviour can change choices – an example from the Taihu basin

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	<p>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.</p> <p>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.</p>
Reduce the potential consequences should flooding occur	<p>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.</p> <p>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).</p>
Mitigate climate and demographic change	<p>Influencing future climate change: Through, as a minimum, use of low-carbon-use solutions. More ambitious flood risk managers will look for solutions that sequester carbon through for example use of existing wetlands and restoration of damaged wetlands to promote natural carbon capture and storage.</p> <p>Influencing demographic change: Positively influencing population growth, integrating flood management with food and water resource security.</p>

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

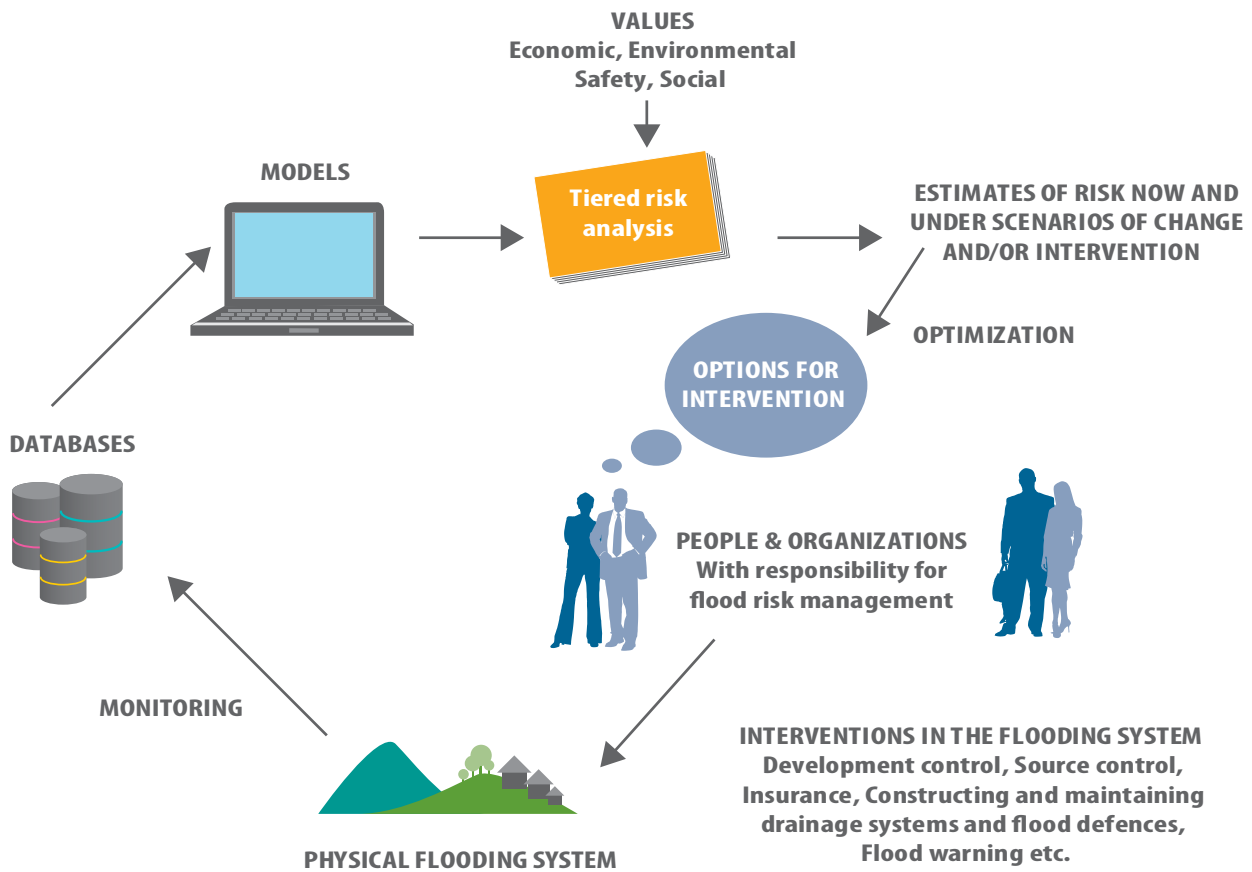
Changing climates, changing socio-economic contexts and deterioration in structural defences all present the decision-maker with complex policy choices. Every time a decision is taken on a major project (such as roads, rail, hospitals, schools, new housing, flood defence and water resources infrastructure), 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 exceedance
- 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 exceedance.** 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).

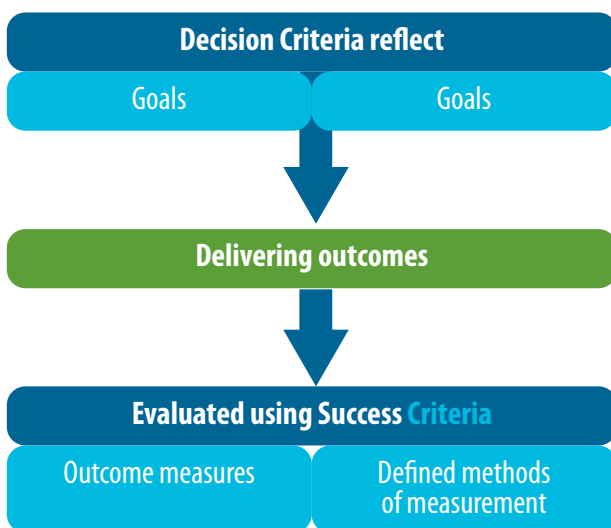
CHAPTER 3

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
<i>Equality (procedural)</i>	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
<i>Maximin rule (distributive)</i>	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
<i>Maximize utility (distributive)</i>	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.

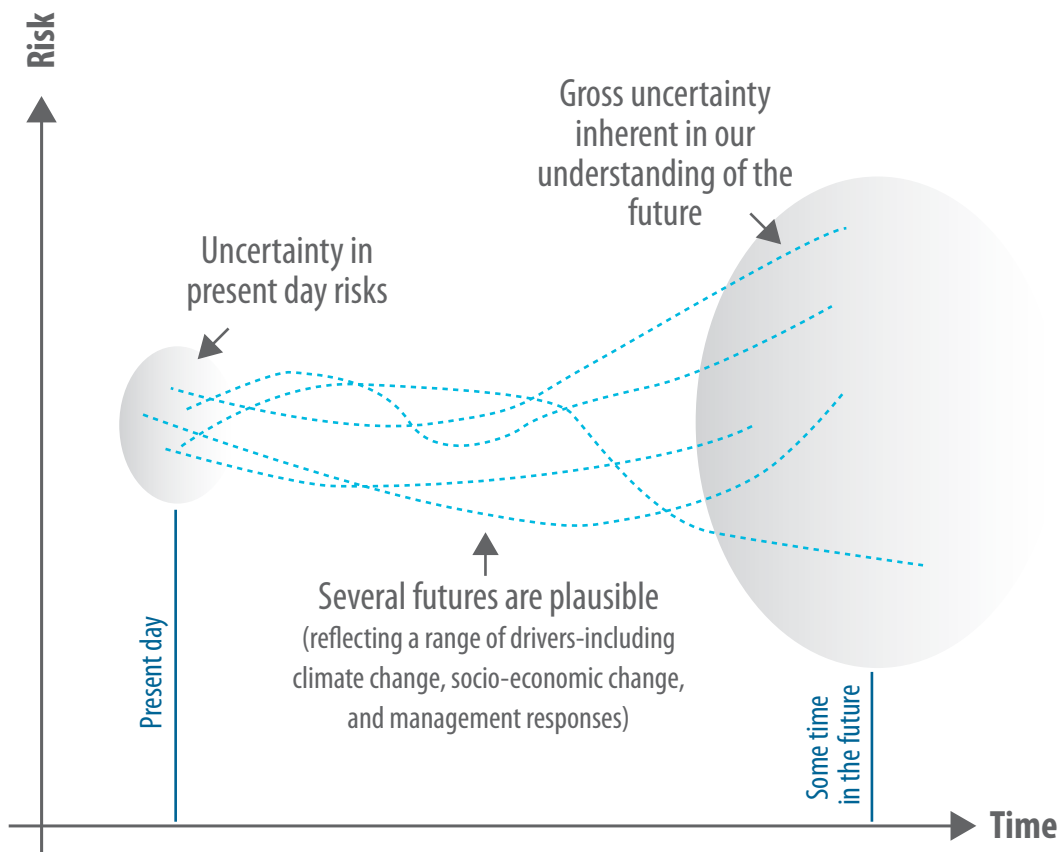
John Maynard Keynes (1937)

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; Boshier 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
<i>Deciding what is needed</i>	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.
<i>Deciding how to achieve it</i>	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.
<i>Understanding the external and internal influences</i>	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.

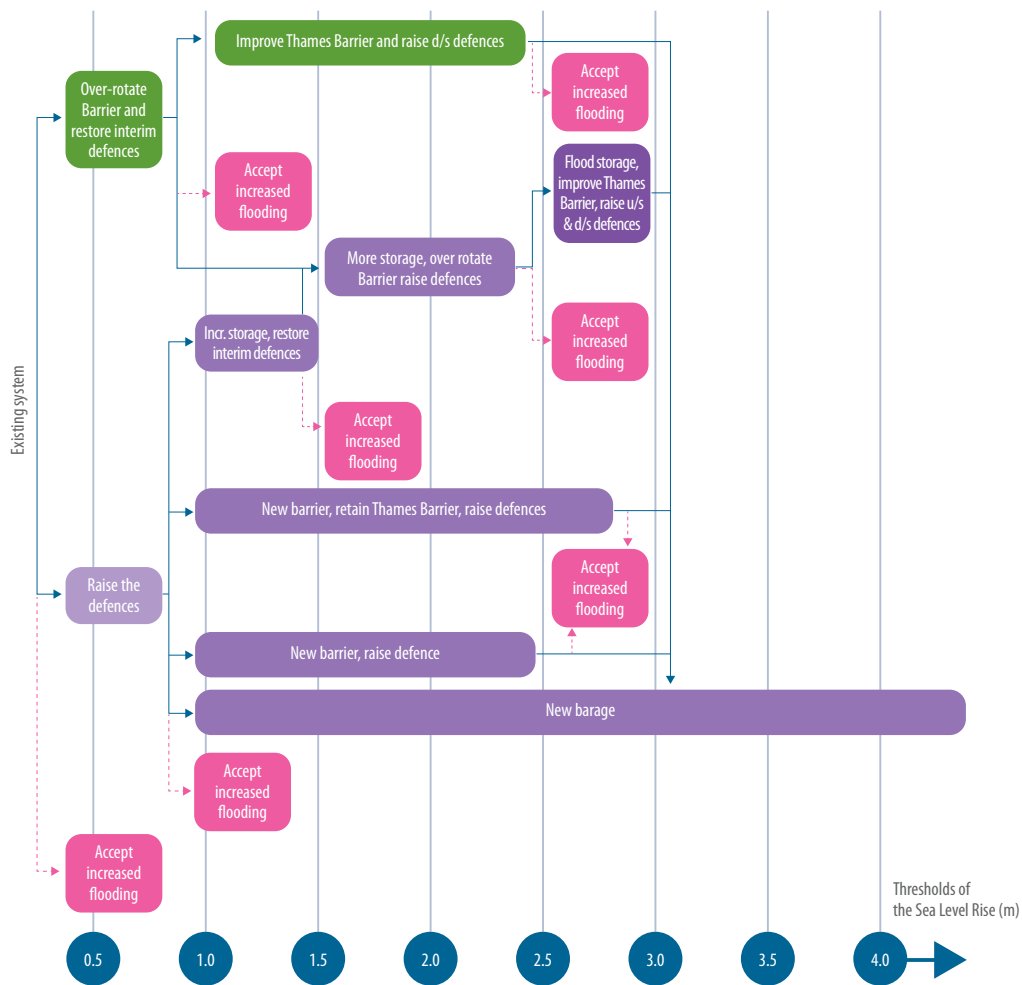
Source: adapted from Hutter and McFadden (2009).

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:

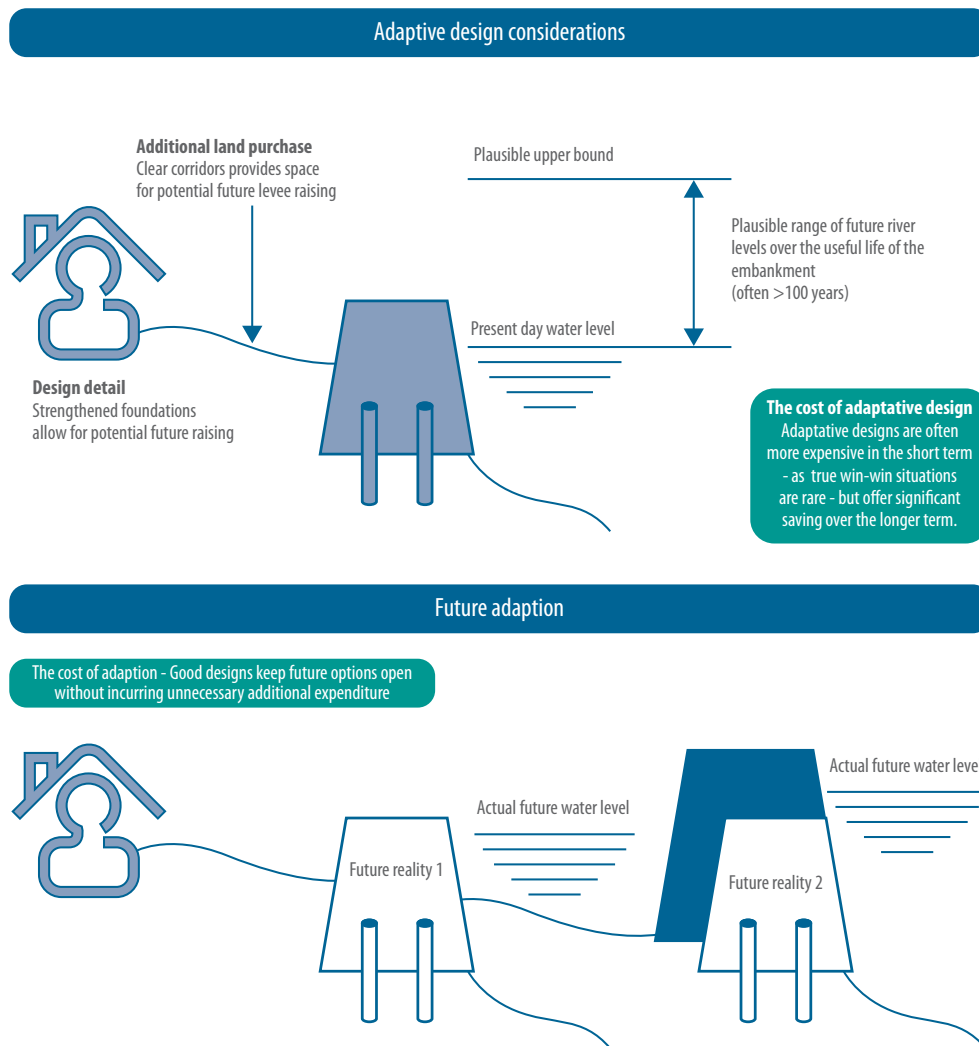
- ▶ **Resilience:** ensuring that engineered structures and nonstructural options perform (and do not fail catastrophically) during storm events that exceed design criteria or are of an unforeseen nature.
- ▶ **Adaptability:** ensuring a given measure (such an embankment) or instrument (such as insurance) 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 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
Viability	<p>Relative economic pain</p> <p>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.</p> <p>Security of appropriate resources in the short and longer term</p> <p>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?</p> <p>Economic benefit and costs</p> <p>Are the economic benefits well understood and assessed, including:</p> <ul style="list-style-type: none"> ■ 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? <p>Degree of public outrage (Sandman, 1987)</p> <p>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) attention to outrage. Not surprisingly, they rank risks differently. However for equity to be perceived as being achieved it is important to minimize the <i>degree of public outrage</i> in the face of floods as seen in media reports, political speeches, and calls for action.</p>
Fair	<p>Are resources distributed to the most vulnerable?</p> <p>Average annual probability of flooding per household (disaggregated by social group)?</p> <p>Average annual damages per household (disaggregated by social group)?</p> <p>Average expenditure on FRM per household protected (disaggregated by social group)?</p>

► **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	<p>An enhanced quality of life:</p> <p>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.</p> <p>Life and limb appropriately protected and adverse impacts on health (mental and physical) avoided:</p> <ul style="list-style-type: none"> ■ 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. <p>(Note: All measures should be disaggregated by social group).</p> <p>Protection and where possible enhancement of the historic and cultural environment:</p> <ul style="list-style-type: none"> ■ number of archaeological sites protected from floods ■ number of listed/historic buildings protected from floods ■ number of museums, art galleries etc. protected from floods. <p>The number of facilities protected must be balanced against the relative importance of these facilities.</p> <p>Community resilience (risk to critical infrastructure)</p> <p>Access to emergency infrastructure and safe evacuation is an important aspect of resilience. Simple measures include:</p> <ul style="list-style-type: none"> ■ 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. <p>Length of road/railway flooded (measure of inconvenience of finding an alternative routes).</p> <p>Equity of access to resources and positive effects of management activities</p> <p>A measure of risk transfer within society through the spatial distribution of:</p> <ul style="list-style-type: none"> ■ 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	<p>Maintenance and enhancement of the landscape and visual amenities to include recreational areas:</p> <ul style="list-style-type: none"> ■ protection or enhancement of characteristic landscape features ■ sympathetic character/design of new flood works ■ number of amenity and recreational sites protected. <p>Protection, maintenance and where possible enhancement of ecological functions and biodiversity:</p> <ul style="list-style-type: none"> ■ 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. <p>Maintenance and where possible improvement of local habitats</p> <p>Impacts on habitat as a result of flooding (both positive and negative).</p>
Viable	<p>Maintenance and where possible improvement of water quality and water supply</p> <p>Increase/decrease in water quality and water supply</p> <p>Maintenance of existing soil quality</p> <p>Increase/decrease in soil quality.</p> <p>Minimizing impacts on air quality</p> <p>Increase/decrease in air quality.</p>

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.

Table 10: 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. <i>Example:</i> 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. <i>Example:</i> 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. <i>Example:</i> less than 100 fatalities nationally, on average, each year
Property damage	Value of (or number of) properties damaged by event or annually. <i>Example:</i> 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. <i>Example:</i> 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). <i>Example:</i> 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. <i>Example:</i> 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. <i>Example:</i> 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. <i>Example:</i> 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. <i>Example:</i> 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. <i>Example:</i> 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 unlikely to view FRM as a success.

CHAPTER 4

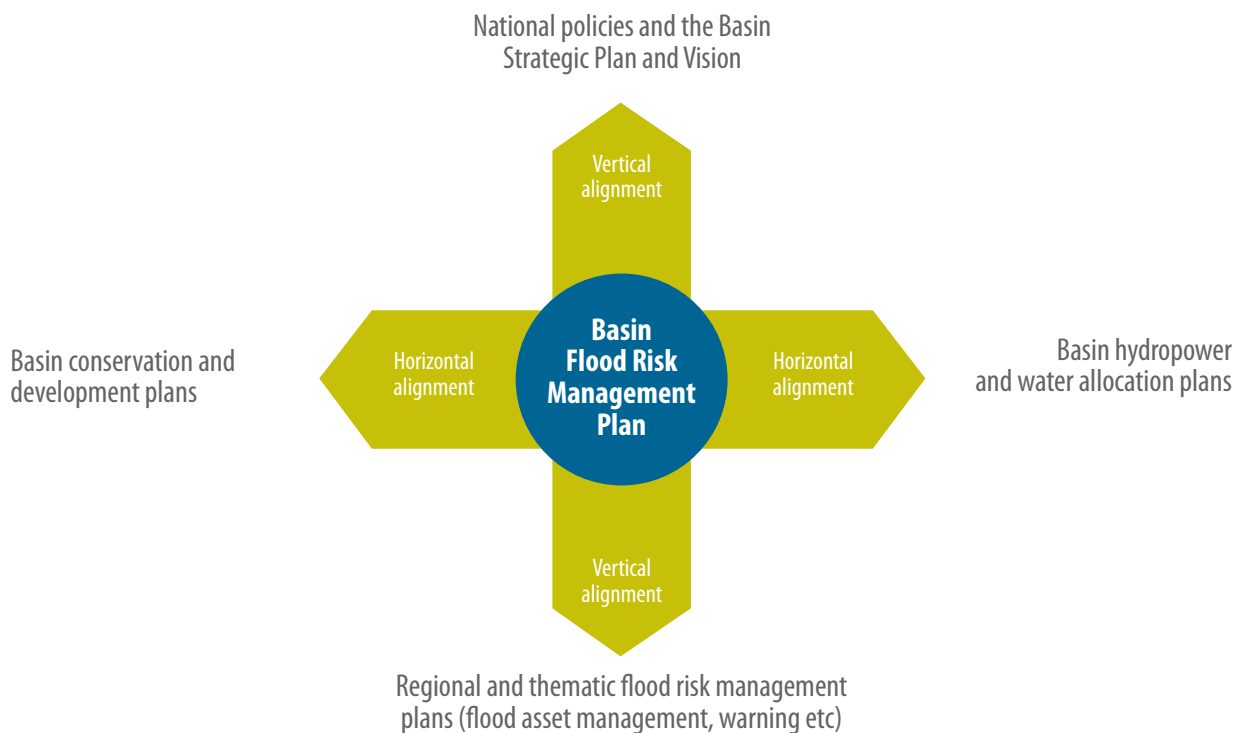
GOVERNANCE FRAMEWORKS OF FLOOD RISK MANAGEMENT

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

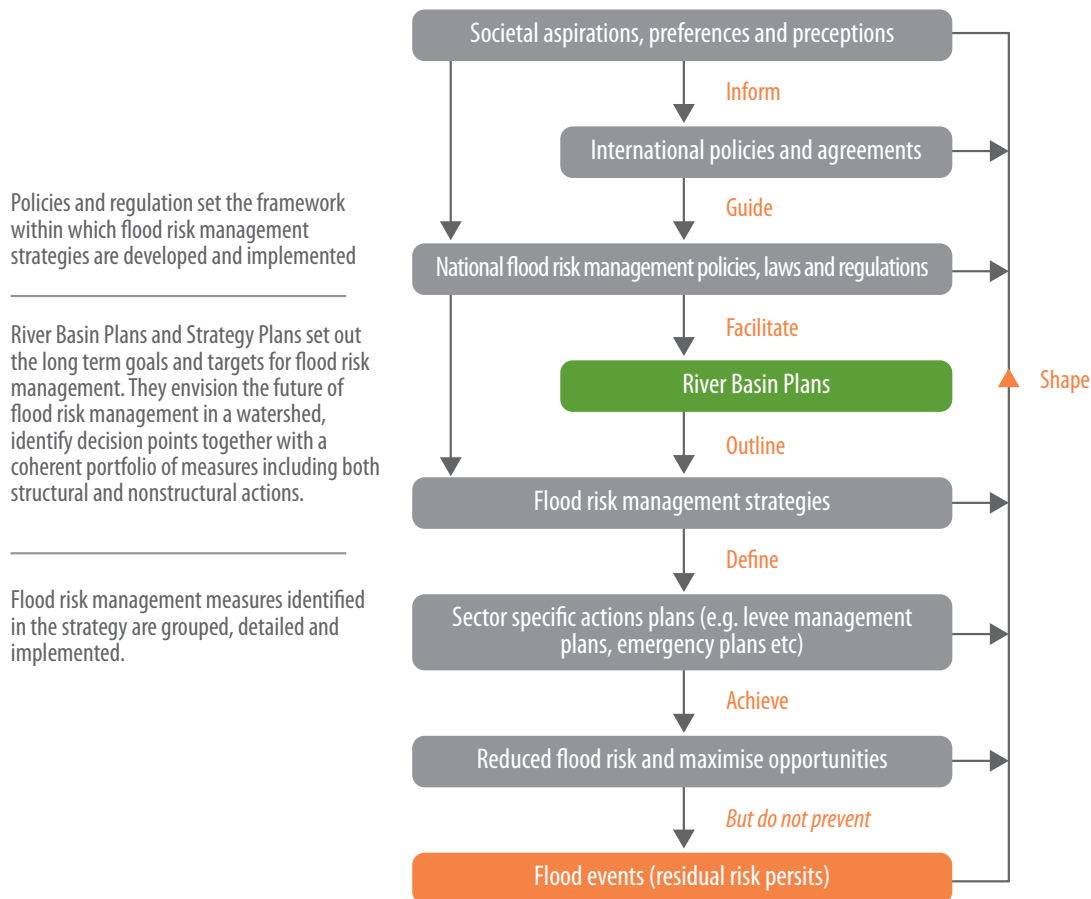


4.2 Translating societal aspirations into action

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.

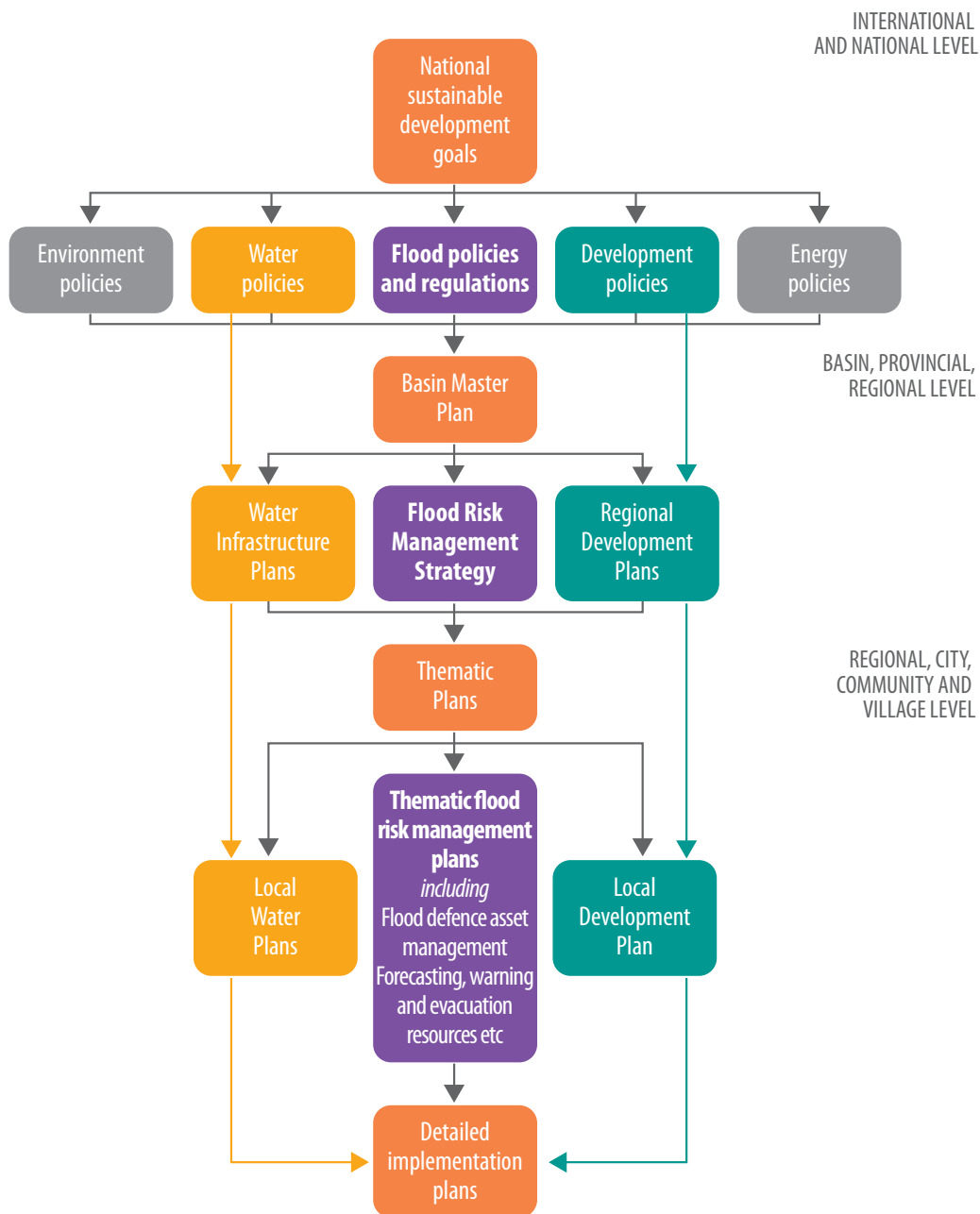
FLOOD EVENTS

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



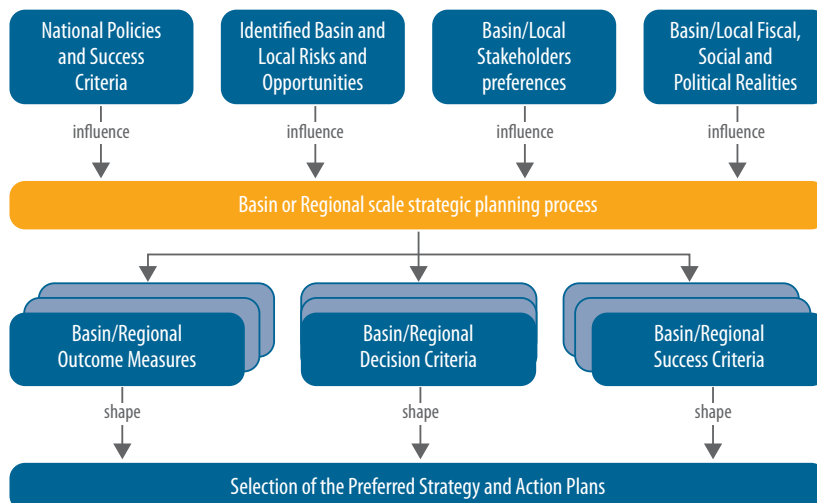
VERTICAL INTEGRATION – LINKING VISIONS AND ACTIONS

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

Source: ICPDR (2009).

- ▶ 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.

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 policies, 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 carried 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	<p><i>As for a single country basin (see below) plus:</i></p> <ul style="list-style-type: none"> ■ data-sharing protocols ■ water sharing agreements ■ operational arrangements during flood and drought extremes ■ making room for water 			<p>Danube basin plans</p> <p>Rhine basin plans</p> <p>Red River plans</p>
National based on societal goals and aspirations	<p>National goals and objectives</p> <p>Policy framework</p> <p>National funding prioritization</p> <p>Process and requirements of planning</p> <p>Decision and success criteria</p> <p>Insurance framework</p> <p>Financing frameworks</p> <p>Data-sharing protocols</p>	<p><i>Sources:</i> extreme storm loading conditions.</p> <p><i>Pathways:</i> River and coastal network, topography, notional defence standards and condition.</p> <p><i>Receptors:</i> Property and people numbers/locations, critical infrastructure locations.</p> <p><i>Other plans:</i> findings from regional and local plans.</p>	<p>Simplified broad-scale, yet quantified, models.</p> <p>Discrete scenario-based exploration of future change:</p> <ul style="list-style-type: none"> ■ climate ■ socio-economic ■ funding ■ Influence of autonomous and planned change ■ impact of flood risk management policy changes. 	<p>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., 2004a, 2004b) and support the development of long-term policy goals.</p>
Basin (within a single country)	<p><i>Translation of the above and below to provide:</i></p>	<p><i>refinements of the above plus</i></p>	<p><i>refinements of the above plus</i></p>	<p><i>refinements of the above</i></p>
based on national policy and regional realities	<p>Basin goals and objectives</p> <p>Regional prioritization of investment.</p> <p>Development planning and spatial zonation of the floodplain.</p> <p>Large-scale responses:</p> <ul style="list-style-type: none"> ■ emergency planning (evacuation planning, warning systems, safe refuges etc). ■ large-scale infrastructure. <p>Trade-offs and synergies with other sectors.</p>	<p><i>Sources:</i> general refinements.</p> <p><i>Pathways:</i> general refinements plus road networks etc.</p> <p><i>Receptors:</i> Demographics, habitat vulnerability.</p>	<p>Increased use of process based models.</p> <p>increased use of continuous simulation and more detailed scenario analysis.</p>	
Regional	<p><i>Translation of the above to provide</i></p>	<p><i>refinements of the above plus</i></p>	<p><i>refinements of the above plus</i></p>	<p><i>further refinement of the above</i></p>
sub-basin – based on basin strategy, national policies and local realities	<p>Detailed implementation plans for each thematic flood risk management plan, e.g.</p> <ul style="list-style-type: none"> ■ asset management ■ evacuation planning ■ land use control. 	<p><i>Sources:</i> general refinements</p> <p><i>Pathways:</i> general refinements plus geotechnical properties, evacuation networks etc.</p> <p><i>Receptors:</i> general refinements</p>	<p>More detailed models as required</p>	<p>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).</p>

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., 2012a). 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

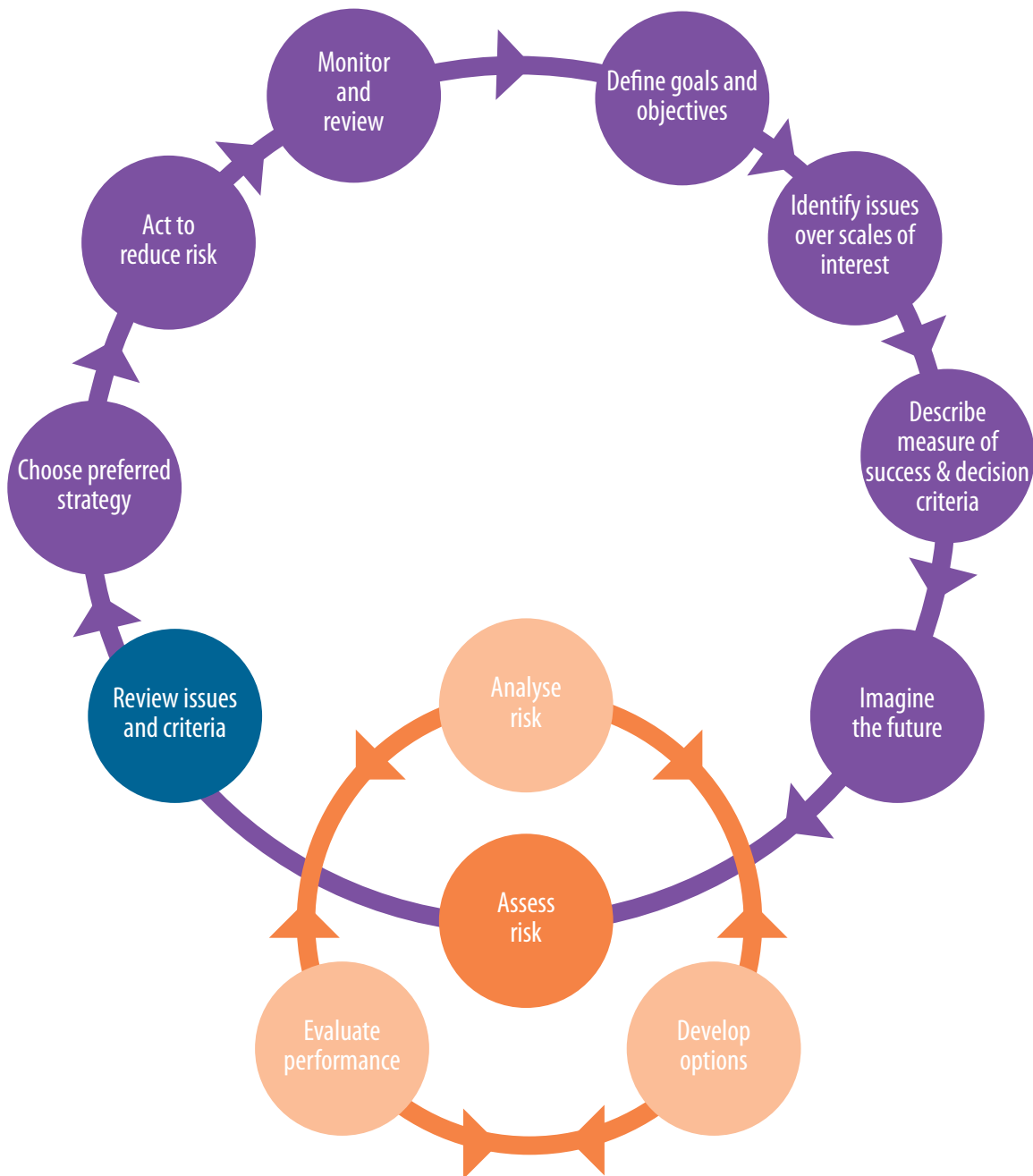
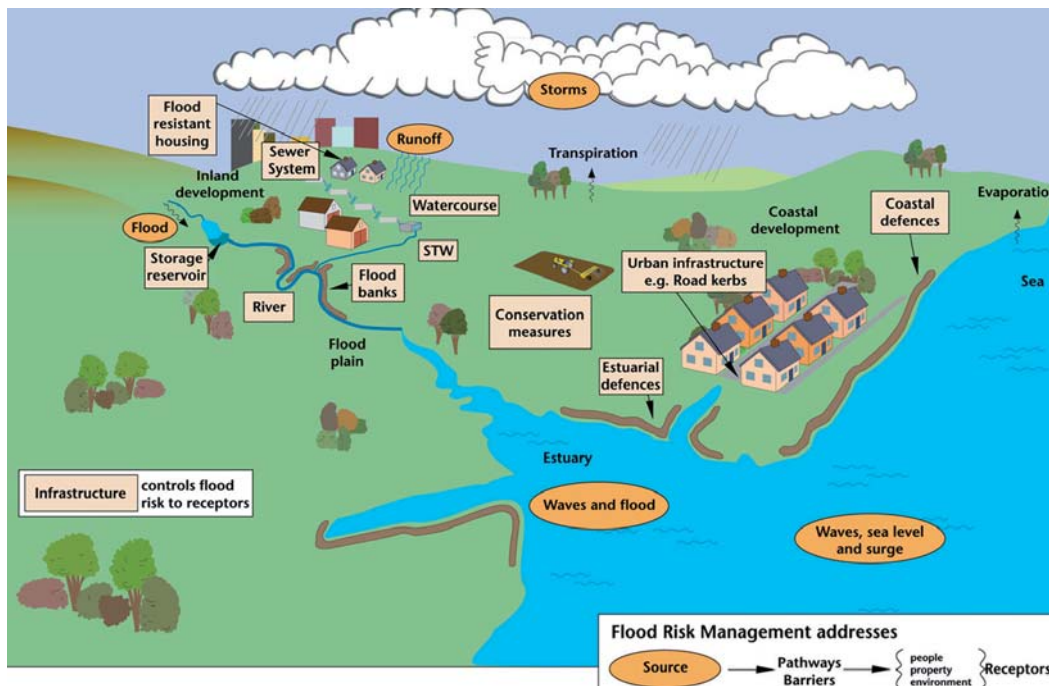


Figure 34: Identifying an appropriate spatial and temporal scale of the decisions and supporting analysis (based on a whole systems view) is critical to good management



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 (2011b).

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 centre

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

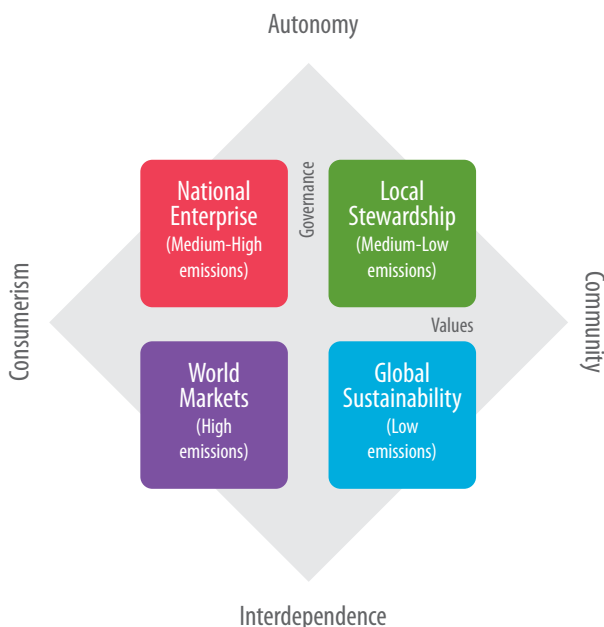
Improved forecasting, warning and emergency planning

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

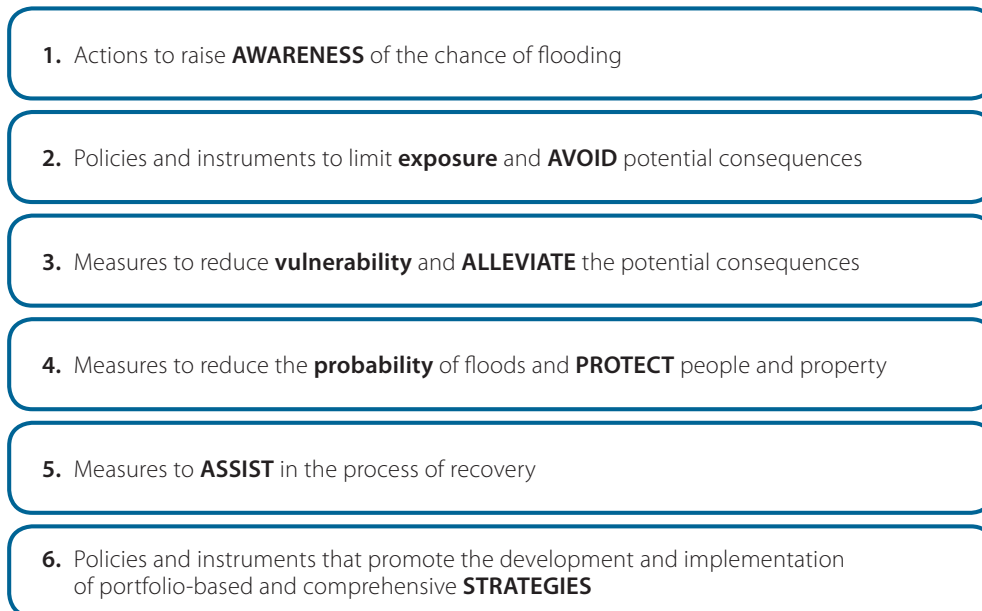


DEVELOP OPTIONS – DEVELOPING ALTERNATIVE STRATEGY PLANS AND ACTIONS

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



Source: adapted from INTERREG EC Flood Resilient Cities, <http://www.floodresiliency.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).

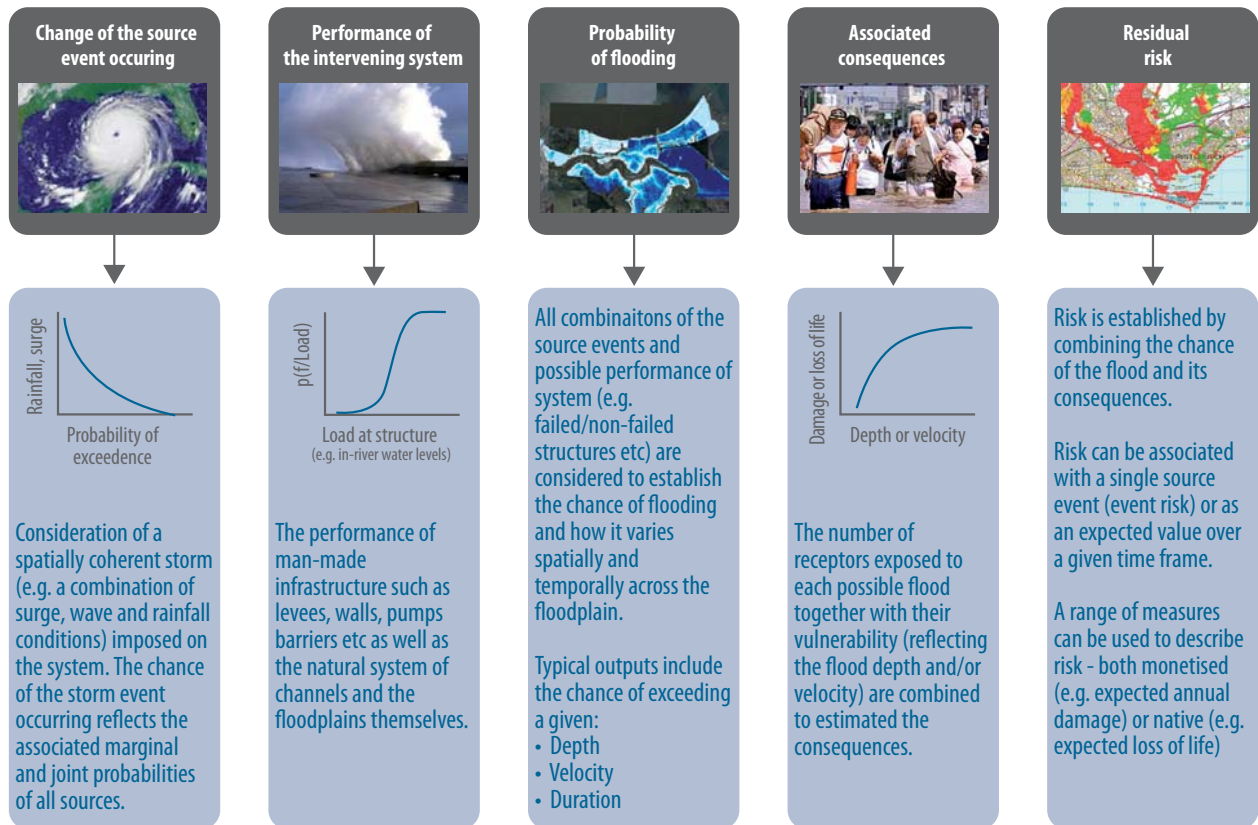
Policies and instruments that promote the development and implementation of portfolio-based and comprehensive strategies

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

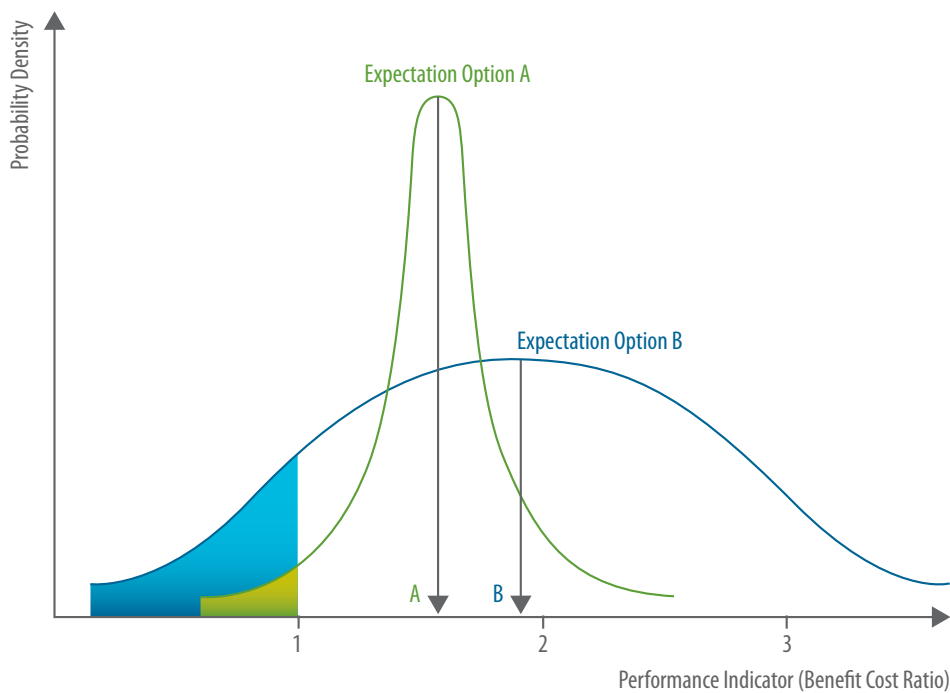
The analysis in support of the decision-making process must, first, analyse the change in risk, and second, identify the associated uncertainty in that estimate. The analysis of risk must appropriately reflect the performance of the whole system (Figure 39). This does not however imply that great detail 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) typically consider one or two design conditions (typically 1:100 or 1:200 years) and highly simplify 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 (Rowse 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 monetization) 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 monetized 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

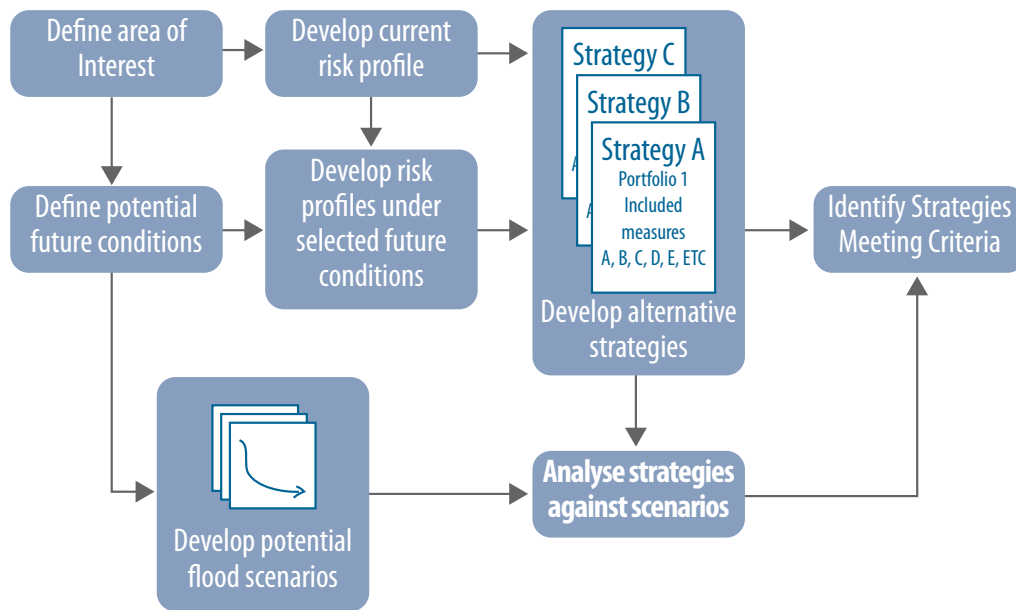
Practical responses to manage uncertainty	Description
Monitor and decide	Monitoring places a central role on adaptive planning – enabling approaches to be changed as the reality of the future becomes known
Increase knowledge	Research and development offer significant opportunities to reduce uncertainty 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

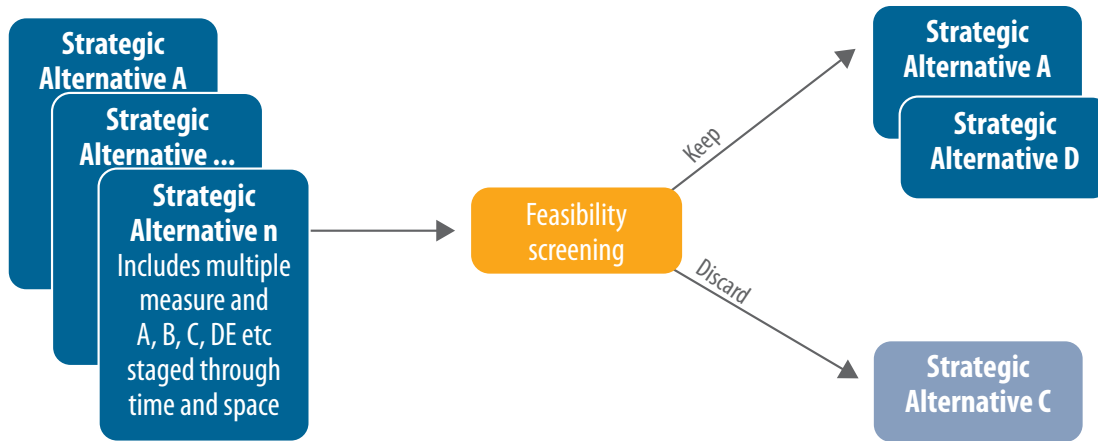


The system risk model can vary from an expert review through to numerical simulation using process-based models or more conceptual serious gaming technologies. Critical in either case is recognition that system risk models provide only the evidence to the decision-makers – not the decision itself. The 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

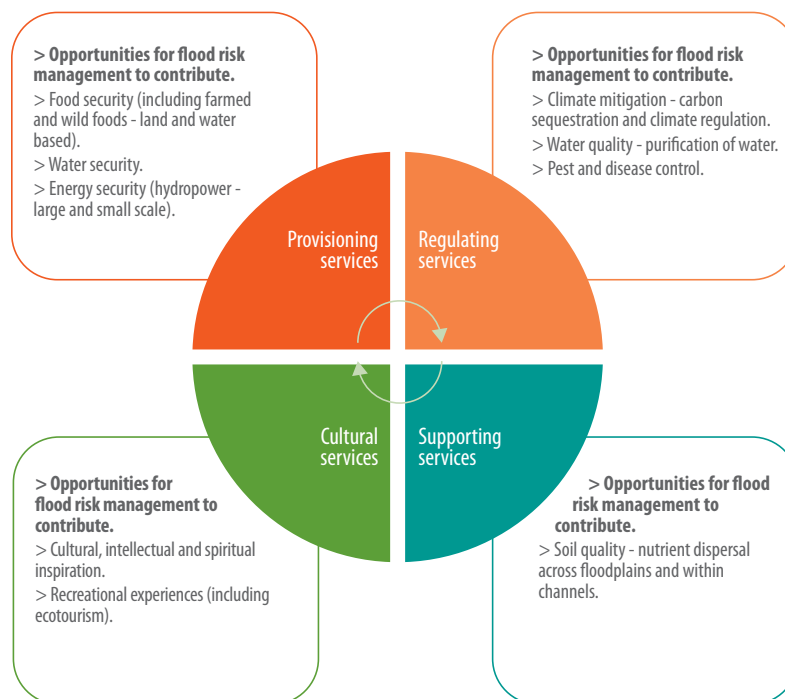
6.1 Introduction

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 km² of wetland was restored, providing storage for up to 285 million m³ 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 dunes	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 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).



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

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

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 km² 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 km² 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 m³/sec, which compares with the Yolo Bypass's capacity of 14,000 m³/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 km² area was left within the confines of the roads, forming the Tonle Sap Biosphere Reserve.



The Great Lake of Tonle Sap

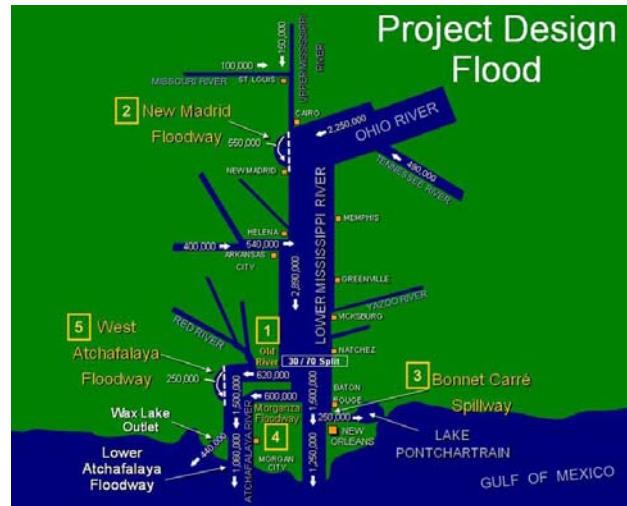
UTILIZING BYPASS CHANNELS AND DETENTION AREAS TO LIMIT STRUCTURAL INTERVENTIONS

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 km² with a flood storage capacity of 102 billion m³. Twelve of the storage areas are operated by the national government and have a flood storage capacity of 22 billion m³. 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.
	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).
	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 play 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

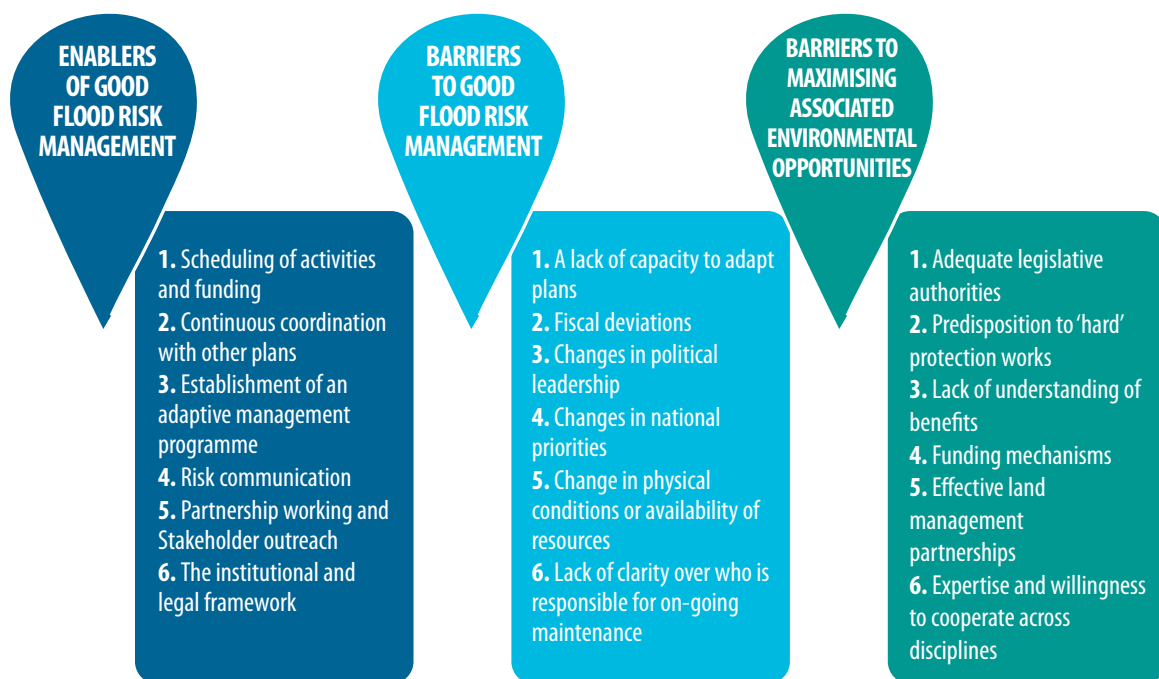
IMPLEMENTING FLOOD RISK MANAGEMENT – BARRIERS AND ENABLERS

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

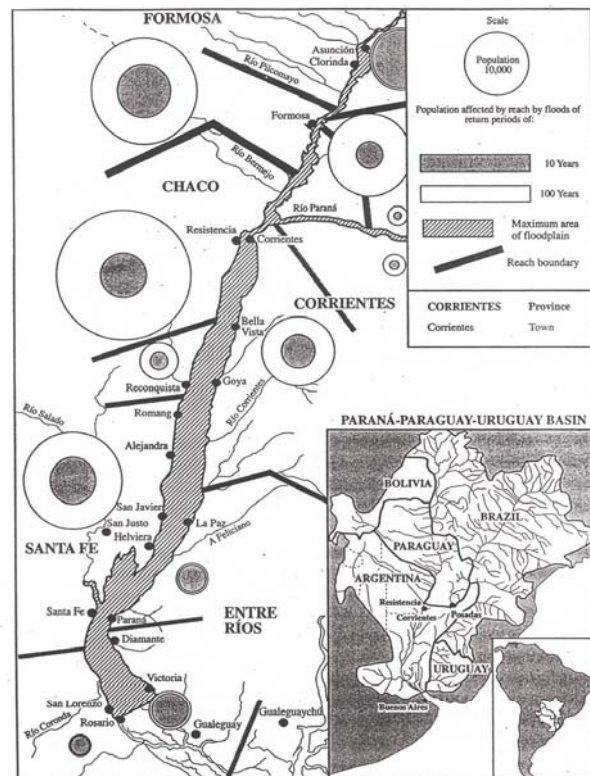
to climate change, encouraging sustainable technologies, protecting communities and the environment better from the risk of flooding'.

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 reevaluation 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 reevaluation 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 reevaluate 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.

PART C

SUPPORTING TOOLS AND TECHNIQUES FOR FLOOD RISK MANAGEMENT

Flood Risk Management consists of various components. This section explores some of the supporting tools and techniques available to the flood risk manager which help support good management decisions.

There are seven chapters in this section on:

- > risk and uncertainty analysis
- > spatial planning
- > infrastructure management
- > emergency planning and management
- > flood hazard and risk mapping
- > flash floods - managing the risks
- > insurance and flood risk.

CHAPTER 8

RISK AND UNCERTAINTY: PRINCIPLES AND ANALYSIS

8.1 Introduction

Concepts of risk assessment and management provide the basis for decision-making on both individual risk management measures, and also on a whole integrated programme of measures and instruments. They enable the following key questions to be addressed when determining policy, strategic planning, design or construction decisions:

- ▶ 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 managed?

However, confusion often exists with regard to what 'risk' and 'uncertainty' mean, how to analyse them and how an improved understanding of risk and uncertainty can help support better decisions. This chapter provides a discussion of the underlying principles surrounding risk and uncertainty and the supporting analysis tools and techniques.

8.2 Risk: the underlying principles

THE UNITS OF RISK

Risk always has units. The units of risk depend on how the likelihood and consequences of an event are defined, and therefore may be expressed in a number of equally valid ways. For example:

- ▶ **Probability** may be defined as the chance of occurrence of one event compared with the population of all events. Therefore, probability is dimensionless but must be referenced to a particular event (the probability of flooding given specific rainfall, or the probability of a head given a single toss of a coin, through to an annual exceedence probability or lifetime exceedence probability).
- ▶ **Consequence** represents an impact such as economic, social or environmental damage/improvement, and may be expressed quantitatively (for example in monetized or native terms), or by descriptive category (such as high, medium or low).

The resulting risk can be expressed and viewed in a number of ways. Typically these include:

- ▶ **Expected annual/lifetime damage:** the consequences that are expected to occur within a given timeframe (Figure 47) – reflecting the average risk that is expected to occur within a specified timeframe. Typically expected annual damage (EAD) is used as a convenient measure of the average damage in a given year. Alternatively expected lifetime damage may be used, reflecting the damage that is expected to occur, say to a house, over an average lifetime. Although the 'expected' damage is a useful term when looking to compare the economic or financial efficiency of various management options (for example using BCA), it does not provide a full picture of the significance of the risk faced – an issue discussed further later in this chapter.
- ▶ **Expected event damage:** the consequences that are expected to occur during a storm event – reflecting the consequences that would be expected (physical damage,

loss of life and so on) in the event of storm of a given return period (measured for example by the return period of the rainfall or flow in the river). In determining the risk it is necessary to integrate all possible states of the intervening pathways (including the performance and reliability of levees, pumps, barriers and so on) and the performance of nonstructural measures (such as flood warning systems). By

considering the response to a number of events the profile of risk can be explored. This is as important as, if not more important than, understanding the expected value. If the risk profile is known, risks with the same numerical value (such as low-probability, high-consequence events and high-probability, low-consequence events) can be distinguished (Figure 48).

Figure 47: The expected risk is a function of various aspects of the hazard and its consequences

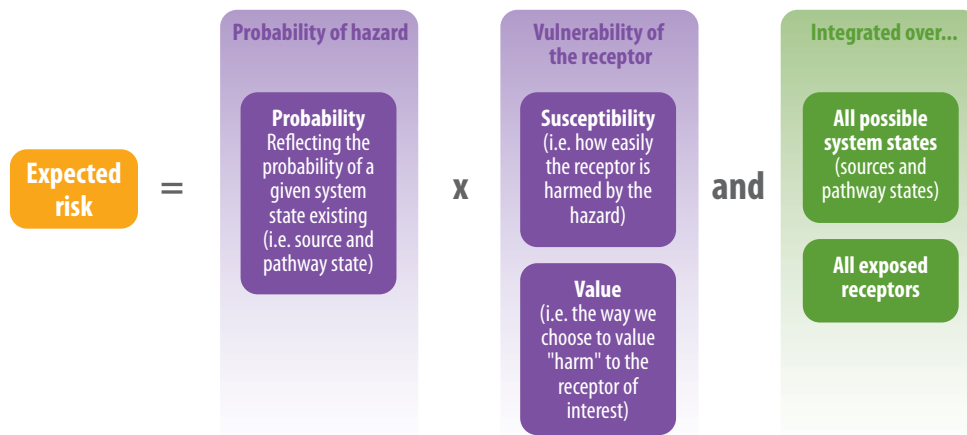
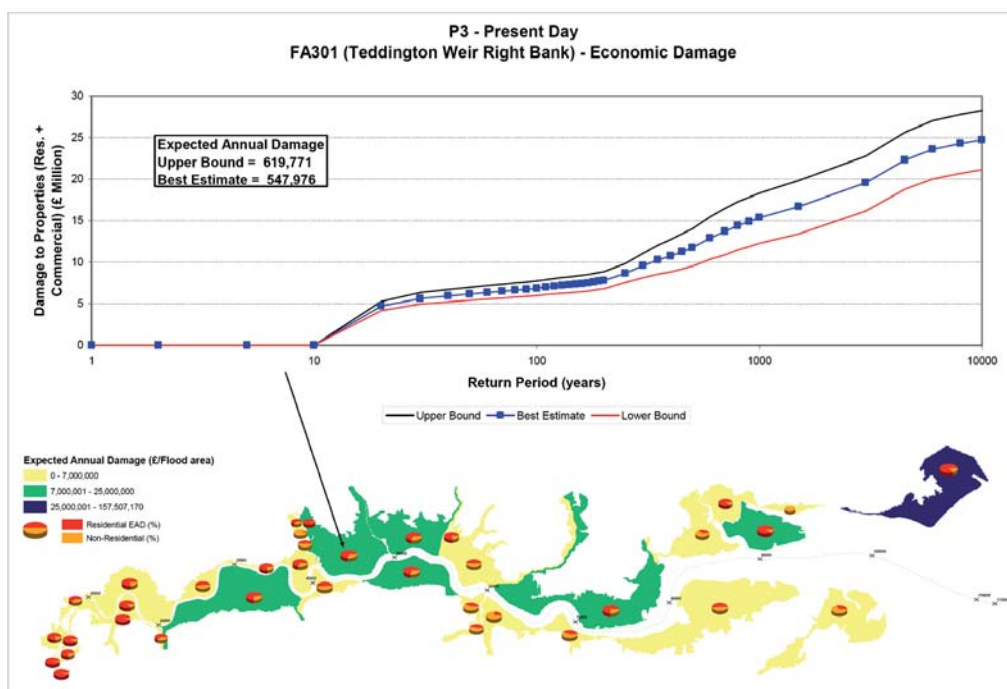


Figure 48: Example of a risk profile for the Thames Estuary. Top, how the risk increases with storm return period (so-called 'event risk') for the West Ham/Royal Docks flood area. Below, expected annual damage (in £)



Source: Environment Agency, 2008a.

Box 25: Return period: understanding its use and misuse

To help understand the difference between frequency and probability, consider the throwing of a fair die. The probability of recording a six with one throw is 1/6. What then is the probability of recording a six with six throws, and what is the expected frequency? We multiply the probability of a six with a single throw (1/6) by the number of trials (6) to give the *expected (average) frequency*: 1 (that is, one six in six throws). However, this does not indicate the probability of that result. A probability of 1 would imply certainty of obtaining one six in any six throws, but clearly this is not the case: the six throws might return any number of sixes from 0 to 6. To calculate the probability of recording one six in six throws of the die, it is necessary to consider the total number of ways in which one six (and only one six) could be obtained, as a proportion of the total number of ways in which outcomes including those with a different number of sixes could be obtained. The answer approximates to 0.40.

In the context of flood management a similar example can be given. Consider the probability of obtaining a once per 100 years return period event in an actual time period of 100 years. The expected frequency is 1, but it is easily possible that the event will not occur at all, or else it will occur more than once.

Thus, while *on average* a flow with a return period of T years is likely to be equalled or exceeded once in T years, this simple description often leads to confusion because:

Source: Sayers et al. (2013).

- ▶ **Frequency and probability are not the same.** The return period relates to the number of times, in a given timeframe, that a particular condition is likely to be equalled or exceeded. That is, it is the reciprocal of the annual exceedence frequency but is **not** a reciprocal of the *annual probability of exceedence* – although this is a reasonable approximation at higher return periods (over 100 years).
- ▶ **The chance of a flood is not the same as the chance of the driving storm event.** The return period typically refers to the hydraulic load or rainfall event, and not the response of ultimate interest: the flood. The probability of harm occurring is often considered the same as the equivalent return period of the flow, but this assumption wholly fails to capture the likely performance of dams, emergency responses and so on.
- ▶ **It gives an unwarranted perception of rarity.** The T-year return period flow has a 63 per cent chance of being equalled or exceeded in any period of T years.
- ▶ **It tends to be incorrectly interpreted as a deterministic return interval.** This is a common misconception which persists today. For example, the flood on the Seine at Paris in 1910 was reported as a one in 100-year event. This caused great concern in 2010, when the media in France questioned the hydrological services about being prepared for the next severe flood, as it was now exactly 100 years since the last one!

UNDERSTANDING THE SIGNIFICANCE OF A RISK

How society and individuals perceive a risk is fundamental to understanding how much effort they are prepared to invest in order to reduce it. Perception is of course influenced by many factors, and each plays a part in shaping our response to the risk faced. These issues are reflected in stakeholder preferences and their appetite for different types of risk. For example, a strong environmentalist may be prepared to accept greater economic risk for environmental gain than a financier who may tolerate a greater risk of environmental damage for certainty of financial return. Equally, the decision-maker's general predisposition to be risk positive, risk neutral or risk adverse will influence the choices made.

Understanding the significance of risk is much more than a simple question of analysis, and is fundamentally associated with the degree of outrage society and individuals experience should an event occur (Sandman, 1987). Some of the factors that influence 'outrage', and hence the perception of risks, and therefore how management is influenced, include:

- ▶ **The perspective of whom?** To an individual or society as a whole? Many hazards can affect whole groups of people or ecosystems (group risk). On the other hand, an individual might be at more (or less) than average risk because of their particular location and circumstances (individual risk). In each case the acceptability of the risk is viewed differently.
- ▶ **Reaction to catastrophic events and disasters.** There appears to be more concern about accidents involving a high number of fatalities or major disruption than many smaller events that sum to the same number of deaths (e.g. Birkland, 2006). For example, coach crashes, air crashes and terrorist activities frequently make headlines on the national news, despite their relative rarity compared with say road accidents, and the fact that the fatalities associated with the former may be less than the monthly fatalities of the latter. A catastrophic flood obviously comes into the former category. Society appears to respond to a shock factor that regards high-consequence events as being more significant than more frequently occurring lower-consequence events; reflecting the general perception that society does not understand probability well as consequence.
- ▶ **Trust in risk managers.** Trust features strongly in how people perceive the significance of a risk. Most people have trust in their own ability to drive safely, for example, and believe accidents happen to others who are less skilled. In FRM the public are asked to trust in the judgement of others, and hence are inclined to view any reported risk with scepticism and to give it either an increased or decreased significance. To build (or enhance) trust, people need to be provided with information on all risks and the associated uncertainties, they need to be engaged, and the issues should be discussed openly (Tinker and Galloway, 2009).

- ▶ **Voluntariness/perceived gain.** Perception of a risk also alters according to whether a person creates the risk or bears the risk, and whether they might gain a benefit from taking the risk. These perceptions are influenced by factors such as whether the risk is undertaken voluntarily (as in rock climbing) or whether it is imposed. Although we all have some choice regarding the place we live, we often ignore available information about hazards. Flood risks are often considered by much of society as imposed risks over which the individual has no control.
- ▶ **Ability to recover and likelihood of permanent loss.** Increasingly, perceptions of flood risks are influenced by the ability to recover from an event. In general terms society is less willing to accept the chance of permanent loss, for example of life and/or habitats. This bias is often reflected in the way both loss of life and ecosystems are embedded into the risk analysis process, and the reluctance to monetize such losses (that is, people prefer to leave such losses described by their native parameters). The ability or inability of individuals and business to recover financially is also a major influence. Following the floods along the Elbe (2002), in Florida and New Orleans (2005), and the 1998, 2000 and 2007 floods in the United Kingdom, the insurance industry raised public concern over the affordable provision of insurance cover and the possibility of withdrawing insurance cover from selected areas.
- ▶ **Perception of protection.** It is often noted that those individuals and businesses located in the floodplain but protected by flood defences (especially dykes and levees) tend to lose their appreciation of the residual risk. Experience in the United States highlights that when individuals are located behind a levee or a floodwall, especially when that structure has been built by the federal, state or local government (a trusted organization) and receives some form of approval and periodic inspection, they make the assumption that the risk has been eliminated or is negligible, 'otherwise the government would not let people occupy the land'. In communities participating in the National Flood Insurance Program in the United States for example, owners of properties in the 100-year floodplain must purchase flood insurance (see Chapter 14). If the property is located in an area perceived to be protected by a USACE 'certified' 100-year (or larger) levee, property owners are exempt from this mandatory purchase requirement. This process of levee accreditation can have a perverse impact, with those protected by a certified levee perceiving that protection is high and therefore the risk is very low, if any. Those living in a less naturally hazardous area, perhaps exposed to a 1:10 year flood with a small uncertified levee protecting them, will perceive the risk as much greater because for them, full

insurance is mandated by the government . They are perhaps are more likely to take action to reduce their residual risk, even though the risk to life (given the nature of the flood wave) might be less.

- ▶ **Perceived inequity.** A perception or reality of an inequitable distribution of risk and benefits as a result of a particular strategy or policy is likely to make a risk less acceptable, particularly to those with the less favourable circumstances.

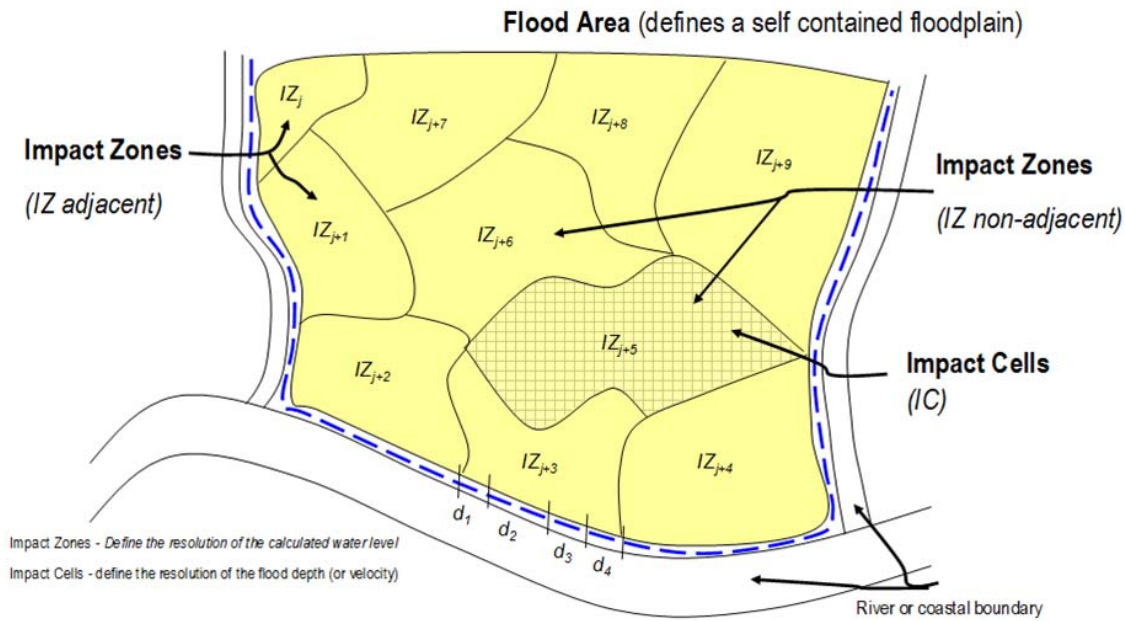
8.3 Risk analysis tools and techniques

The concept of a tiered approach has been, and continues to be, translated into tiered risk assessment methodologies that are appropriately detailed depending on the circumstances and consequences of any particular decision. The aim of risk analysis is to help make sense of the complexity in the flooding system and aid decision-makers in understanding where the most significant risks lie and how best to manage them. This section presents some of the approaches to the underlying analysis.

AN EXAMPLE SYSTEM RISK ANALYSIS MODEL – RASP (RISK ASSESSMENT FOR STRATEGIC PLANNING)

The RASP methods Environment Agency, 2003; Sayers and Meadowcroft, 2005; Hall et al., 2003a; Gouldby et al., 2008) are currently being widely taken up in the United Kingdom as a means of analysing risk. The RASP flood risk analysis method accounts for aleatory uncertainty through the integration of a full range of (return period) loading conditions (extreme water levels, wave conditions and their joint occurrence). In the model, the performance of defences is represented in terms of their likelihood of failure. An efficient flood-spreading model (RFSM, or rapid flood spreading model: Sayers and Marti-Mulet, 2006) is used to spread flood waters across the floodplain. The RFSM is then linked with an economic damage module to enable the consequences of flooding to be established. A conceptual diagram that depicts the model backdrop is shown in Figure 49.

Figure 49: Conceptual backdrop to the RASP system risk model



Source: Gouldby et al., (2008).

Discrete flood defences (d_1, d_2, \dots, d_n), protect the floodplain area from extreme flood events. Each defence is assumed to be independent from any other and have a unique resistance to flood loading. The floodplain area is discretized into a series of impact cells (z_1, z_2, \dots, z_m). Any specified impact cell can be influenced by flood water discharged through any of the (n) defences in the flood area. Aleatory uncertainties (that is, occurrences of extreme water levels within tidal and fluvial areas or joint wave and water levels in coastal areas) are defined as continuous random variables (L) associated with each defence. The probability of an individual defence section failing (structural failure leading to breach) is defined as a continuous random variable, conditional on load (L). These distributions are commonly referred to as fragility curves (see next section). During any flood event each individual defence section can exist in two possible states, with the likelihood of any particular state obtained with reference to the fragility curves.

As the performances of consecutive defence lengths are assumed to be independent of each another, the probability of any particular defence system state, for example $d_1, \dots, d_k, d_{k+1}, \dots, d_n$, occurring on any given hydraulic load (l), is:

$$[1] \prod_{i=1}^k p(d_i|l) \prod_{i=k+1}^n [1 - p(\bar{d}_i|l)]$$

The random variable of flood depth, Y , in any impact cell is a function of the flood volume discharged into the floodplain during the flood event and thereby a function of the defence system state. Determining the conditional event probability of exceeding any particular flood depth (y) in any particular impact cell during a flood event therefore involves enumeration of the

probability mass function for defence system states that yield flood depths greater than y (the set that contains these system states is denoted as A).

$$[2] p(Y > y|l) = \sum_A p_{D|L}(d, l)$$

Because of the computational burden of simulating flood events (that is, establishing floodplain flood depths) a conventional Monte-Carlo procedure is used to sample defence system states, with reference to the fragility curves or surfaces developed from an analysis of their reliability under load (see Chapter 10). For uncertainty analysis it is, however, convenient and appropriate to consider the flood volume discharged into the floodplain through any defence section to be a continuous random variable. Thus rather than sampling discrete defence system states, a continuous distribution of flood volume can be constructed and sampled. This distribution is constructed by assuming the volume discharged from a defence section, under a specified loading condition, to be considered as the volume obtained from the assumed breached and nonbreached cases, weighted by the likelihood of breaching:

$$[3] V = (g_1(X)[1 - P(d|l)]) + (g_2(X')P(d|l))$$

where g_1 and g_2 denote the functions for the volume calculation for nonbreached and breached defences, respectively and where X' denotes a proper subset of the vector X , the set that comprises all of the uncertain basic variables (including the breach dimension variables) that relate to the calculation of flood volumes.

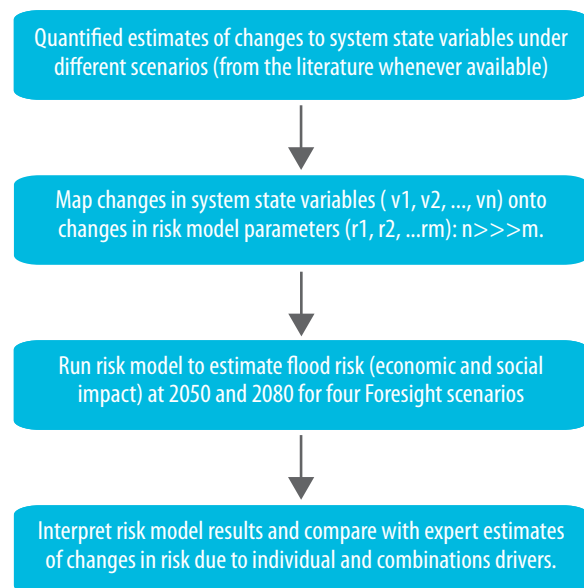
The flood risk is a function of the probability of flooding and the consequences of flooding. Information on the type, floor area and number of properties is used to establish the economic consequences of property damage (c). Each modelled flood event results in a flood depth grid over the floodplain area and hence a flood event economic damage measure. The impact cell risk (R), expressed as expected annual damage (EAD), is then calculated using the same load discretization procedure and the mean economic damage.

$$[4] R \approx \sum_{i=2}^{q-1} \left[\left[p\left(L \geq \frac{l_i + l_{i+1}}{2}\right) - p\left(L \geq \frac{l_i + l_{i-1}}{2}\right) \right] c_{li} \right]$$

INCLUDING FUTURE CHANGE IN THE ANALYSIS OF RISK

Once established, a flood risk system model provides an efficient tool for exploring the influence of change. Change can be either driven by external forces – such as climate change or demographic change – or internal forces – such as the changes to management practice. Chapter 2 highlights how different components of the flood risk system model can be changed to reflect different futures and revised estimates of risk established. This approach to including the influence of change in the system risk models is formalized in Figure 50. Such tools have been used to good effect in the United Kingdom (through the Foresight Future Flooding Programme, with the Thames Estuary – Planning for Flood Risk Management in 2100) and Germany (in the Elbe River Basin Management Plan) to explore the robustness of different policy choices in the context of an uncertainty future.

Figure 50: Representing change in a system risk model (as applied in the UK Foresight studies)



Sources: Evans et al. (2004a, 2004b).

8.4 Uncertainty: principles and tools

It has been, and always will be, necessary to make decisions in the absence of perfect information. In the past, uncertainty has been implicitly accounted for in FRM decisions through safety factors and allowances rather than with explicit analysis of uncertainties. Recognizing uncertainty does not however 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 can we be better placed to decide how best to manage it.

In this context it should be the goal of the analysis not to eliminate uncertainty, a practical and philosophical impossibility, but to understand its importance in terms of the decision being made. If the decision would remain the same, despite the recognized uncertainty in the evidence upon which it is based, then no further refinement of the analysis is required.

FORMS OF UNCERTAINTY

Typically three forms of uncertainty are distinguished, each of which presents its own challenges:

- ▶ **Natural variability** (often called aleatory uncertainty): this refers to randomness observed in nature. Such uncertainties are routinely dealt with through consideration of a range of different return periods (for instance, for storm events) or through the use of multiple stochastic time series. This enables an extremes distribution of damage to be determined as well as the expected annual damages, while it is accepted that it is not possible to determine when or where the next major event will be. This is in contrast to a design standards paradigm where typically single extremes are designed for. Uncertainty generated through natural variability is generally regarded as irreducible.
- ▶ **Knowledge uncertainty** (or epistemic uncertainty): this refers to our state of knowledge of a system and our ability to measure and model it and predict how it might change in the future. The concept and importance of knowledge uncertainties – in the data and models used – has to date been less commonly considered and formally assessed than natural variability. In traditional standards-based engineering, safety factors are used to account for such uncertainties both in present-day conditions (uncertainty in the geotechnical parameters, for example) and as a result of future change (with precautionary allowances provided for changes in sea level or river flow). An FRM approach demands that all uncertainties are explicitly

stated and their importance determined in the context of the specific decision being made. This is a radical departure from traditional approaches but presents significant opportunities to target data improvement, research and future analysis as required.

- **Decision uncertainty** is a state of doubt about what to do. Externalizing decision uncertainty is fundamental to understanding why certain options are preferred over others. The view of the world promoted in this report asserts that uncertainty is natural and that for all important decisions there will exist to a greater or lesser extent uncertainty surrounding the selection of a particular course of action. This should be recognized as wholly acceptable. Understanding how knowledge of uncertainty influences the preferred choice gets to the heart of our value system and the trade-offs we are prepared to make: the risks found acceptable and those that are not, the priority given to achieving social equity and fairness at the expense of ecosystems and vice versa, how much are we prepared to invest to reduce unknown future risks, and so on.

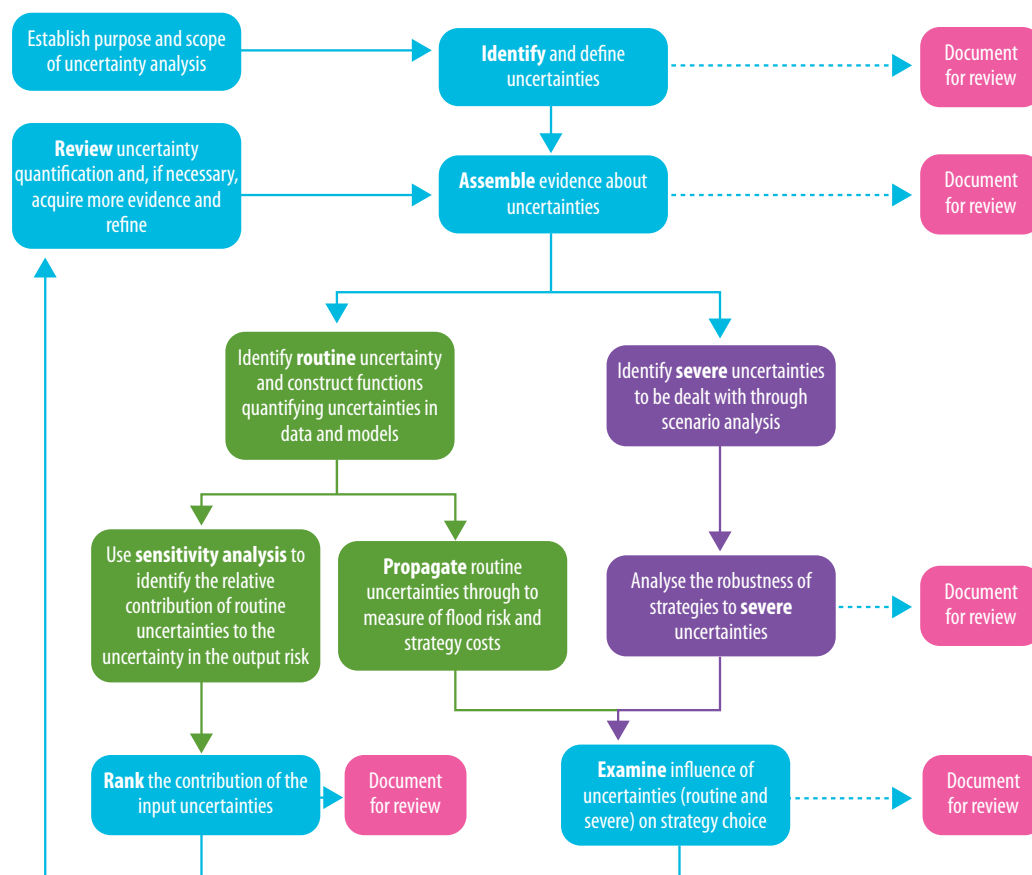
UNCERTAINTY AND SENSITIVITY ANALYSIS AS A DECISION AID

Uncertainty and sensitivity analysis are closely related, but not the same, and both provide useful decision support. Uncertainty seeks to enable decision-makers to better understand the confidence in the evidence presented and the choices taken. Sensitivity analysis seeks to highlight to decision-makers those aspects of the analysis to which the evidence presented, and the choices being made, are most sensitive.

In this chapter a distinction is made between routine uncertainties – those associated with input data (crest levels, topography, damage functions and so on) and severe uncertainties – those associated with future change in socio-economics and climate. Frank Knight (1921) recognized both of these situations and defined the concepts of ‘decision-making under uncertainty’ – under severe uncertainty where no sensible attempt can be made to describe the likelihood of any given future – in contrast to the situation when probabilities are known, which he termed ‘decision-making under risk’.

A general framework for handling both routine and severe uncertainties is given in Figure 51.

Figure 51: Framework for uncertainty analysis and structured recording of the uncertainties in the risk analysis



Source: adapted from Hall et al., (2009).

8.5 Supporting approaches to uncertainty analysis

Various approaches are available to handle routine uncertainty, for example:

1. **Deliberate conservatism** (single estimates – plausible worst case): selecting loads and parameters that are plausible ‘worst case’ extreme values. In this way single values are used for all parameters in the risk analysis and a single worst case risk estimate is obtained. Such an approach maintains the simplicity of the analysis and is a useful first-pass screening. However, the crudeness of the method means it cannot necessarily be relied on to correctly order the priority of contributors to risk or to make risk reduction investment decisions.
2. **Range of estimates** (plausible upper and lower bounds): here plausible bounds are used to describe the uncertainty. Notionally these could be the 5 and 95 percentiles or perhaps based on a plausible upper and lower bound value, or they could be a request for a maximum probable value (such as with probable maximum flood).
3. **Full distributions of parameter values and functions:** full probability distributions are used to capture the uncertainty within parameters and equations.
4. **Comprehensive uncertainty analysis:** in this case consideration is given to capturing the uncertainty inherent in the structure of the analysis as well as the parameters and equations used. Handling model incompleteness represents a significant challenge.

Approaches 1 and 2 are most readily understood and easily translated to support simple analysis using spreadsheets or other simple software. However they provide limited insight, and often mislead as important uncertainties are missed or their impact underestimated. Approaches 3 and 4 are more demanding in terms of computation and knowledge of uncertainty, but can also provide much more useful (and specific) insights.

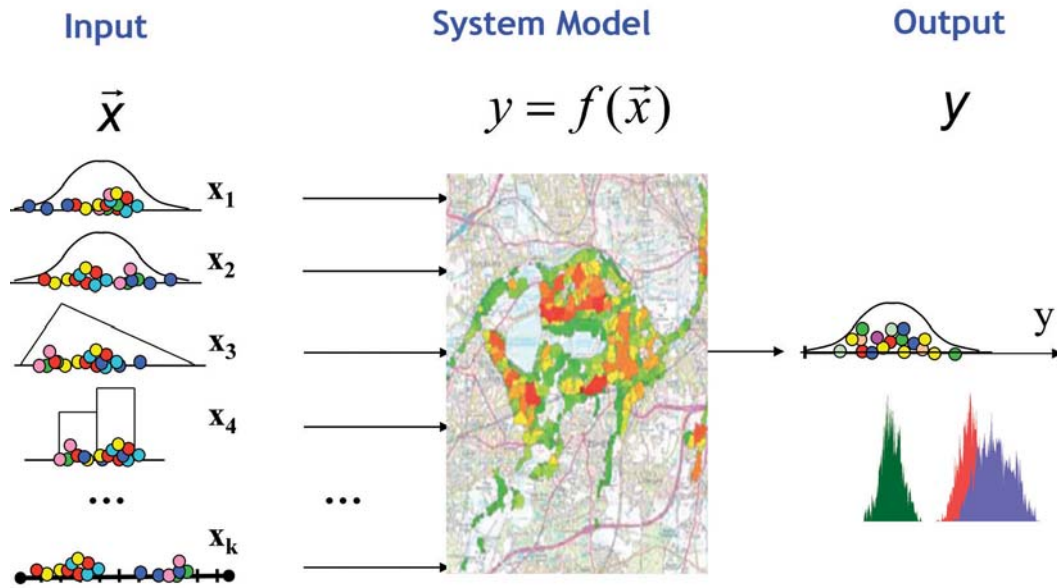
Associated sensitivity testing can be used to target effort towards reducing the most important routine uncertainties. For example, is it better to invest in research, perhaps to improve the representation of the flood physics in the model components (for example the representation of breach size or flood propagation), or data collection, perhaps to improve topography or crest-level data; which would reduce the uncertainty more? Two basic approaches to sensitivity analysis are:

- ▶ **Selective testing to assess the impact of uncertainty.** This typically involves examining a number of expert-defined scenarios without attaching probabilities to them and

determining by how much key variables can change before a different preferred option is identified. There then follows some judgement of the likelihood of that change actually being applicable. Sensitivity testing in this way usually involves varying selected parameters over a plausible range in turn with other parameters held at their ‘best estimate’ value. Although limited in scope, this approach is practical and transparent. It can also be credible, if done well, in enabling key variables in the analysis of risk to be identified and the associated uncertainty either reduced or managed. (It is often appropriate to conduct some sensitivity tests before embarking on more thorough simulation methods, as discussed below).

- ▶ **Simulation approaches to assessing the impact of uncertainty.** The simulation approach involves representing uncertainties by probability distributions. These probability distributions are then combined to provide a probability distribution of the response variable (such as the probability of a levee failure and associated consequences), which incorporates the uncertainties in the parameters, variables and model relationships. Where few observations or very limited data are available with which to ‘condition’ a model, forward-propagating uncertainty techniques are the most viable approach for the analysis of routine uncertainties. Of the options available, Monte-Carlo procedures are the most flexible, robust and therefore prevalent (Pappenberger et al., 2006). These methods involve assigning probability distributions to input variables. Samples are drawn at random from the input distribution functions and passed through the model. Model structural uncertainties can be included by specifying error terms associated with different functions, or the overall model, and assigning a distribution/s. If there are many different types of uncertainty, involving many different parameters and variables, this approach can become complex. This is particularly so where there are dependencies between separate parameters and variables. To avoid overcomplicating the process, it is worthwhile considering the sensitivity of the response variable to each of the parameters, together with the associated uncertainty. If a parameter has a narrow confidence interval (small uncertainty) and has a minor effect on the response, it is feasible to consider the parameter as perfectly known. Additionally, it may be necessary to consider the different sources of uncertainty as separate elements and structure the analysis to calculate specific uncertainty sources before combining these analyses in an overall simulation.
- ▶ Such an approach supports a range of formal sensitivity analysis techniques including variance-based sensitivity analysis, a generic method for establishing the relative importance of variables contributing to the output of interest (Figure 52). For a further description see Saltelli et al. (2004).

Figure 52: Forward propagation of uncertainty through the RASP risk analysis model and associated sensitivity analysis

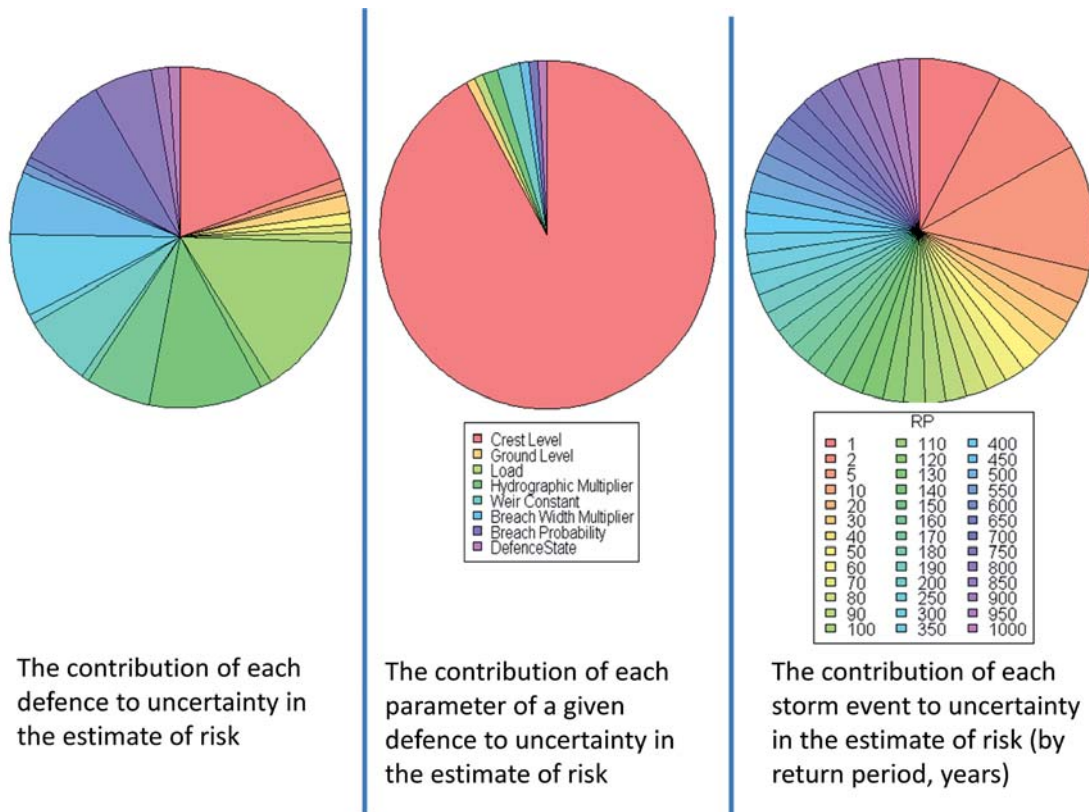


Source: Zhengfu Rao (2009), unpublished workshop presentation.

Such an analysis provides the decision-maker with a much richer understanding of the level of confidence in the risk estimates and which uncertainties are most important in terms of their

contribution to uncertainty in the risk. Examples of the type of additional outputs are given in Figure 53.

Figure 53: Illustration of disaggregating the driving sources of uncertainty



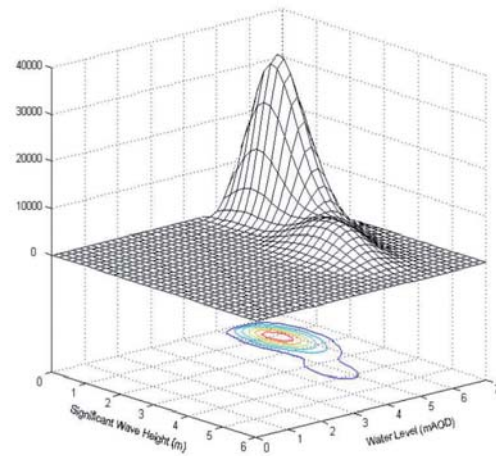
Source: Environment Agency, 2009d.

SEVERE UNCERTAINTIES: DECISION-MAKING UNDER UNCERTAINTY

Climate and demographic change can have a profound influence on FRM and the choices made. Making the right choices under this severe uncertainty is a significant challenge. Many of the choices made today will persist for several decades if not centuries, so taking a longer-term strategic view when planning FRM investment is critical to making the right choice. Various methods and approaches have been applied in practice to support good decision-making under severe uncertainty, including scenario development, robust decision-making and adaptive management (based on multistage interventions), and embedding adaptive capacity appropriately within the choices made. A detailed discussion of the issues and decision aids can be found in Sayers et al. (2012a). The methods include:

- ▶ **Robust satisficing:** a solution is thought of as being robust if it performs acceptably irrespective of what the future holds. The approach is referred to as 'satisficing', to describe how decision-makers seek solutions that satisfy their range of decision criteria under multiple futures rather than optimizing performance assuming a single future. Robust satisficing aims to maximize the degree of sureness that a satisfactory outcome will result. It therefore asks, 'are the outcomes good enough?' and seeks to identify options that satisfy performance thresholds across multiple criteria and under all plausible future scenarios.
- ▶ **Sensitivity analysis and visualization:** as with routine uncertainties the starting point for the identification of solutions robust to severe uncertainty is a process of isolating the most important uncertainties and understanding the response of decision alternatives with respect to those uncertainties. Figure 54 illustrates typical results from this type of analysis, based on sampling three main sources of uncertainty (sea level rise, dyke deterioration and economic growth). While a probabilistic representation of these three significant epistemic uncertainties has in this case been adopted, the approach does not integrate out the uncertainties into an expectation, but illustrates the full distribution of option performance, so decision-makers can see how performance varies over a wide range of input conditions.
- ▶ **Info-gap analysis:** any approach that explores option performance over a set of possible uncertain quantities relies upon definition of that set of possibilities. Info-gap analysis (Ben-Haim, 2006) circumvents the need to define the set of possible uncertain quantities precisely by conducting a progressive sensitivity analysis with respect to an expanding set of possibilities.

Figure 54: Flood damage (in £) for an area in North Wales subject to two major sources of uncertainty – tidal level and significant wave height



Source: Dawson et al (2004).

EVALUATING FLEXIBILITY AND ADAPTABILITY

In a changing world it makes sense to adapt solutions that can be modified if the future should turn out to be different from expectations. Adaptive management is much easier in systems that are flexible. However, designing for adaptation will often bring some additional cost, and that cost needs to be justified in terms of the whole-life risks in a range of uncertain futures. There is of course a close connection between flexibility and robustness, so the methods for robustness analysis outlined in the previous section are also applicable to the analysis of multistaged decisions that offer future choices (that is, flexibility). Various more formal techniques are starting to emerging as practical means for constructing and analysing multistaged decisions, as discussed below.

Decision trees

Decision trees are a well-established method for analysis of sequential decision problems. They are very useful in the context of long-term planning problems, where processes of long-term change trigger particular system management decisions. Each decision point is constrained by previous actions, and each is more or less suited to different future states that might exist. The performance of each decision pathway – the set of decisions that constitute a single route through the decision tree – under each future can then be assessed against a range of future scenarios, and the most robust strategy identified (through a robust-satisficing, robust-optimizing or combined approach). The performance evaluation is over the whole lifetime of the strategy.

These whole-life view flexible options are often highlighted as preferred as they tend to perform better over a wider range of possible future conditions; this is despite the additional cost that is typically associated with flexible strategies at certain stages during the life-cycle. Analysis with decision trees provides an intuitively appealing means of developing flood management strategies and identifying those that offer maximum flexibility and do not foreclose future choices unnecessarily. Perhaps their greatest strength is their ability to identify both those actions that can be taken now, and those that should be delayed. The approach was demonstrated for strategic FRM decisions in the Thames Estuary by McGahey and Sayers (2008).

Automated optimization methods

While the decision tree approach is intuitively appealing, the number of possible combinations and sequences of options rapidly increases, so it becomes impossibly time-consuming to evaluate exhaustively every pathway through the decision tree. To overcome this problem, automated methods to optimize FRM strategies have recently started to appear in the context of asset management (Sayers et al., 2012a). The most promising methods make use of genetic algorithms (GAs), which have been widely used in other discrete optimization problems, including problems with multiple objectives. The search for optimal solutions proceeds by a process that involves recombination of promising solutions with random variation to ensure that the search does not get stuck in local optima.

Where multiple, and potentially conflicting, objectives are set (for example maximizing net present value, minimizing cost, minimizing loss of life), maximizing environmental gain sets of optimal solutions will be developed, each optimal with respect to a single variable (for example the maximum benefit for a given level of expenditure). These sets of solutions, or Pareto front, provide decision-makers with a graphical understanding of the trade-offs being made.

As with any automated analysis method, however, the outputs from an optimization process need to be supplemented with engineering judgement. It is seldom possible to encode in the GA objective function all of the considerations that engineers will include in their design decisions. The identified solutions will need to be carefully scrutinized, and if necessary modified so that they satisfy all design criteria.

Real options analysis – formally valuing flexibility

The theory for valuation of financial options is well developed in financial economics. Real options analysis extends this theory to deal with real-life options, such as the decisions we are concerned with in this chapter, like physical modifications

to flood defence systems. Keeping one's options open will not, on the whole, be cost free. Real options analysis provides the theory required to estimate the financial value of having the option to do something in future. In other words a real option is 'a choice that becomes available through an investment opportunity or action' (HM Treasury, 2009). Real options analysis has in recent years been promoted as a means of evaluating climate change adaptation decisions (Ranger et al., 2010) and is also increasingly being recognized as applicable to FRM.

8.6 Risk-based decisions – a consistent decision process or set levels of acceptable risk

In recent years a number of studies and workshops have focused on the issue of what is, and what is not, an acceptable risk (HSE, 2001; USACE, 2010). A consensus from these studies is that a framework of risk acceptability is a prerequisite for the implementation of a coherent approach to risk management. This does not imply a need to define a common 'standard of protection'. Rather it is necessary to be explicit about how decisions will be made when faced with complex choices to prioritize, recognizing resources to be finite. This does not imply a uniform approach, but a consistent framework. Developing such a framework, particularly in situations where loss or promotion of important ecosystems or loss of life is possible, is central to the FRM decisions. This area remains an ongoing challenge, with two distinct approaches commonly being adopted, either a consistent process of decision-making or a defined safety standards approach. Both of these are briefly discussed below.

I) A CONSISTENT PROCESS OF DECISION-MAKING

In England and Wales, for example, decisions to invest or not in FRM are based on a multicriteria approach, summarized at a national level as people, environment and economic issues. A sequential benefit-to-cost test is used to determine the level of investment, as opposed to strict benefit-cost optimization, where actions to reduce risk to larger groups of people are promoted over actions that reduce risk only for the few. Neither a minimum level of 'protection' nor a minimum acceptable level of residual risk are defined. This reflects, first, the heterogeneity of the flood risk across England and Wales (and the associated mix of response measures that are feasibly available), and second, the recognition that to set minimum

levels would necessarily lead to inefficient expenditure, directing resources to one area where they could be better deployed elsewhere.

This process of decision-making broadly follows the following steps:

1. Consider a number of 'do something' strategies for any catchment, coastal (sub)cell, community or other defined unit.
2. Determine the monetary and nonmonetary benefits associated with each strategy with reference to a 'do nothing' approach.
3. Identify the strategy yielding the highest BCR, often a 'do minimum' strategy, that also performs satisfactorily against nonmonetized criteria (if any).
4. Compare this with the strategy that requires the next highest level of investment, and determine the incremental BCR (iBCR) – by comparing the incremental benefits and the increment in cost required.
5. If the iBCR is sufficiently high then this new alternative becomes the preferred approach, and so on. For example, the iBCR must be greater than 1 to invest additional funds to ensure that receptors in urban areas are protected from significant damage – taking account of structural and nonstructural measures – down to an annual probability of 0.02. To provide greater protection the iBCR must be robustly greater than 1 (notionally exceeding the BCR of other activities competing for funds, such as investments in hospitals and schools). Where this is the case the probability of flooding can be reduced.

This approach attempts to link efficiency with general societal preferences to provide minimum protection according to the number of people protected whilst helping to ensure that the additional levels of investment needed for higher standards in one location would not have been better spent elsewhere. The societal preference is quantified through judgement, but based on an estimate of the likely national funds available to FRM and potential risk reduction that could be achieved if these funds are used wisely. The use of this simple 'decision rule' is not the sole consideration – for example meeting legislative requirements such as statutory obligations for habitat protection will override benefit–cost considerations, and these obligations are simply met based on least-cost approaches.

Box 26: Moving from design standards to a risk approach in the United States

When the US federal government assumed primary responsibility for flood control in 1928 and 1936 following disastrous floods on the Mississippi (1927) and in the Midwest and East (1936), design standards for structural responses were developed for each flood control system being authorized. The standards were tied to major meteorological events, and represented flood return periods generally thought to be in excess of 500 years. When cost-sharing between the federal government and local sponsors of flood damage reduction projects was instituted in 1986, local officials campaigned to minimize the costs of the flood protection, and the design standard was effectively reduced to a 100-year return period (allowing those behind a new levee to be exempt from a federal requirement to buy flood insurance). Following Hurricane Katrina, USACE and FEMA initiated a national Flood Risk Management Program with an emphasis on a broader use of risk-informed approaches.

Increasingly the United States is trying to recognize the need for a strategic approach where a portfolio of structural and nonstructural measures are implemented; however, a decision on how best to determine the nature of the portfolio is in debate. The current focus remains on individual levee performance, the level of protection the levee provides, and whether this level of protection and its attendant residual risk can be judged as acceptable. It is unclear at present how the decision-making process will move forward, and whether a safety standards approach (with prescribed levee design standards established according to the acceptability/tolerability of the residual risk) or full-risk approach (trading off resources used and benefits gained) will prevail. The latter is most likely. For example, the state of Louisiana, in a plan prepared shortly after Katrina, acknowledged that, for economic and physical reasons, the same level of protection could not be provided to all communities that faced hurricane and flood challenges. It identified, in general terms, which areas would receive higher levels of protection. The direction is also clear at the highest levels, with the US Congress directing the President to consider not only economic costs and benefits but also public safety and the environment in the development of projects. Any future decision processes will need to reflect all of these aspects.

II) A DEFINED SAFETY STANDARDS APPROACH

In this case, either through legislation or guidance, the minimum protection against the chance of flooding (through a combination of structural and nonstructural measures) is defined in advance, often by the national or federal government. For example, based on a periodic national-scale discussion of the benefits and costs of flood defences, and their affordability, the Netherlands set national safety standards. Such approaches typically promote the use of structural solutions. Partly as a result of the historic use of this approach, the Netherlands has not implemented a broader portfolio of measures. In part, this reflects the homogeneity, and severity, of the flood hazard and the potential catastrophic consequences – where much of the country is below sea level with few alternative options available.

Given this central role and legislative imperative for flood defence, detailed and prescriptive processes around the assessment of defence performance have been developed (see for example CUR/ TAW, 1990) to help ensure the safety standards are met (in terms of the probability of failure and overtopping thresholds). In more recent years, this approach to managing risk has increasingly been challenged, and the Netherlands is moving slowly towards a more portfolio-based approach (seeking to provide 'room for the river', increased attention to warning and evacuation systems, improvements in maintenance standards, and a decision-making process that reflects greater attention to economic efficiencies).

8.7 A summary of recommendations – principles and analysis of risk and uncertainty

A number of summary conclusions can be drawn from the above discussion:

- ▶ To analyse risk efficiently and effectively the whole risk system must be considered using a structured approach – for example the source, path, receptor model. This facilitates an understanding of system behaviour and avoids inappropriate focus on individual elements of the flood or erosion system.
- ▶ Risk can be described as a function of probability and consequence. However, care should be taken to understand the *significance* of the risk.
- ▶ **Routine** and **severe** uncertainties are important. Overlaying uncertainty and sensitivity analysis over a system risk analysis can provide the decision-maker with additional information on which to base a decision.
- ▶ Uncertainty can stem from a variety of different sources. These sources can be generally categorized under three headings:
 - natural variability
 - knowledge uncertainty
 - decision uncertainty.
- ▶ Uncertainty can be presented or expressed and handled in a variety of ways. To facilitate incorporating uncertainty effectively in FRM, the following practices are recommended:
 - Consistent terminology must be adopted when considering uncertainty.
 - Be clear on the sources of uncertainty and their importance to the decisions made.
 - Explicitly identify and record uncertainty in any decision-making process.

CHAPTER 9

SPATIAL PLANNING IN SUPPORT OF MANAGING FLOOD RISK

9.1 Introduction

Spatial planning is perhaps the most effective approach to preventing the increase in flood risk, through active controls on (re)development of land and property in these areas.

When a **floodplain is developed** (for example through a change of use from agricultural use to urban use, or from open recreational areas to densely populated housing estates) the potential for flood damage rises, and therefore risk rises. As population numbers and densities rise, more serious social effects of floods follow – such as the threat of loss of life – together with the need to evacuate ever larger populations to prevent or lessen these effects. As a result FRM becomes more complex and more expensive.

Arrangements for **spatial planning** are different across the world. In general, these arrangements are not designed with FRM in mind, but for other societal goals, such as controlling the location of populations (by controlling housing development), determining the location of industry and commerce, or protecting wildlife and agricultural areas from encroachment by urban land uses. As such, spatial planning arrangements are usually decided at an administrative level, often not based on catchments. Stronger connections to FRM are starting to emerge, and changes to traditional development planning are being negotiated and agreed between FRM organizations and those responsible for spatial planning (usually local authorities or city agencies, as well as national policy-makers). The needs of FRM usually cannot be imposed on such city authorities by FRM organizations. As policy-makers recognize the need for good natural hazard risk management as central to sustainable

economic and social development, concerns over flood risk are, however, increasingly recognized in spatial planning policy, but often not fully enforced locally.

9.2 Spatial planning and its role in flood risk management

Spatial planning and the control of development is perhaps the primary vehicle for managing flood risk in a sustainable manner, and works directly to reduce the increase in the future consequences of flooding. In particular spatial planning can act to reduce risk through:

- ▶ **avoidance** – through spatial planning and flood zoning (regulations in the United States and Europe restrict development – not always entirely successful)
- ▶ **resistance measures** – buildings designed to prevent flood water entering
- ▶ **resilience measures** – buildings designed to minimize water ingress, minimize the resulting damage and promote fast drying/cleaning to promote recovery of the buildings' use and avoid lasting damage
- ▶ **repairability** – buildings designed to ensure flood damage can be easily repaired or affected items easily replaced.

Through land uses choices, spatial planning can also seek to reduce the probability of flooding in one area by purposefully increasing the chance of flooding in another. For example,

this can be done by the creation of 'blue corridors' in urban areas and along river corridors, or the deliberate creation of flood **detention areas** to 'store' water at times of peak flows. This may require relocating existing users and properties in the floodplain to create the space for the river or sea. Creating space, and designating agricultural or existing wetland areas for storage, is common practice, but purposeful relocation of existing development to 'make space for water' remains very contentious, and no significant examples are known to the authors where such a policy has been implemented on a significant scale. However, many countries have adopted policies to designate flood storage areas, which therefore need special spatial planning provisions to ensure that new development is controlled or eliminated.

DEVELOPMENT ZONING

Floodplain zoning is widely used to divide the floodplain into areas where the flood hazard is different, and define the types of development and land use that are suitable in each zone. The purpose of flood zoning is to prevent inappropriate development by only allowing certain types of development and land use in areas where the flood hazard is highest.

Flood zoning relies first on a statement of the flood conditions that are considered unacceptable for particular uses of the floodplain, for example:

- ▶ Development in areas near the river where flow velocities are high should be restricted to uses where no buildings are permitted; for example only recreational areas are allowed.
- ▶ Residential buildings should not be permitted within the unprotected 1 in 100-year floodplain.
- ▶ Hospitals and other highly vulnerable buildings should not be permitted within the unprotected 1 in 1,000-year floodplain.

Flood zoning is a process that is well embedded in countries such as Germany, the United States and elsewhere. Box 27 provides an example based on the flood zoning policy in Cape Town, South Africa.

Effective spatial planning can result in new development and cities that are much more resilient to flood disasters, and can ensure that:

- ▶ important infrastructure is outside the floodplain and will continue to function during times of flood
- ▶ the risks to residential, commercial and industrial buildings can be limited through appropriate building control and regulation

- ▶ space is created to allow the natural process of flooding on the floodplains to take place.

Where it is not possible to avoid new development in the floodplain, planning policies can be introduced that restrict the vulnerability of new development to flooding. Such policies might require:

- ▶ living accommodation in houses to be above flood level
- ▶ buildings to be constructed using flood resilient materials and techniques so that the damage that could occur during a flood is minimized.

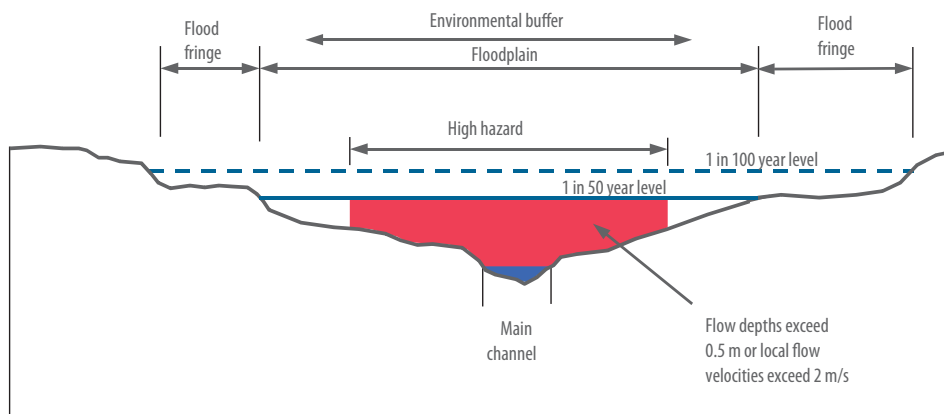
LAND USE MANAGEMENT (URBAN AND RURAL)

Spatial planning also provides the opportunity to introduce development policies that contribute to reducing flood hazard by restricting runoff. In this context, land use management and land management are often considered separately. Land use management is focused towards spatial planning – the creation of preferential flood routes, urban development controls, creation of SUDS and so on – and land management is associated with soil husbandry, site management and the like. This is a useful distinction because, in general terms, better land use management requires action by policy-makers and planners whereas better land management requires action by farmers and others at a local level. For example, a policy to restrict runoff from new developments by requiring all flood flows to be contained within the development site would prevent the increase in runoff that occurs when natural ground is covered by a hard surface as part of a development. This in turn would prevent an increase in flow into drainage channels downstream, thus preventing an increase in floodwater levels and risk in this area. Agricultural and rural land management practices can help to reduce flood runoff, for example by growing buffer zones of dense vegetation along river channels, but the effects of these measures tend to be only felt locally, rather than at a catchment scale (see Chapter 6).

Influencing rural management through spatial planning is therefore an important part of the FRM portfolio, and has the potential to have a significant impact on lower return period flood flows (often an important component in the expected annual damages), but is unlikely to have a significant impact on severe flood flows.

Box 27: Example of a policy for development control in Cape Town, South Africa

This policy is based on the approach adopted in the city of Cape Town in South Africa. The key elements of the policy are shown below.



Development control policy in Cape Town

The key features of the policy are as follows:

- ▶ The **floodplain** is defined as the area susceptible to inundation by a 1 in 50-year flood.
- ▶ The **flood fringe** is defined as the area between the 1 in 50-year and 1 in 100-year flood envelopes. Most development types are permissible in this zone with limited requirements or conditions.

- ▶ The **high hazard zone** is defined as the area where flow depths exceed 0.5 m or local flow velocities exceed 2 m/s.
- ▶ Most types of development are not permitted in the high hazard zone.
- ▶ Ground floor levels of nonhabitable structures should be above the 1 in 20-year flood level and where feasible above the 1 in 50-year flood level.
- ▶ Ground floor levels of habitable buildings should be above the 1 in 100-year level.
- ▶ Access routes to habitable buildings should be at least above the 1 in 50-year flood level and where feasible above the 1 in 100-year level.

Source: City of Cape Town (2002).

ZONING DETENTION AREAS

One important method of reducing flood risk is by the construction of flood detention areas (see above). These are areas that are deliberately inundated by flood water during a flood to reduce the risk of flooding farther down the river system. They may be located far upstream of the relevant urban areas. For much of the time these areas will be dry, and therefore a policy is needed on the type of development that should be permitted in these areas. As far as possible it should be limited to open space and recreation, although agriculture and other uses that do not take up flood storage volume can be permitted depending on the frequency of flooding. Complementary emergency plans covering the evacuation of those people living or working within such areas when flood events are forecasted or planned must be robust and well rehearsed.

CREATION OF SAFE HAVENS AND ASSOCIATED EMERGENCY ROUTES – LARGE AND LOCAL SCALE

The creation and use of safe havens plays a vital role in times of flood. It is at the spatial planning stage that creation of such safe havens, located appropriately in the floodplain, is most easily achieved. This is a requirement not only in detention areas but in all areas with the potential to flood. Such activities range from large-scale modifications, such as the purposeful design of sport stadia and similar large structures to provide legitimate means of creating safe havens for limited expenditure, through to individual property modifications (roof access, property wall strengthening and so on).

Awareness of escape routes is crucial for the success of a self-evacuation. Spatial planning has an important role to play in this through the creation of clearly marked and controlled access and egress routes. Well-designed road networks with well-defined preferential access and egress roads are readily incorporated within new developments, and can be very effective in moving large numbers of people efficiently in times of flood. Retrofitting into existing cities is more complex and resource-intensive

but worthwhile if done well, avoiding complex evacuation routes and bottlenecks that could place those evacuating in considerable additional risk.

LOCATION AND PROTECTION OF CRITICAL INFRASTRUCTURE

As was seen during and after the Asian tsunami and the majority of major flood events worldwide, critical infrastructure is often located for the convenience of the community it serves rather than based on consideration of its resilience in times of floods.

For example, the hospital in Galle, Sri Lanka was overwhelmed by the tsunami and out of action when it was needed most. Similarly in the 2011 floods in Pakistan, the impact was exacerbated by the inundation of critical power generation and supply infrastructure. Comparable problems also persist, albeit on a smaller scale, in the United Kingdom, where in July 2007 critical electrical power infrastructure was overwhelmed (Figure 55). Avoiding these kind of impacts is relatively straightforward, but requires forethought and embedding a consideration of flood risk into the development of relevant spatial and infrastructure project plans.

Figure 55: Castlemead power distribution station is inundated in July 2007, UK



(taken from a presentation by Martin Kane for the Institute of Water Annual Conference 2010, Belfast).

9.3 Prerequisites for spatial planning to affect flood risk

For spatial planning to be effective in reducing the build-up of flood risk, two key prerequisites are essential and one is highly desirable:

- ▶ **Essential:** maps to show the extent of future flooding, preferably showing areas where there are different probabilities of flooding (such as 1 per cent and 5 per cent probability floods).
- ▶ **Essential:** a decision-making process that deals with individual development proposals, whether they are for single buildings or whole towns.

- ▶ **Desirable:** a land use plan that incorporates some information from the flood risk maps and sets out desired and current uses of different zones within that planning area (so for example it separates out land proposed for future housing, for industry and for agriculture).

Without flood risk maps it is not easy to identify the areas at risk, and without a systematic way of making development decisions there will be no consistency in deciding how and where to reduce urban encroachment into at-risk areas. The availability of the land use plan gives readily available guidance to developers, planners and others on which areas may be developed for which uses, and allows the incorporation of flood risk information into their decisions and judgements.

All these prerequisites need to be agreed by all parties involved. The alternative is protracted disputes about actual levels of flood risk, and the merits and demerits of each and every development proposal. The prerequisites, when in place, therefore reduce the levels of dispute and speed all development decisions.

A caveat

The development of floodplains is not of itself undesirable. Indeed in many countries where land is scarce and populations are dense it is essential that floodplain areas are used as intensively as possible, commensurate with plans and schemes to minimize the impacts of floods when they come.

We must not 'sterilize' these at-risk areas. For example, in the United Kingdom it is not logical to forbid the development of floodplain areas in London with intensified human use when Parliament and many government officers are sited usefully on the Thames tidal floodplain or when 60 per cent of all the best agricultural land in England is to be found in other protected floodplain locations.

Similarly it is not logical in China to forbid the growth of cities such as Shanghai or Wuhan simply because they are at risk of flooding, or to use spatial planning to prevent or constrain the intensification of agriculture when there is a growing population to feed. What is needed is careful spatial planning integrated with parallel FRM measures so that wise development can proceed but future flood risk is minimized.

9.4 A summary: the impact of wise spatial planning on flood risk

Spatial planning for wise FRM has the aim of preventing risk from increasing in the future as a result of decisions to locate vulnerable property and people in areas that are exposed to flood risk. The problem is that such decisions are not generally made by the organizations that are responsible for FRM, but usually by local organizations such as city councils or regional agencies that have land use responsibilities and generally have aims in favour of promoting development rather than restricting it.

Systems need to be in place to coordinate FRM and land use management plans and to agree a strategic relationship between the two areas of public concern. Usually such systems are designed at a national level, or at least at the level of the region or large area, for local implementation. It is important therefore that the national systems are rigorous, are enforced, and are enduring, rather than local agencies being allowed to operate without direction and supervision.

Flood risk managers should strive not to allow developers and spatial planners to compromise attempts to control risk and protect human populations by making unwise decisions. At best, if this happens, money will be wasted on work to reduce the risk that has unthinkingly been created or increased. At worst, people will suffer and possibly die as a result of their being encouraged by the unwise spatial plans to live or work in places where flood risk has not been adequately recognized and where development has proceeded regardless.

CHAPTER 10

INFRASTRUCTURE MANAGEMENT

10.1 Introduction

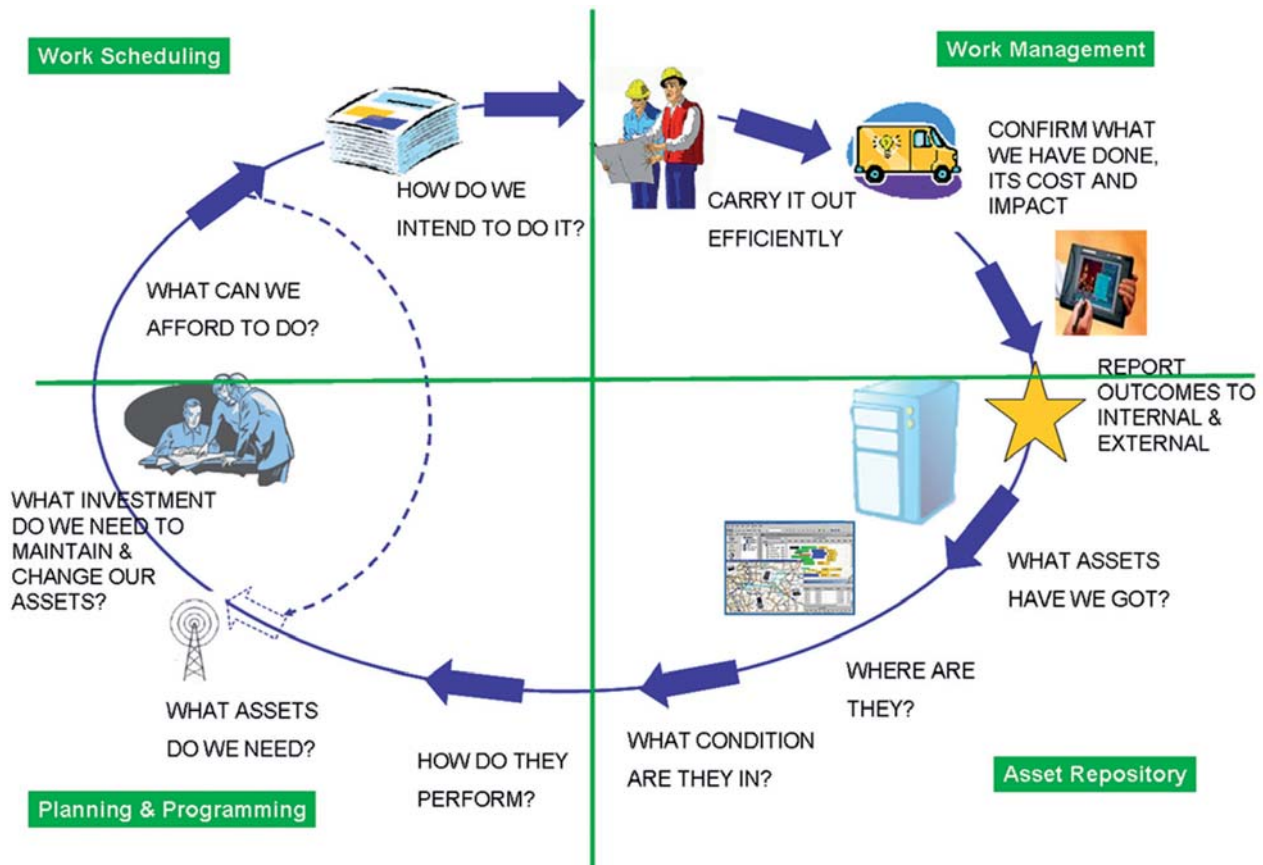
As any flood defence asset manager will acknowledge, ensuring acceptable performance of flood defence assets and asset systems is a considerable challenge. The wide variety in asset types and forms and, uniquely to flood and erosion risk management, the interaction between each asset and its physical surrounding (including other assets) further complicates the task. In this context, the concepts of risk and performance provide the asset manager with a consistent framework to integrate short to longer-term actions to maintain, repair, improve or replace assets appropriately alongside nonstructural measures, while avoiding unnecessary expenditure. In particular an understanding of risk can help identify the critical components of an asset system, and target data collation and/or physical intervention appropriately.

This chapter explores some of the challenges as well as some of the tools and techniques available to assist the asset manager in making informed decisions, from the requirement for further data collection and analysis through to actions to repair, renovate, replace or indeed remove assets.

10.2 The challenge of asset management

Asset management is not a simple construct and maintain process, but exists as a continuous process of data gathering, analysis, planning, action and review. This cyclic process has long been recognized in manufacturing and process industries, and is starting to be more formally embedded in many FRM organizations (Figure 56).

Figure 56: The cyclic process of asset management followed by the Environment Agency, England



Source: Environment Agency.

Whole-life considerations are at the heart of this process; linking actions from inception through to demolition/removal. Implementing the approach outlined in Figure 56, however, presents a number of practical challenges, including:

- ▶ **Understanding the role of infrastructure as part of a wider portfolio of responses.** Increasingly FRM is recognized as a wide-ranging approach that implies a portfolio of measures and instruments (both structural and nonstructural) to appropriately manage risk (e.g. Sayers et al., 2002). This need to utilize infrastructure appropriately as part of a wider response to managing flood risk places new demands on asset managers to become more proactive and integrated with others.
- ▶ **Incomplete understanding of the existing asset base.** Many towns and cities that are prone to flooding are already 'protected' by some form of structural defences. Often these have been constructed over many years, with changing design and construction practice and functional requirements. The physical dimensions and engineering properties of these existing assets are often unknown or poorly resolved. In recent years many countries have devoted significant effort to improving data and marshalling it into structured, accessible, databases (see e.g. Simm et al. 2007; USACE, 2008). It would

however be impractical to seek to maintain comprehensive data on all assets, therefore typically effort is devoted to providing a minimum level of data (often considered to be the location, type, notional standard provided and associated condition) with further data gathered only when required. An incomplete understanding of the existing asset base will therefore always exist (regardless of the effort directed towards data collection).

- ▶ **Incomplete understanding of structural/operational performance.** Assets are often a complex composite of structural components with spatially varying materials, profile, operational rules and so on. The physical processes that lead to failure are equally complex and often poorly understood in detail (for example internal erosion and associated piping failures), and can be costly to analyse without significant gains in knowledge. The performance of an asset will also vary in time through deterioration, a process that will be influenced by maintenance, fatigue caused by on-demand usage and climate change (for example accelerated desiccation and associated fine fissuring of soils: Dyer et al., 2009).
- ▶ **Variability of impact.** The impact of failure can vary markedly from one asset to another, and change depending on the time of year or the time of day the failure occurs (for example

in summer when tourists are camping in the floodplain, or during the rush hour when the roads downstream of a dam are congested with traffic). Not all assets are therefore equally important, and hence there is no requirement for them to have a common standard or condition. The impact of failure can also vary over a longer timescale as the land use in the floodplain or downstream valley changes (through increased development, changes in demographics, or simply change in awareness of the flood risk). Many examples exist where the construction of structural defences has promoted the development of the protected floodplain, radically altering the potential consequences of a failure and perhaps undermining the adequacy of the design standards originally used. (See for example the continued development of the Thames floodplains and the extensive floodplain development in Sacramento, USA, often despite planning regulations that seek to limit residual risk, such as (in England) Planning Policy Statement 25 on Development and Flood Risk (CLG, 2010).

- ▶ **Affordability.** Budgets are limited and it is common to have insufficient resources (of time, money, social and environmental capital) to undertake, maintain, periodically inspect, and properly operate all 'desirable' works. For example, in the United States it has been estimated that \$2.2 trillion would be needed to raise all linear defences (levees) to the 'desired standard and condition' (Steve Stockton during an address to the Association of Floodplain Managers, Orlando, 2009). Historically, funds have frequently been made available for the initial construction but not for subsequent maintenance and inspection. This separation of capital and revenue funding streams persists today, and continues to undermine good whole-life asset management. This is especially true when the funding responsibility is devolved to local communities (rather than national or regional governments) or commercial partnerships where long-term funding can be difficult to secure.
- ▶ **The need to balance different interests.** Flood defence assets seldom have a single object of reducing the chance of flooding. Visual impact (material and profile choice, working with nature and so on), amenity (beach management activities and the like), ecosystem services (wetland creation and protection, maintaining sediment connectivity and so on), transport and navigation are all common functions that flood defence assets must also support. Balancing these different, and often conflicting, interests presents a major challenge to the asset manager and demands an open and transparent dialogue about the trade-offs being made. Truly integrated actions are often undermined by separate funding streams, differing time horizons and priorities. This fundamental constraint is starting to be recognized, and policies to promote multiple

functional and cost-shared projects are starting to emerge (see for example the UK Flood and Coastal Resilience Partnership Funding: Defra, 2011).

- ▶ **Decision complexity.** The invariable complexity of asset systems and the floodplains they protect makes expert and engineering judgement difficult to apply. For example, an asset system of 100 or more items might protect a heterogeneous floodplain, and it will be all but impossible to identify the most critical assets by attributing the residual risk to individual assets. Given the imperative to utilize limited resources to best effect, this often leaves asset managers with doubts about which action to take and when.

10.3 Towards risk-based and resilient engineering design and infrastructure planning

Both developed and developing countries are seeking to promote communities that are resilient to flood hazards, and both are struggling to turn good theory into practical action. Building resilience demands a new way of thinking from that found in traditional design approaches. There is as yet no common blueprint for resilient design. A common understanding is however starting to emerge (for example see US NIBS; Boshier et al., 2007). This understanding acknowledges resilient 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 that:

- ▶ utilize sustainable materials and processes (based on locally sourced and renewable materials for example)
- ▶ continue to function when exposed to natural hazards that exceed design levels (for example a levee that is overtopped should not collapse or breach without warning)
- ▶ can rapidly recover from a disruptive event (supporting the rapid return to normality – avoiding the need for complex plant, highly specialist skills or difficult-to-source materials)
- ▶ continue to operate during extreme events (for example, critical infrastructure such as pumping stations, bridges, gates etc must continue to operate on demand).

Box 28: Emerging guidance: the US Disaster Resilient Design Expert Group

The Disasters Roundtable of the US National Academies National Research Council and National Academy of Environmental Design hosted a workshop on 'Disaster resilient design' on 26 October 2010. Bringing together thought-leaders and experts in the design and disaster communities, this workshop identified ways to integrate principles of sustainability and disaster resilience in building, site and community planning and design. Disaster-resilient design embodies a broad range of ideas and specifications that can include site planning and building codes, sustainability and green design principles, pre-event plans for risk reduction and mitigation, and post-event retrofit, reconstruction and resettlement considerations. The workshop drew upon examples from research, planning and design studio work to address how building, site and regional plans can mitigate exposure to risk and effects of disasters to:

- ▶ identify areas of intersection between sustainability and disaster resilience
- ▶ identify ways to integrate green design and disaster resilience principles in the United States and in international arenas
- ▶ identify new models for disaster-resilient design research and education
- ▶ raise awareness, facilitate dialogue, and create collaboration among experts in the disasters and environmental design communities.

Emerging challenges continue to persist, including how best to:

- ▶ integrate green design and disaster resilience into physical design
- ▶ identify new models that integrate disaster resilient design research and education.

Source: DRNA (2010).

Equally the move towards a risk-based philosophy requires a move away from traditional engineering design practice. In a traditional engineering/safety standards-based approach the decision-making procedure is simple and follows along the lines of (after Hall and Penning-Rowse, 2010):

1. Establishing the appropriate standard of defence (such as the '100-year return period' river level) based on the land use of the area protected, or reasons of uniformity or tradition.
2. Estimating the design load, such as the water level or wave height with the specified return period.
3. Designing the structures to withstand that load (considering crest level, structural strength and so on).
4. Incorporating safety factors, such as freeboard allowances, to account for local uncertainties using local guides.
5. Incorporating deterministic warning systems – based on comparing in-river or at-sea forecasts with levels that would trigger action for the warned area.

Such an approach has a number of shortcomings. In particular, it relies on the definition of an acceptable engineering/safety standard, a difficult task that has often been attempted but never fully achieved. Typically, such efforts have tried to draw analogies with other risks individuals and societies accept in an

attempt to set acceptable risk levels for flooding, for example. Although such approaches have been applied successfully to regulated industries in the developed world (e.g. HSE, 2001), they have offered limited utility in the context of a modern risk approach where resources are accepted as finite and require prioritization. This is because an engineering standards approach leads to, first, inequality, protecting some and not others, and second, inefficiency of spend, by providing standards above the minimum for economic efficiency. The benefits accrued 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 including an explicit trade-off of benefits and resource requirements (see Chapter 5).

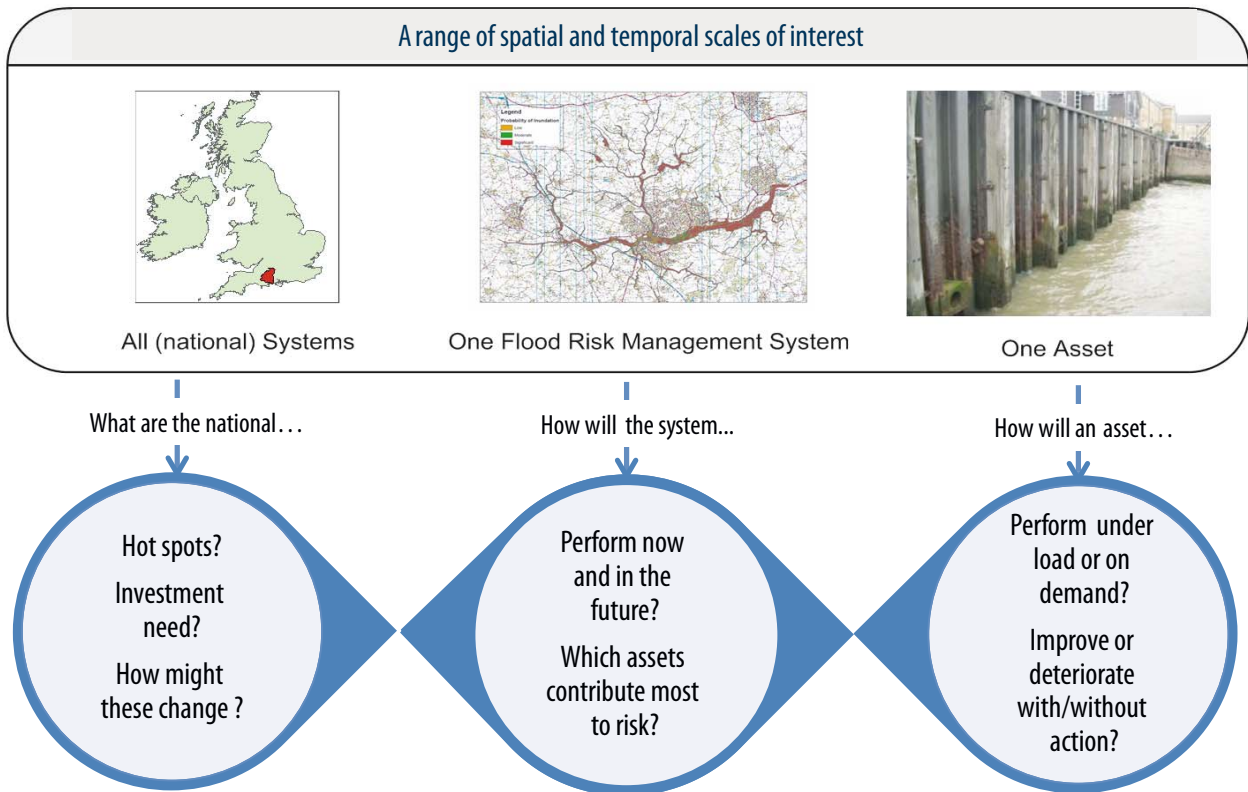
10.4 Adopting a hierarchical approach to infrastructure management decision-making

Asset management involves a vast range of asset types. A flood defence asset can be described as any feature that is actively managed to reduce the chance of flooding (as opposed to the associated consequences). This includes a wide variety of individual structures and activities that act together to form infinitely diverse asset systems comprised of:

- ▶ linear assets (above ground), from raised defences (levees or dykes) to major dam structures
- ▶ linear assets (below ground) such as urban drainage networks
- ▶ interface assets (linking above and below-ground systems) such as culverts, gulleys and manholes
- ▶ point assets such as pumps, gates and culvert trash screens
- ▶ watercourses and channels – which can include the vegetation and sediment within a channel and floodplain
- ▶ coastline features such as groynes, beaches and backshores.

A nested approach, where policies set the direction for the type of approaches used and the 'on-the-ground' realities inform policy, is a prerequisite to good management (see Chapter 4). In this context, infrastructure assets are managed across a range of spatial scales – from a single asset to the national allocation of funding – and across temporal scales – from short actions to long-term investment planning. Across these multiple scale the questions and decisions vary in nature, and so does the nature of the supporting evidence (see Figure 57).

Figure 57: The management of infrastructure assets takes place across a range of scales of time and space



Source: Sayers et al., 2012b.

This approach is now starting to become a reality in practice (for example in the national Long Term Investment Strategy through to System Asset Management Planning undertaken by the Environment Agency). Although these are positive steps it is likely to be some time before policies, strategies and actions are routinely integrated.

10.5 Common issues faced when assessing the performance of flood defence infrastructure

Many common issues are faced by asset managers as they attempt to manage an ageing and extensive asset base and appropriate integrated new engineered structures, including the following.

A NEED FOR BETTER EVIDENCE ON THE CONDITION AND PERFORMANCE OF INDIVIDUAL ASSETS

In England and Wales, the Environment Agency has stated that it will have succeeded in its asset management role when it knows exactly: 'what assets we have; where they are; what standard of protection they provide; how they were constructed; their current engineering integrity; and, how they work together to provide a flood defence system' (Tim Kersley, head of asset management, Environment Agency, 2008). Similar, seemingly basic, requirements can be seen to exist around the world and across sectoral disciplines (for rail, road and so on), and are a central thrust of the USACE National Levee Safety Program (USACE, 2006).

BETTER DECISION-MAKING – HOW, WHERE AND WHEN TO INVEST

All asset managers seek to make good investment decisions, which minimize whole-life costs and maximize environmental gain while ensuring communities are appropriately protected

from flooding now and in the future. Such decisions will reflect a set of common characteristics, including:

- ▶ **robustness:** ensuring the strategy performs well in the context of a wide range of possible futures
- ▶ **flexibility:** ensuring future choices are not constrained by previous choices, and that alternative actions can be taken at a future date with limited additional cost
- ▶ **adaptability:** embedding the capacity to adapt as the reality of the future unfolds (so that for instance an asset can be raised or widened at minimal cost).

A NEED TO DEAL WITH UNCERTAINTY BETTER AND MORE EXPLICITLY

In addition to severe uncertainty about the future climate and demographic conditions within which an asset will operate, uncertainty in the data and models used to assess risk is unavoidable. Handling this type of uncertainty is fundamental to the progressive nature of a hierarchical approach to risk assessment. Without understanding the nature of the uncertainty at each stage it is impossible to determine when the analysis and data used are sufficiently credible in terms of the decision being made.

It has been, and always will be, necessary to make decisions in the absence of perfect information. In the past, uncertainty in decisions has been implicit rather than explicitly accounted for. Recognizing uncertainty does not however prevent decisions from being made. In fact, understanding uncertainty is a key requirement for risk-based decision-making. By quantifying and acknowledging uncertainty we are better placed to decide how to best to manage it (Figure 58).

Figure 58: Levee truths



Levee “Truths”

- Levees are now abundant in many communities in the United States;
- Levees have often inadvertently increased flood risks in the country by attracting development in the floodplain;
- Levees only reduce the risk -they do not eliminate the risk;
- The number and location of all the levees in the United States is currently unknown;
- Levees have too often been the primary tool in flood risk management;
- There is currently no national policy relating to the safety of levees;
- Government officials and the general public often have only a limited understanding of levees and the risks associated with them;
- Many levees were constructed without the benefit of modern engineering and provide only limited protection to communities;
- Many levees originally constructed to protect agricultural fields now protect large urban communities;
- Many urban areas protected by levees, particularly those in deep floodplains, place people who live behind them at an unacceptably high risk. Failure of such levees can result in high loss of life, property damage, and economic losses; and
- The reliability of many levees is commonly not known.

Photo: Chino Canyon Levee. Palm Springs, CA. 2008— Courtesy of Riverside County Flood Control and Water Conservation District

Source: NCLS (2009).

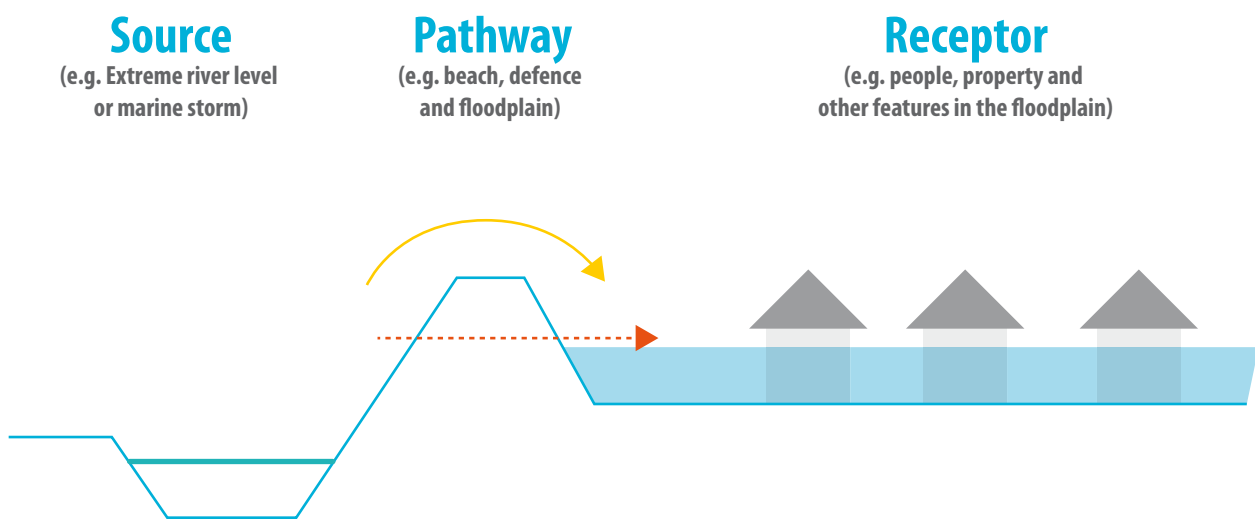
Similar tools exist in the United Kingdom (through the National Flood and Coastal Defence Database) the Netherlands through the dyke safety programme, and elsewhere.

SYSTEM RISK ANALYSIS TOOLS – DEVELOPING A WHOLE- SYSTEM UNDERSTANDING

Structured approaches for dealing with whole systems of infrastructure assets, rather than individual structures and defences, are becoming embedded in practice. A key aspect of these whole-system tools is the structural description of

the system components. In the United Kingdom, source–pathway–receptor terminology (used widely in environmental assessment: DETR, 2000) has in recent years been adopted by FRM (Sayers et al., 2002). As introduced in Chapter 2, in this model consideration is given to extreme climatic conditions (sources that initiate a flood), through the response in the form of the hydrological, hydraulic and structural behaviour of the rivers, coasts and control infrastructure (including breach, blockage, failure to open or close and so on – the intervening pathways that link the source to the receptors) – to the individuals, properties and other features in the flood plain that suffer the consequences (the receptors). See Figure 60.

Figure 60: The source–pathway–receptor notation provides a useful framework for describing the flooding system and the influence of the infrastructure assets



Source: adapted from Sayers et al., 2002.

In this framework, infrastructure management is focused on managing the pathway of flooding, and in this context the river channel, floodplain surfaces and topography, nearshore morphology and natural backshore features are all legitimate parts of the asset system alongside human-made infrastructure. The performance of these assets modifies the probability of flooding and its nature (the depth, velocity, debris content and so on). The action taken may influence either the ultimate limit state failure (a breach or mechanical failure, for example) or a serviceability failure (overflow or overtopping of the crest of an embankment or the flow capacity of the pump being exceeded).

Two primary issues are therefore of concern in understanding the performance of a flood infrastructure:

First, how does the asset system function and how can flood waters enter the floodplain? Two situations must be considered, if there are one or more flood control assets:

- ▶ the asset fails and structurally degrades (in other words it experiences an ultimate limit state failure such as a breach for a linear asset or a blockage or inability to operate a point asset)
- ▶ the asset remains structurally intact but fails to prevent flood water entering the floodplain (in other words, a serviceability limit state such as overtopping, through periodic wave action, the overflowing, as the still water levels exceed the crest, of a linear asset or the surcharging or bypassing of a point asset).

Second, what is the probability of either an ultimate or serviceability limit state failure under given load or on demand? For example, for a certain marine storm or river flow/water level, how likely is the failure of a given embankment, or how likely is a pump or barrier to fail when requested to pump or close?

Not all failures are equal in risk terms. The significance of the failure will depend on the consequences associated with that failure. The contribution of an asset to the residual risk will therefore reflect its role in the asset system, the chance of failure and the associated consequences should failure occur (given the performance of the other assets in the system at the time of failure). Only through consideration of all important system states (that is, all important combinations of potential failures in a group of assets and the consequences associated with each) can risk be calculated and attributed to individual assets (e.g. Gouldby et al., 2008).

Understanding the performance of the intervening system of infrastructural assets is therefore critical, and often dominates the understanding of the probability of flooding in the majority of occupied floodplains (as they are typically protected, to a greater or lesser extent, by raised defences, flood gates, barriers and pumps). In risk analysis models, the reliability of individual structures and systems of assets must therefore be represented if their role in managing risk and their contribution to residual risk is to be understood. In England and Wales the RASP approach provides a framework for system risk analysis (e.g. Sayers et al., 2004; Gouldby et al., 2008) that enables all important components of the flood risk system to be represented and the role of individual assets in managing risk to be quantified, helping to target asset management efforts appropriately.

UNDERSTANDING THE PERFORMANCE OF A SINGLE ASSET – THE CHANCE OF FAILURE (RELIABILITY)

To understand the performance of a single infrastructure asset under load or on-demand in detail can be a major undertaking. Often such an analysis will involve geotechnical, structural and hydraulic considerations, models and data. If however, the particular asset has a limited role in managing risk or the management decision clear in the absence of detailed analysis; such detailed investigations are not required.

Hierarchical frameworks of inspection (from visual through to intrusive and nonintrusive: Long et al., 2011) and reliability analysis that enable more progressive detail and data to be used and uncertainties reduced (where possible) have started to emerge. The basis for any analysis of asset performance – from the most simple to the most detailed – is an understanding of the failure process and modes.

For example, analyses ranging from initial analyses such as potential failure mode analysis (PFMA) and failure mode and effects analysis (FMEA) through to full detailed reliability analysis start with an understanding of asset condition and how failure may develop when a given asset is loaded by a storm or operation.

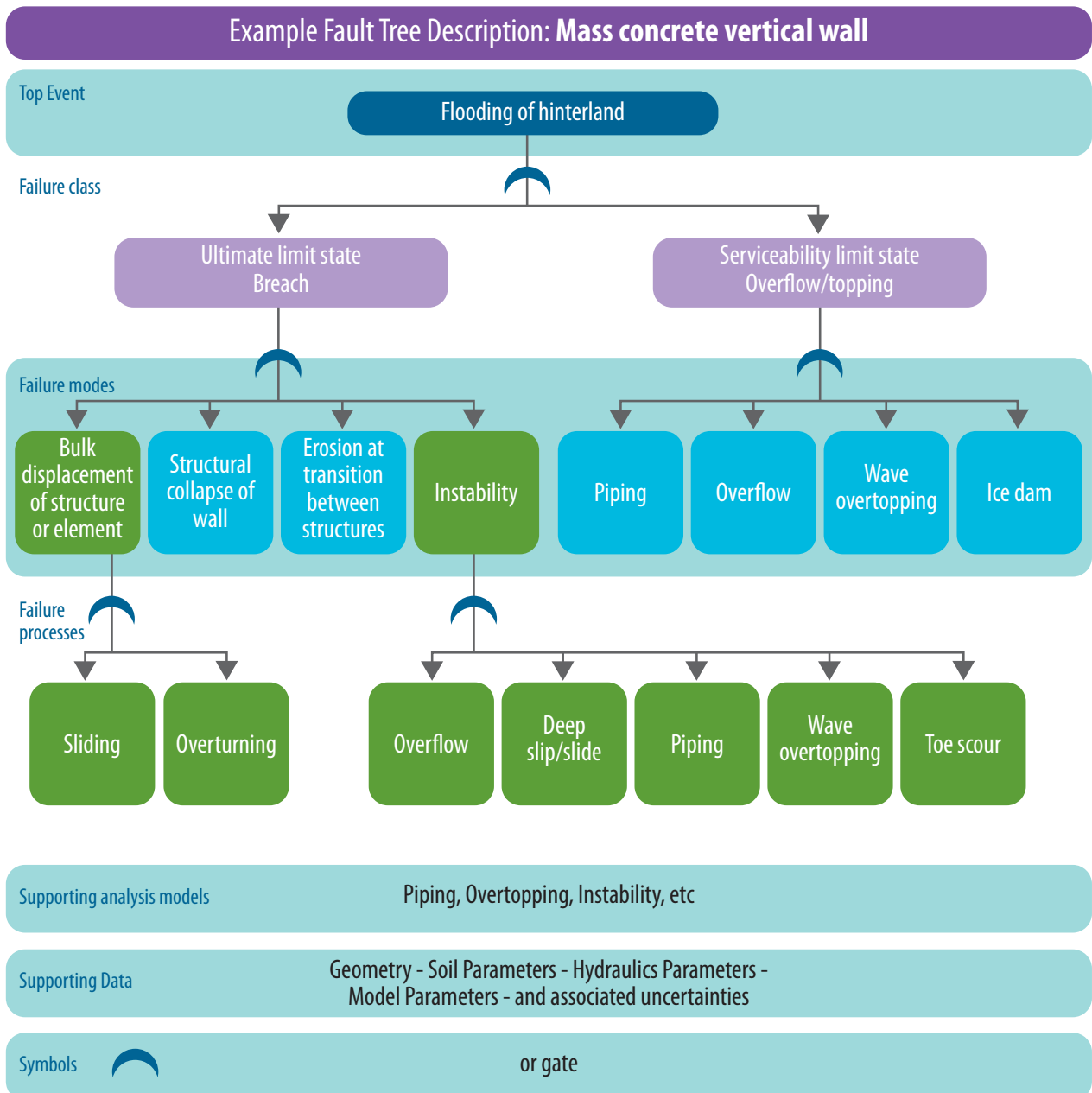
Typically, two approaches are used to provide a framework of thinking:

- ▶ **fault tree analysis** (as first provided by Watson, 1961 and revised by many authors since): here a top-down, deductive framework of thinking is adopted, where the processes that may have led to a hypothesized undesirable event, such as a breach, are deduced
- ▶ **event tree analysis** (as first applied to the dam industry in the context of a risk assessment by Whitman, 1984) provides a bottom-up, inductive framework of thinking where initiating processes are hypothesized, such as piping, and the ensuing processes of failure explored.

Although fault trees and event trees are infinitely extendable, perhaps the fault tree analysis is most convenient in the context of a hierarchical risk analysis. The skill in the asset manager is ensuring the tree remains as simple as possible, but no simpler, while capturing the most significant failure modes and process.

Figure 61 shows an example fault tree for a generic mass concrete vertical wall, showing varying levels of detail associated with different failure modes (see Allsop et al., 2007 for a wide range of generic fault trees and associated limit state equations).

Figure 61: An example fault tree



Source: FLOODsite Task 4 - www.floodsite.net

To assess the reliability of an asset, the primary failure modes must be described and their correlations known (or inferred) as set out in either a fault tree or event tree. Each failure process and failure mode in the fault or event tree must be described in quantified terms and the threshold at which failure is assumed to occur known (this is known as a limit state equation). The process of analysis is summarized in Table 19. There are various software tools to support the fault tree and reliability analysis elements of this process (Kortenhaus, 2012).

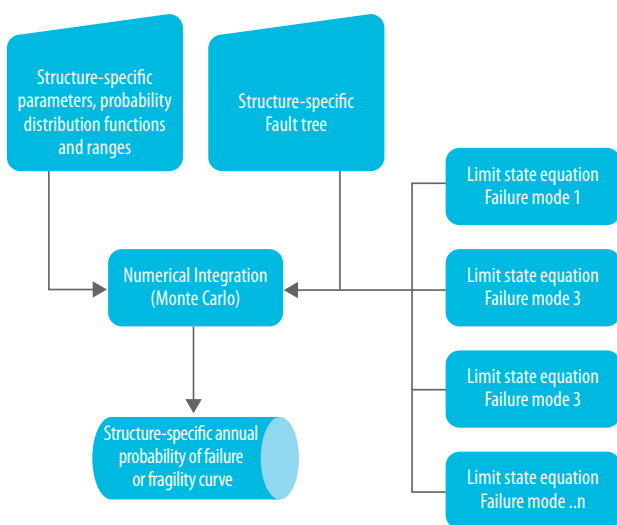
In general however, to establish the response variable as a probability distribution some method of integration of the input probability distributions is required. Where the distributions are continuous, often Monte Carlo simulation techniques are used to sample the input probability distributions. This approach avoids analytical integration, which can be complex or even impossible. The common building blocks of a numerical integration approach (known as Level III reliability analysis) are shown in Figure 62.

Table 19: Basic steps in the analysis of infrastructure reliability

Step	Description
1. Define asset function	A flood defence asset rarely acts solely to protect from flooding; it often functions as a valuable environmental habitat, navigation or amenity asset. Understanding the multifunctionality of the asset is an important precursor to understanding how to manage it.
2. Establish incident loading	An asset may be subject to a range of loading conditions – joint wave and water levels, marginal high or low water levels, groundwater levels or perhaps a combination.
3. Identify failure modes	The <i>failure mechanisms</i> (processes that can lead to ultimate failure) and the <i>failure modes</i> (that define ultimate failure) also need to be described. To avoid unnecessary effort, conventional deterministic approaches can be helpful to eliminate unrealistic failure mechanisms (that is, relatively low-probability individual events in comparison with the likely overall reliability of the asset). Research into failure mechanisms continues to be vital to better understand asset performance (e.g. Allsop et al., 2007, Dyer et al., 2009; Sentenac et al., 2009).
4. Prepare a fault tree	Fault trees provide a useful visual, and formal, encapsulation of the failure mechanisms and their relationship to the failure modes. (Various software tools are available to aid this process – see van Gelder et al., 2008).
5. Identify/ establish appropriate limit state equations	An appropriate model needs to be selected to represent each failure mechanism/mode. In many cases empirical relationships will exist and these can easily be translated into the form of a limit state equation (used in the reliability analysis – see below). In some cases, the failure mechanisms are complex (as with slip failure) and demand the use of more sophisticated models (for example, traditional slope stability analysis or a finite element model). It is possible to link such models in the reliability analysis (Lassing et al., 2003; Vrouwenvelder, 2001a, 2001b) but this is often difficult and can incur an unacceptable runtime overhead. Emulation of these more complex models, through artificial neural networks for example, provides an efficient and effective means to enable such complete mechanisms to be incorporated into the reliability analysis (Kingston and Gouldby, 2007).
8. Document uncertainty in model variables and parameters	The engineering parameters, and the empirical variables, in the limit state equations will not be perfectly understood. Describing the uncertainty in these relationships and the supporting data on the asset of interest is an important task. In describing the uncertainty it is important that this process is comprehensive (ignoring uncertainty at this stage is to assume the data is perfectly known). Two groups of uncertainties can typically be distinguished (USACE, 1999; Sayers et al., 2002) : <ul style="list-style-type: none"> ■ natural variability (aleatory uncertainty): uncertainties that stem from known (or observable) populations and therefore represent randomness in samples ■ knowledge uncertainty (epistemic uncertainty): uncertainties that come from basic lack of knowledge of fundamental or measurable phenomena. Perhaps most critically, it is important to record the assumptions made regarding the uncertainty in the variables and parameters and the associated supporting evidence for these choices. This provides a vehicle for peer review and audit (Hall and Solomatine, 2008).
7. Undertake reliability analysis and display results	Once the above inputs have been established the reliability analyses can be undertaken. For each hydraulic loading condition a series of simulations (across the uncertainty bands for each input parameter) are resolved. Failure arises in a particular case when the combinations of parameter values in the limit state function (Z) yield a value for Z which is less than or equal to zero. The probability of failure for that given loading condition is then the number of times when the simulation gives Z as less than or equal to zero divided by the total number of simulations. Repeat for all hydraulic loads (Kortenhaus et al., 2002, Lassing et al., 2003, Simm et al., 2008, van Gelder et al., 2008).
8. Display results	Present the results of interest (for example an annual probability of failure or fragility curve).

Source: adapted from Simm et al. (2008).

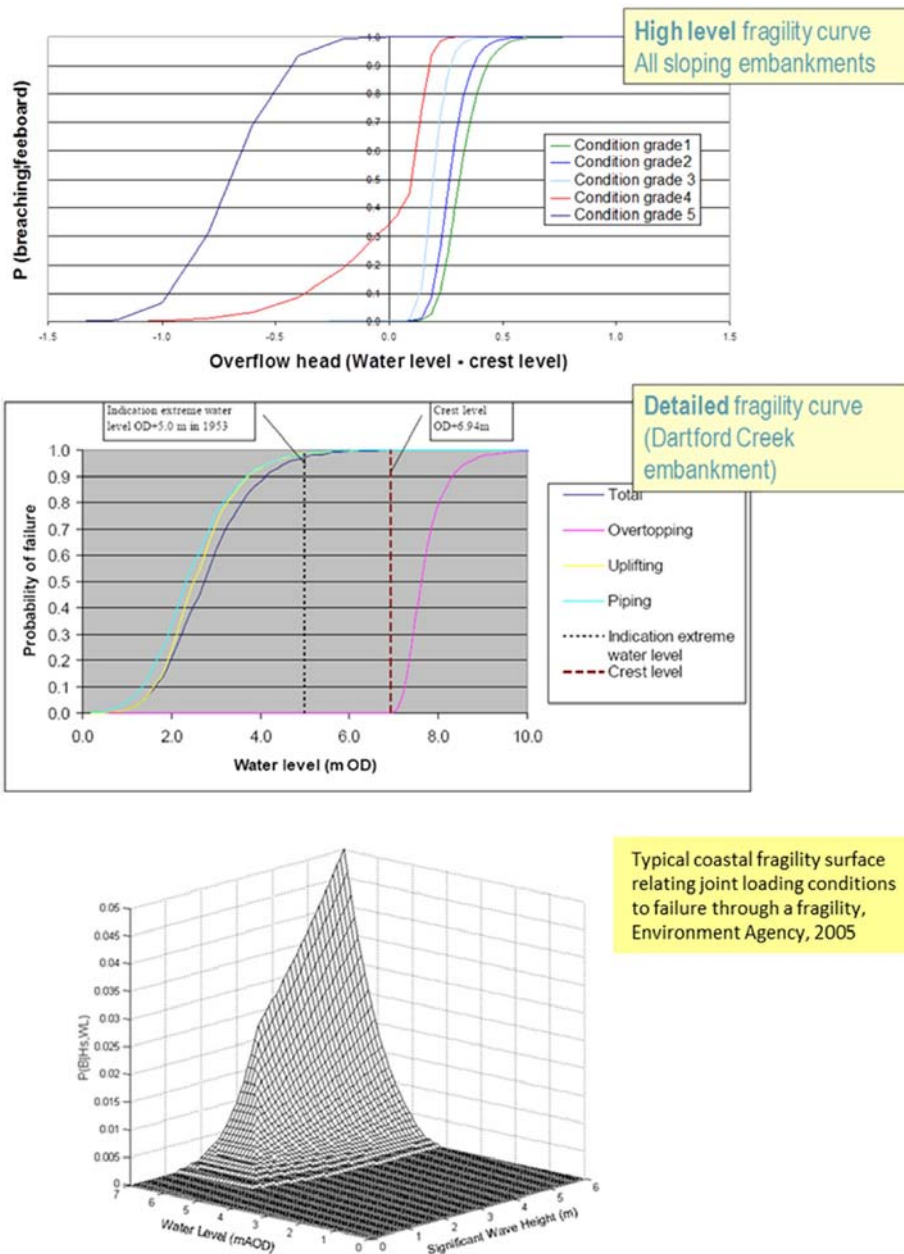
Figure 62: Building blocks of a structured Level III reliability analysis



EXPRESSING THE RESULTS OF A RELIABILITY ANALYSIS

The results of a reliability analysis can be expressed in a number of ways. The most convenient for both expert review and validation, as well as for onward use within a system risk model such as RASP, is perhaps a fragility curve or a fragility surface. A fragility curve is a means of displaying the probability of failure for a given loading condition. The Environment Agency has developed a set of generic fragility curves, covering all basic types of coastal and fluvial linear defences, for application in broad-scale risk models (see for example Hall et al., 2003a; Environment Agency, 2003, 2007). Only where more confidence in the assessment is required are these high-level curves refined using more detailed analysis. The form of the fragility curve remains unaltered regardless of the level of detail; it is only the degree of certainty that is assigned that changes. A comparison of the fragility curves results from a high level and more detailed analysis is shown in Figure 63.

Figure 63: Fragility curves and surfaces representing the conditional probability of failure given load. Top: high-level fragility curves have been developed for all linear structures in the England and Wales (Environment Agency, 2003); middle: an example from a more detailed reliability analysis in the Thames (Sayers et al., 2006); bottom: a fragility surface developed for a coastal defence along the Towyn sea front, North Wales (Dawson et al., 2004).



ACCOUNTING FOR DETERIORATION

All assets are subject to deterioration. Deterioration of relevance to a flood risk manager can include lowering of the defence crest through settlement (increasing overtopping at lower water levels), animal infestation (increasing the chance of piping and the probability of a breach), and siltation of a watercourse or debris blockage of a culvert (reducing the conveyance capacity of the channel).

The consideration of deterioration in design typically leads to two types of design issue:

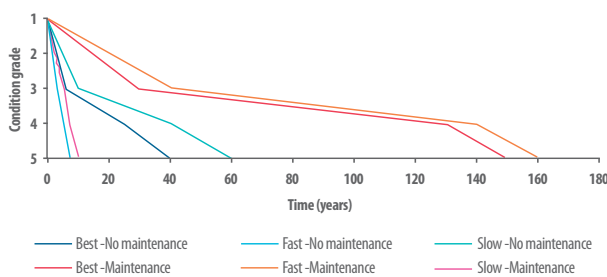
- ▶ minimizing deterioration by the choice of materials and structure types
- ▶ taking deterioration into account by considering the expected design life and the need for (and ease of) inspection and repair or enhancing designing – allowing

for settlement through raising crest levels, thickening sheet section and so on.

An example of the choice of materials is the use of imported high-quality rock for a revetment rather than locally available poor-quality stone that would break down quickly under hydraulic forces. An example of allowing for deterioration is increasing the thickness of steel in a sheetpile wall to allow for corrosion over the life of the structure (which might be thirty to fifty years).

In flood risk analysis, understanding deterioration is an essential element of asset management, and is crucial for assessing whether or not it is worth extra initial investment to prolong the life or reduce the maintenance interval of an asset. In recent years a series of R&D projects has been undertaken to help understand the process of deterioration, from more detailed process-based models (Buijs et al., 2005) through to more expert judgement-led deterioration curves (Figure 64). Although it is improving, the level of understanding remains basic, and this will be an important area of research going forward.

Figure 64: Example deterioration curves



Source: Environment Agency (2009c).

High-level deterioration curves have been developed for each fluvial and coastal defence type, under assumptions of business as usual as well as enhanced and decreased maintenance. The example shown in Figure 64 is for a narrow, turf-covered fluvial embankment.

UNDERSTANDING THE PERFORMANCE OF A SINGLE ASSET – BREACH, OVERTOPPING AND BLOCKAGE

Understanding the chance of failure is, of course, only part of the story. The implications of failure, in terms of the increased flow into the floodplain, are equally important to understand the performance of an individual asset. This includes understanding:

- ▶ **The breach growth and inflow:** Understanding breaching is important not only to improve the ability to calculate the volume of water entering the floodplain but also, and most importantly, to assess the velocity and rate

of rise in flood waters as these develop around the breach, and the associated risk to life. Various research projects have been directed towards breaching, and through the international Dam Safety Interest Group various breach models from around the world have been usefully discussed and compared, leading to a focus of effort on two models (HRBreach from the United Kingdom and the SIMBA model from the United States, by Greg Hanson). Such models represent the state of the art, but they also demand information on various geotechnical parameters which often are simply not known. As in the assessment of reliability, more simplified methods are starting to emerge that support broader-scale risk analysis. For example through the Flood Risk Management Research Consortium effort is being devoted to the development of rapid and simplified breach models (www.floodrisk.org).

- ▶ **Overtopping:** Wave-driven overtopping often dominates coastal flooding, and is often highly sensitivity to changes in beach levels and subsidence of the seawall crest. In recent years the approaches to coastal overtopping have been consolidated through the Eurotop manuals and tools (see www.overtopping-manual.com/eurotop.pdf).
- ▶ **Blockage of point structures:** Blockage of culverts, bridges and other point assets by debris – both anthropogenic and natural – can cause local flooding in urban areas. Through the Flood Risk Management Research Consortium in the United Kingdom, effort is being devoted to updating longstanding guidance on how to assess the potential recruitment of debris and the degree of blockage. Although it is early in the research programme, promising predictive capability is emerging (see Wallerstein et al., 2012).

10.7 A summary of recommendations

Good risk-based asset management should better target capital expenditure, reducing and delaying spend where possible to ‘make assets sweat’ and deliver the performance required but not necessarily more than is required.

The implementation of risk-based asset management reflecting whole-life performance demands close collaboration between the activities of those organizations with a direct interest in managing flood defence assets and those outside. As this chapter highlights, inspections and data, system analysis, reliability and risk attribution provide a number of important insights and aids to the decision-maker when deciding how

best to manage a complex infrastructure system with limited resources.

An understanding of an asset’s chance of failure (now and in the future) is an important contribution to understanding the risk and how best to manage it, but it is not the only consideration. Assets must be understood in the context of the asset system in which they reside. It is important to:

- ▶ consider a full range of inundation scenarios (with and without one or more asset failures) across a wide range of storm events (from the frequent to rare)
- ▶ evaluate the potential associated impacts (economic as well as other damages and importantly opportunities)
- ▶ integrate the results accordingly.

Credible system analysis methods are now available and embedded in various tools. These tools are capable of attributing risk to individual assets which in turn provides a powerful support to the identification of critical defence assets.

Information technology is at the heart of an efficient approach to asset management (supporting the principles of good asset management). The USACE, the Netherlands government and the Environment Agency have all undertaken similar initiatives to improve the underlying data and access to it.

Some key recommendations in the support of good infrastructure management are:

- ▶ Provide clear national guidance on best practice management.
- ▶ Develop and maintain a flood defence database to enable baseline information to be gathered and used in risk analysis and inform priorities, and provide data for risk-informed assessments and decision-making. At a national scale basic information on all infrastructure should be included; not only state-owned but private structures too, with details of where the structure is, what it is (embankment, vertical wall and so on), its crest level and condition.
- ▶ Develop tools and techniques for assessing infrastructure performance and identifying risk-informed priorities (see Table 20).
- ▶ Delegate responsibilities to provinces and regions to assist provincial and regional governments in developing effective management focused on continual and periodic inspections and improvements.
- ▶ Explore potential incentives and disincentives for good behaviour.

Table 20: Best practice principles in support of asset management tools

Appropriateness	Appropriate level of data collection and analysis reflecting the level of risk associated with an asset and the uncertainty in the decision being made.
Understanding	Improving understanding of assets and their likely performance.
Transparency	Transparency of analysis enabling audit and justification.
Structure	Structured knowledge capture encapsulated through a fault tree, breach potential etc.
Tiered assessment and decision-making	In terms of both data and modelling approaches.
Collect once, use many times	Reusing data through the hierarchy of decision-making stages and supporting tools – from national policy to local detail.
Simple use and practical	There is a significant challenge in converting good science into practical tools. Therefore, even though the underlying analysis may be complex, the user experience must be well constructed and intuitive.

Source: Sayers et al. (2010).

CHAPTER 11

EMERGENCY PLANNING AND MANAGEMENT

11.1 Introduction

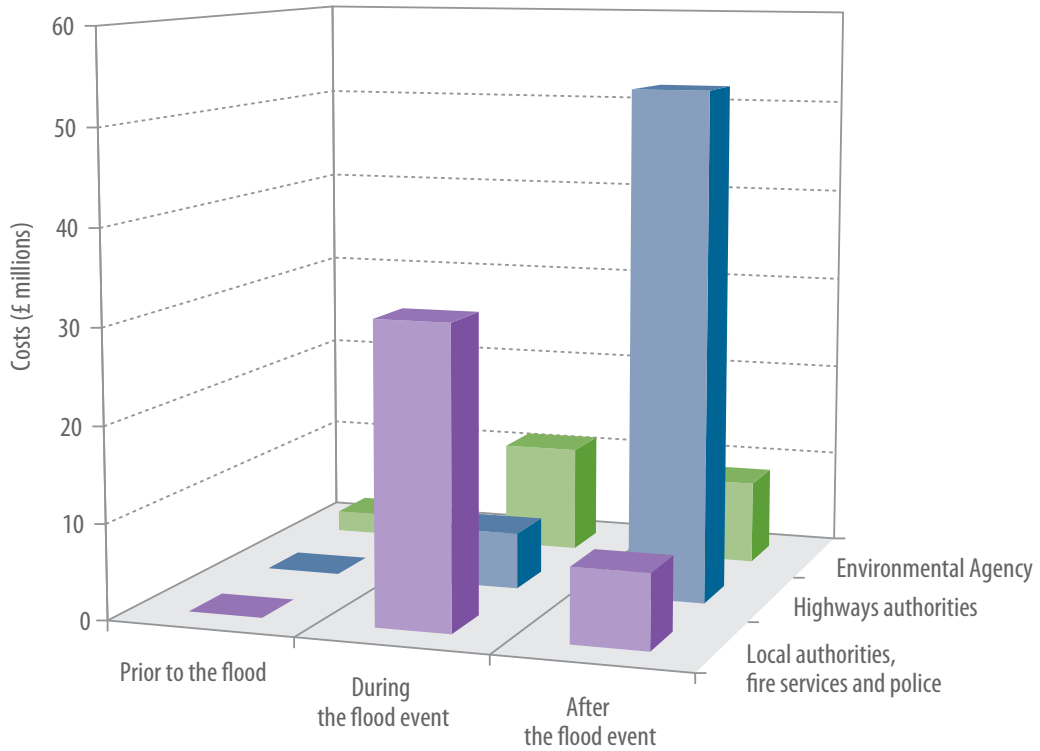
The Hyogo Framework for Action 2005–2015: Building the resilience of nations and communities to disasters (Framework for Action: ISDR, 2005) summarizes the principles for reducing the impact of disasters as:

- ▶ Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.
- ▶ Identify, assess and monitor disaster risks and enhance early warning.
- ▶ Use knowledge, innovation and education to build a culture of safety and resilience at all levels.
- ▶ Reduce the underlying risk factors.
- ▶ Strengthen disaster preparedness for effective response at all levels.
- ▶ In their approach to disaster risk reduction, states, regional and international organizations and other actors concerned should take into consideration the key activities listed under each of these five priorities and should implement them, as appropriate, to their own circumstances and capacities.

In the context of FRM, emergency planning and management aims to first, minimize the adverse impacts of the event(s), and second, promote recovery. There is a cost to emergency management and inevitably, therefore, there is a balance to be struck between meeting these aims and the cost and effort of the emergency management itself. It is however evident from past floods that efforts to better prepare for a flood are highly efficient (Figure 65).

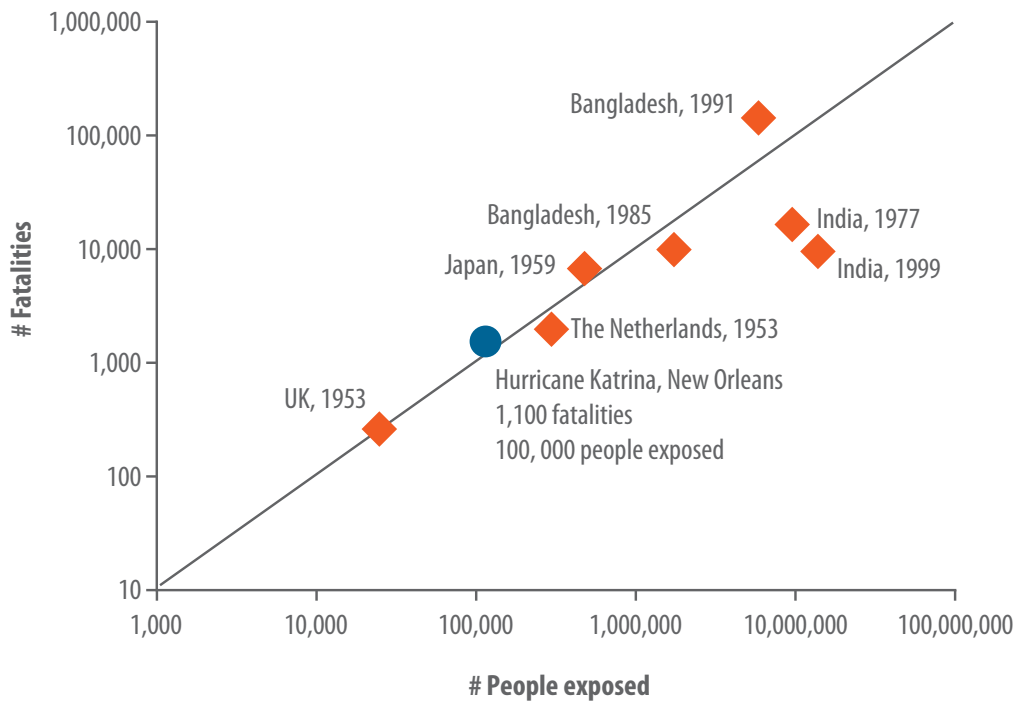
Loss of life and injury can be significant in major flood events. The number of injuries will depend on the execution of effective emergency plans, but as a general rule the relationship between the number of fatalities and the number of people exposed during a flood event is fairly constant (Figure 66). Effective emergency planning and response can, however, have a significant influence on the scale of the loss of life/injury.

Figure 65: The distribution of expenditure, prior, during and after the 2007 floods in the United Kingdom



Source: Environment Agency (2008b).

Figure 66: People exposed and fatalities of major flood events



Source: Jonkman (2007).

11.2 The developing nature of emergency management

The nature and effectiveness of emergency management is the subject of intense debate. In most flood circumstances mistakes are inevitably made, and many are quick to blame the relevant authorities for poor performance. This is inevitable, but it needs to be recognized, and the situation and risks of failure and bad performance must be managed.

Issues that are commonly debated are:

- ▶ **Redundancy:** how much redundancy to build into the emergency management system. It may be necessary to have equipment and materials stockpiled for many years in advance of any event, but how much? How do we decide?
- ▶ **Warning:** flood victims commonly claim that there was insufficient warning, but often do not react to warnings that are given very early in the emergency planning process. The fear of 'false positives' (warnings against an event that does not occur) can impede the delivery of early warnings. In the early 1990s, for example, India's Central Water Commission conducted operational flood forecasting for several major rivers; but the results were used only for in-house alerts and were not made public – because of the fear of widespread inconvenience if the (inherently uncertain) warnings turned out to be unwarranted. Developing a more mature relationship between those issuing and receiving the warning in terms of the trade-off between certainty and lead time is therefore fundamental to providing better more targeted warnings.
- ▶ **Response:** flood victims and the media commonly claim that responses to a major flood were inadequate, but forget that such responses cannot be perfect.
- ▶ **Liability/blame:** it is now the common view that floods are not 'acts of God', but the fault of someone or some organization who is therefore to blame. Several countries have dedicated bodies that are responsible for official alerts, but this does not make that body responsible for the flood. This view is therefore generally erroneous, but there are cases where liability is to be attributed, and this needs careful analysis and management.
- ▶ **Moral hazard:** people live in dangerous places, know that this is so, yet still expect the government to come rushing to their assistance when disaster strikes. This is unreasonable, and unfair on the general taxpayer. When the government provides programmes that permit unwise development to take place, and provides post-disaster support to those who have made poor judgements, it encourages further losses and creates a moral hazard. Governments must make it clear that they will only take prudent actions in managing emergencies.

The implementation of the necessary stages of emergency planning and management should be pursued rigorously, with national guidance, and it should also be location-specific, reflecting the characteristics of the flood to be experienced and the nature of the people and development in the floodplain. For example, some common faults are:

- ▶ **Failure to understand the speed of onset of the flood.** Rapid rise flood events require more preparation and even pre-preparedness planning. There will not be sufficient time in the event itself for any planning activities: at that point people simply respond through pre-planned actions.
- ▶ **Failure to prepare for loss of life.** Rapid-rise events are also those more likely to lead to loss of life, and therefore the emergency operations and management need to be focused on that issue, with for example:
 - evacuation arrangements
 - hospital plans
 - mortuary arrangements.

Emergency planning and management will never be perfect, not least because nearly all floods are somewhat different from their predecessors. However some other key pitfalls include:

- ▶ poor preparation (leading to action that is inadequate or too late)
- ▶ unclear lines of command
- ▶ poor understanding by those involved of who should do what
- ▶ poor communication
- ▶ poor understanding of the opposition to evacuation
- ▶ poor prioritization of who to assist and when.

11.3 The cycle of emergency management

The management of flood risk involves a wide range of actions and activities (a portfolio approach – see Chapter 2). Emergency management planning forms part of this process, and as such it is one of the many options decision-makers must utilize. Figure 67 shows how emergency management fits into the disaster cycle, and highlights the interaction between FRM as a whole and emergency planning processes:

- ▶ **Prevention and mitigation:** Understanding the residual risk and the potential 'what-if' scenarios following implementation of other prevention and mitigation measures provides the starting point of the emergency planning process.

- ▶ **Preparation:** When an alarm is activated, how can the impact of the event be minimized? Actions could include improved forecasting and warning, creation of safe refuges/havens, and preferential routes of access and egress from potential flood areas. Additionally, pre-emergency plans can be used to communicate to the affected stakeholders, and alert the appropriate decision-makers to what might be required during an event and where resources should be stationed.
- ▶ **Response:** Coordinated response across all emergency services and the provision of real-time information to responders and the public alike is central. Communication systems must however be reliable; as has been shown through many events worldwide, technology can fail (mobile networks jam and internet sites go down). Nonspatial information like procedures, emergency plans and authorization modules should be readily accessible and easily communicated. Further,

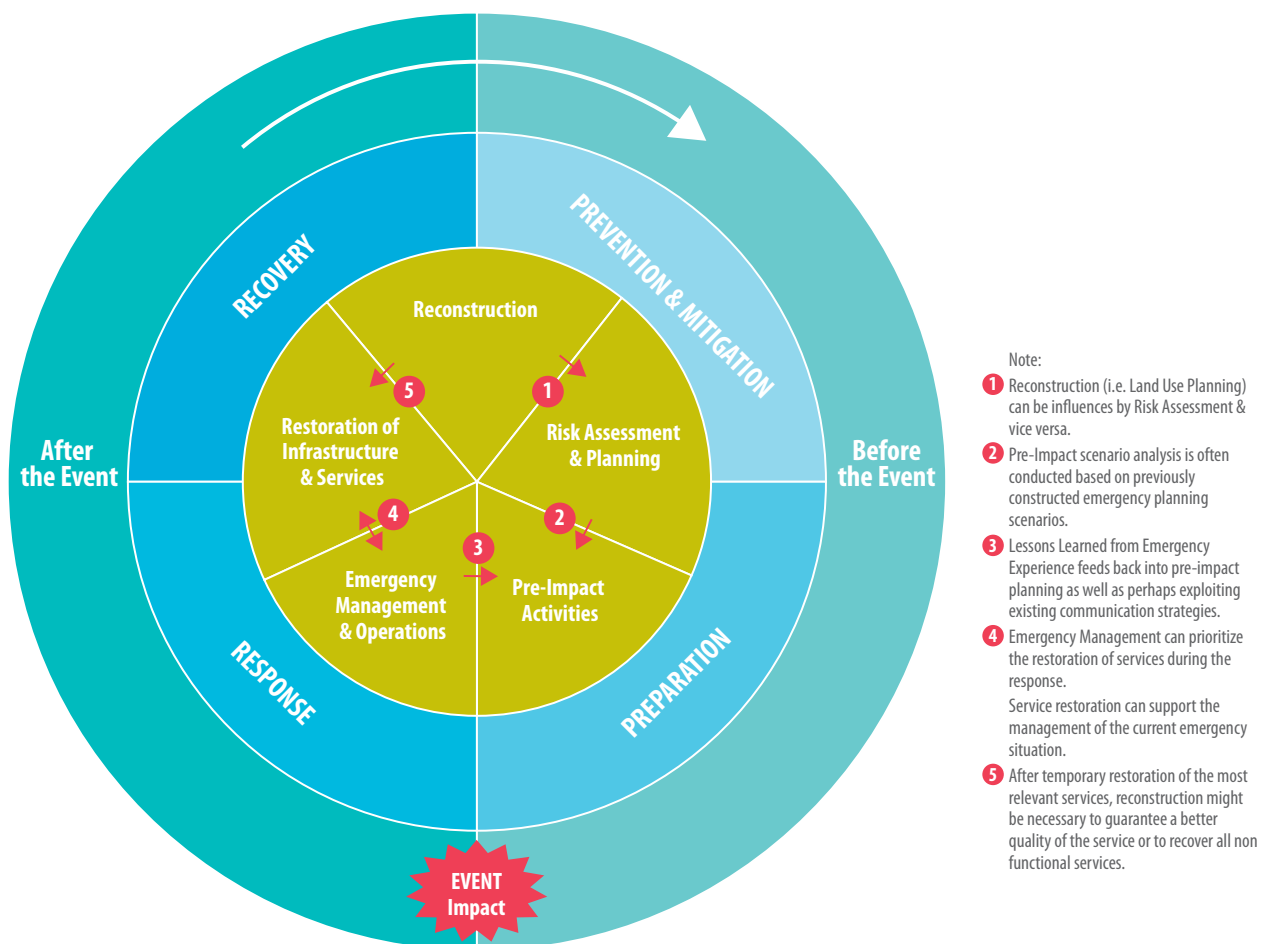
information on critical infrastructures and services damaged by the event will be needed to prioritize actions to protect the affected area. Finally, efficient and reliable communication channels will be necessary to assure the transportation of this information between the appropriate decision-makers and other emergency management actors.

- ▶ **Recovery:** Information on damaged infrastructure and services will be needed as well as the location of the population at risk, in order to prioritize actions. This stage often focuses on reconstruction.

Each of these key stages demands different resources, skills, information and authority to act. All four of these must be in place, across all stages, for the process to be successful.

The cycle of activities in emergency management is summarized in Figure 67 and discussed in more detail in the following sections.

Figure 67: The disaster risk management cycle



Source: Atkinson et al. (2006).

BEFORE THE EVENT – EMERGENCY PLANNING

Flood emergency planning involves preparing for floods – regardless of the perceived level of protection – and planning the response during a flood emergency. One of the most important decisions is whether people should be evacuated or stay in or near their homes and businesses. The decision is based on the likely depth and duration of flooding, the warning time and the availability of local safe havens where people can stay during the flood event.

If evacuation forms part of the emergency plan, the following should be covered in the plan:

- ▶ For each community, define the locations to where people should be evacuated (the evacuation points).
- ▶ Define the evacuation routes and ensure that these are maintained (so they are available when needed).
- ▶ Establish emergency shelters.
- ▶ Establish evacuation priorities and procedures.
- ▶ Provide information on evacuation procedures and routes to all those who will be involved with the evacuation (including organizers and communities to be evacuated).
- ▶ Provide warnings where access routes are dangerous during floods.
- ▶ Provide adequate emergency services resources (land-based crews, boats, helicopters and so on).

- ▶ Provide adequate emergency support resources (food, water, medical supplies and so on) at the evacuation points.

Evacuation routes should:

- ▶ lead to high ground or buildings that are safe from flooding
- ▶ not cross areas that could be flooded, for example areas of low ground
- ▶ avoid bridges and other crossings of watercourses that could be washed away during a flood.

Evacuation is itself a hazardous activity and is unlikely to be risk free, with road traffic incidents, looting and civil unrest all possible consequences. To limit such risks, preferential evacuation routes should be well marked and understood by the public and other stakeholders (for example along raised roadways or purposefully managed clear ways, with limited or no parking, and good signage systems), and access routes for emergency responders should be determined in advance, locating emergency equipment stores. Even with such measures risks can be increased if evacuation is delayed, and takes place after a flood has started to occur. For these and other reasons, in large floodplains widespread evacuation should be avoided as far as possible, and communities should over time learn to 'live with rivers', developing community-based local safe havens and resilience and resistance within the floodplain. When well-structured and planned, however, evacuation has a legitimate role to play as part of a portfolio of measures (Figures 68 and 69).

Figure 68: Communicating the risk and preparing people and businesses to act



Source: New South Wales Government (n.d.).

Figure 69: Preparing for a possible flood – A household preparation plan

1 As the flood approaches

- Advise neighbours and friends

Name	Contact Number
.....
- Move important documents, personal effects, precious photographs and vital medical supplies to a safe and easily accessible place with your emergency flood kit
- Locate your Emergency Flood Kit
- Locate your pets
- Raise items to a higher level

<input type="checkbox"/> Rugs	<input type="checkbox"/> Personal Items
<input type="checkbox"/> Electrical appliances	<input type="checkbox"/> Furniture
<input type="checkbox"/> Computers	<input type="checkbox"/> Sound Systems
<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>
- Secure hazardous items (e.g. gas bottles)

Items
- Dangerous items to move or elevate (e.g. chemicals)

Items
- Install flood proofing devices

Where
- Monitor Bureau of Meteorology forecasts and warnings, listen to ABC 891 radio

2 Immediately before and during the flood

- Switch off electricity at the switchboard

Location of switchboard
- Turn off gas at the meter

Location of meter
- Turn off water at the meter

Location of meter
- Block toilet bowls with a strong plastic bag filled with earth or sand
- Cover drains in showers, baths, laundries etc with a strong plastic bag filled with earth or sand

Drain location
- Shelter in the highest part of the building
- If you evacuate ensure you tell a neighbour or friend where you are going
- Continue to monitor Bureau of Meteorology forecasts and warnings

If we become separated we will meet at:

.....

.....

Never drive, ride or walk in flood water – this is the main cause of death during floods as water may be deeper or faster flowing than you think and contain hidden snags and debris.

FloodSafe

Source: FloodSafe Australia (n.d)..

Planning for evacuation is not the only focus of activity prior to the event. The provision of safe havens, allowing people to stay close (or closer) to their homes and livelihoods in the floodplain, forms an important component of any emergency plan. A safe haven (or refuge) is simply an area or building that is constructed so that it will not flood (in all plausible events), and where people can congregate safely in times of flood. It could consist of an existing building with accommodation above flood level, a raised area of ground or a new

structure. The construction and workmanship must be high-quality and strong enough to resist the flow of flood water that is likely to occur in the area where it is constructed.

A safe haven should normally have an alternative use during normal periods, for example as a local market or community centre. The community should be aware of the purpose of the safe haven (see for example Box 29).

Box 29: Use of dual-purpose safe havens in Bangladesh

Bangladesh, a low-lying delta nation at the foot of the Himalayas, is prone to many natural disasters, especially floods and windstorms, including tornadoes and cyclones. More than 3 million people live in high risk areas along the 400 km coast. In 1991 a cyclone killed more than 138,000 people and left 300,000 homeless. The estimated damage caused by the cyclone was US\$1.8 billion. Following this the government of Bangladesh along with many nongovernmental organizations began a programme of disaster preparedness and management, which included the construction of cyclone shelters in vulnerable coastal areas. Disaster warning systems and evacuation procedures were put in place and some 1200 multi-storey concrete cyclone shelters constructed adjacent to the coast. An example purpose-built shelter is shown below.

Primary school designed for use as a cyclone shelter in Bangladesh

The result of this programme was that when a severe cyclone occurred in 1997, even though the number of homeless reached 1 million, the number of people killed was 111. Thanks in part to these shelters, the death toll in the cyclone that struck in 2007 was less than 4000, demonstrating a great improvement on the

1991 figures. Many of the cyclone shelters, such as the one shown here, are used as primary schools, clinics or mosques on a day-to-day basis.



Source: Japan International Cooperation Agency (JICA), 2004

In addition to community-based safe havens, significant opportunities exist to improve the resistance and resilience of existing buildings – preventing floodwaters entering the building (by using flood gates and the like), strengthening the structure, using materials that are not damaged by flood water, or protecting the building by external means, for example by constructing earth embankments around houses in areas where the depths of flooding are low. Such approaches enable people to stay in their home during floods, and importantly, speed the process of recovery after the flood.

Once it is decided where people will stay during a flood (in their house, a safe haven or an emergency shelter), it is likely that people will have to stay for several days or weeks. This is because of the time it could take before a flood recedes. Buildings where people stay during floods should therefore be equipped with sufficient safe drinking water, food and other essentials (see Box 30).

Box 30: Lessons from Hurricane Katrina, New Orleans – safe havens must be safe for prolonged periods

Immediately following Hurricane Katrina, New Orleans residents who were unable to evacuate gathered at two large facilities that were out of the flood zone, the Super Dome and the Convention Center. While these structures took the people out of harm's way from flooding, a failure on the part of the local authorities to provide adequate food, water and sanitation as well as police protection created unsatisfactory conditions that led to sickness, discontent, and in some cases crime. If a safe haven is established, planning for its use must include provision of those resources necessary to provide a safe and healthy environment for the anticipated duration of the disruption. These matters cannot be left to be dealt with during the event itself.

One of the most serious consequences of flooding is large-scale contamination of drinking water. In such situations water-borne illnesses, usually associated with poor hygiene and sanitation, can affect a large part of the population. Methods of water treatment with chemical sterilization (such as chlorine) or boiling water for human consumption are therefore of primary importance in emergency planning. It is also important to reduce the vulnerability of drinking water supplies and sanitation systems in floods, and restore these basic services as soon as possible after the flood has occurred.

Other issues to be covered in emergency planning include:

- ▶ the provision of food supplies
- ▶ the protection of essential services (including communications and health services)
- ▶ the protection of infrastructure (particularly roads to allow transport of food and other essential supplies)
- ▶ the rescue and protection of animals
- ▶ minimizing crop losses.

BEFORE AND DURING THE EVENT – FLOOD FORECASTING AND WARNING

The purpose of flood forecasting and warning is to provide as much advance notice as possible of an impending flood. It therefore forms a vital component of emergency planning, as implementation of an emergency plan will be triggered by flood warnings.

The main components of flood forecasting and warning systems are:

1. Collection of real-time data and forecasting of the timing and severity of the flood.
2. Interpretation of the forecasts and other flood information to determine flood impacts on particular communities.
3. Preparation of warning messages describing what is happening, predictions of what will happen and the expected impact. These messages could either advise what action should be taken or trigger a particular emergency response in the emergency plan.
4. The communication and dissemination of such messages.
5. Response to the warnings by the agencies involved and communities.
6. Review of the warning system and improvements to the system after flood events.

Flood warnings must be issued to a range of users, for various purposes, and in this respect warnings may have a different character for these different users. These roles include:

- ▶ bringing operational teams and emergency personnel to a state of readiness
- ▶ operation of floodgates and other flood control structures
- ▶ warning the public of the expected timing and magnitude of the flood
- ▶ warning about the likely impacts of the flood, including the areas likely to flood, houses affected, roads affected and so on
- ▶ giving individuals and organizations time to take preparatory action
- ▶ implementation of evacuation and emergency procedures.

It is important that everyone in each community receives the warning so that they are able to respond. As urban areas become more heterogeneous, the challenge of dealing with multiple languages must be addressed. There is a wide range of ways in which messages are disseminated in communities depending on local conditions, including:

- ▶ Media warnings.
- ▶ Sirens.

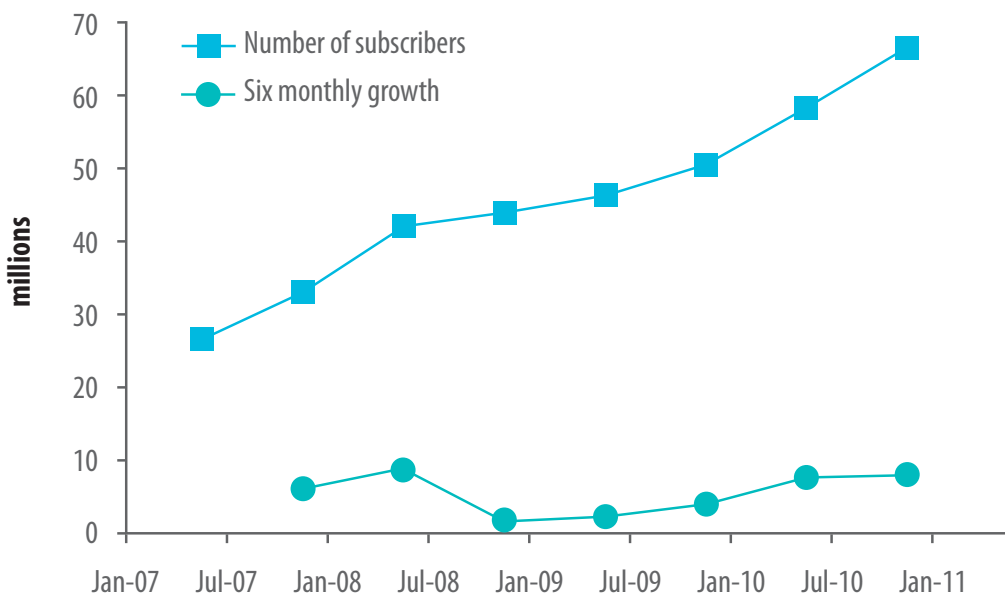
- ▶ Mobile phone and internet alert messages.
- ▶ Warnings delivered to areas by community leaders or emergency services.
- ▶ Information about flooding and flood conditions from communities upstream. One approach to disseminating messages is to pass warning messages from village to village as the flood moves downstream.
- ▶ 'Flood watches', where local people monitor the river level and embankment conditions in the local area. The frequency

of the river and embankment watches should be increased as the flood height increases and approaches, then crosses, the critical danger level.

- ▶ A community-based warning system to pass any information about a coming flood to every family.

The penetration of mobile phones should be used to maximum advantage. Figure 70 shows the growth of mobile phones in Bangladesh over the last few years, showing that even in a poor country, communication systems are growing rapidly.

Figure 70: Mobile phone growth in Bangladesh, 2007–2010



Source: Bangladesh Telecommunication Regulatory Commission.

DURING THE EVENT – RESPONDING TO A FLOOD

The response to a flood begins either when a flood warning is received or, if there is no warning, when flooding first starts to occur. Where an emergency plan exists, this should be implemented. A key decision is whether people evacuate or 'shelter in place' (in either a house or safe haven).

Evacuation requires moving people from their settlement to a safe place. The organization of the evacuation will be set out in the emergency plan. It may be either community led or led by the authorities, for example the police. The objective of evacuation is to get people to safety before the flood arrives wherever possible, as evacuation during a flood is far more hazardous.

Once the decision to evacuate is made, communities must accept the authority of the evacuation organizers. It is generally advisable that evacuees only carry emergency supplies and personal documents (including identification).

Other requirements set out in the emergency plan must also be implemented, including, for example, preparing and opening emergency shelters, arrangements for emergency water supply and sanitation, storage of food, and moving animals to safe areas.

Another aspect of the emergency plan is mobilizing the resources needed to undertake emergency work during a flood, including repairing and maintaining flood protection structures and assisting with the evacuation of people. These arrangements vary from country to country, but there is a requirement for an 'emergency workforce' that is able and trained to undertake these tasks. In national-scale floods armed forces are often called upon for damage control and recovery. Such additional labour power has played a visible role in responding to many major events, for example after the 1991 cyclone flood in Bangladesh, and the 2004 South-East Asian tsunami. Such forces lend themselves to providing support to the mainstream responders, as they have clear operational command structures, logistical capability, strategic stockpiles and mobile clinics – but to be effective they must be included in training exercises. China has well-developed

procedures for mobilizing an emergency workforce, as shown in Box 31.

The emergency workforce should be prepared through progressive stages of alert as warnings are received, culminating in mobilization. The emergency workforce should be organized on a rota basis to facilitate round-the-clock working during the flood emergency. One requirement of an emergency plan is to ensure that plant, equipment, supplies and fuel stocks for the emergency workforce are checked, serviced and replenished before the flood season.

Other relief actions depend on local circumstances. They may include building temporary defences (using sandbags or other materials) and helping vulnerable people to respond to the flood, for example evacuation of the elderly and infirm.

Box 31: Example of a community emergency workforce in China

The Ministry of Civil Affairs, the National Development and Reform Commission, the People's Bank of China and the ministries of finance, water resources, agriculture, transport, health and education have recently united in China to form a powerful disaster relief force. Their teaming-up constitutes China's most dynamic 'emergency squad' whose task is to minimize the losses inflicted upon victims. Recently the Chinese army formally added disaster relief training to its set of compulsory courses. To strengthen the nation's capability to handle emergencies, various disaster relief schemes are currently being mapped out across the country, especially in those regions vulnerable to natural calamities. These include mobilizing communities to make sure major flood defences are not breached.

AFTER THE EVENT – POST-EVENT RESPONSE

The adverse effects of floods do not finish when the flood waters recede. The people and communities affected will feel the effects for many weeks or even months after the flood has occurred, and this needs to be planned for in pre-event emergency planning.

It is clear that floods have an economic impact, through damage to property and infrastructure. What has been less appreciated until recently is the effect that floods have on the health of the people affected. Again, these need to be anticipated and the proper levels of assistance planned and put in place in an efficient way.

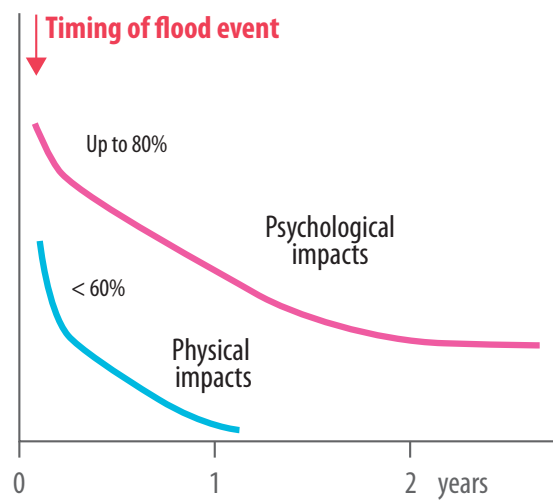
In this way disruption and trauma after an event can be minimized. The issues to be considered are:

- ▶ the awareness that the post-event period is one when the effects of a flood disaster are still being felt
- ▶ that elderly and previously infirm members of the public are likely to be affected most

- the need for health and other related services to be alerted prior to flood events that they may be needed
- ▶ that recovery from these events may take months or even years (Figure 71).

This might not appear at first sight to be part of FRM. However it is an element of seeking to reduce the consequences of floods, and thus rightly sits alongside other measures such as spatial planning to reduce the growth of risk and flood insurance to spread the economic and financial effects of hazardous events away from just those most directly afflicted.

Figure 71: The health effects of flooding in the United Kingdom, showing that some effects last for many years after the flood event



Source: Rowsell et al. (2010).

That this effort to reduce this risk involves health authorities, hospitals, doctors, clinics, ambulance services and other social services just illustrates the complexity of genuine FRM compared with the relative simplicity of flood defence.

11.4 Understanding the cascade of risks

Numerous flood events have highlighted the highly interconnected and mutually dependent nature of risks (Figure 72). In this context of a highly interdependent system, what happens to one infrastructure, such as a water or power supply for example, can directly and indirectly cascade risk, and often escalate the risk, across large geographic regions. It is likely to send ripples throughout the national and global economy (Rinaldi et al., 2001). If an understanding is developed of these critical interactions and interdependences (where risks are cascaded through primary, secondary and tertiary

connections), appropriate levels of redundancy of service can be utilized to promote resilience (for instance, utilizing multiple power suppliers from independent sources). Without an understanding of these critical connections, communities, nations and potentially multiple nations can be left exposed to risks that are disproportionate to the severity of the initial natural hazard event.

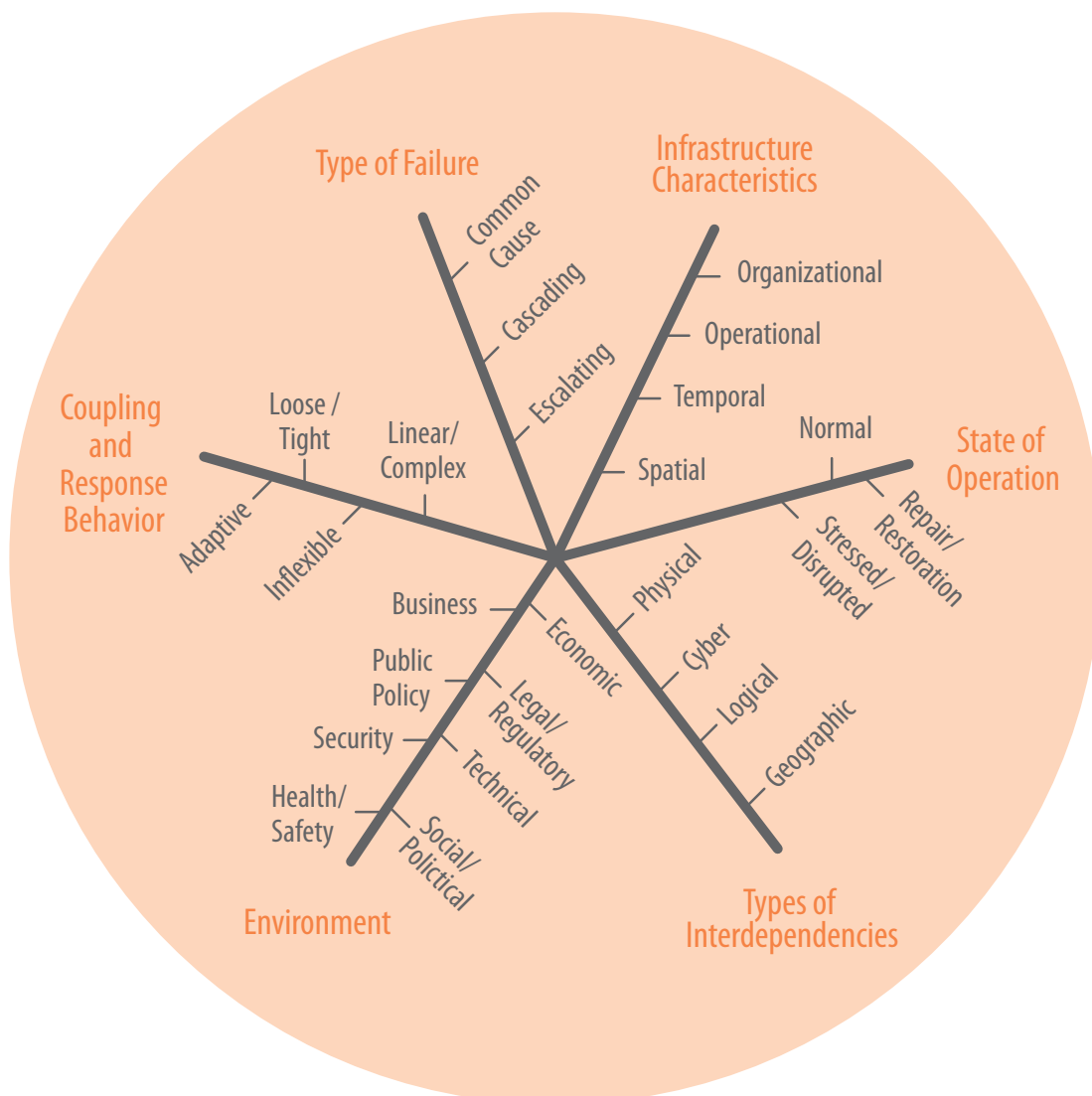
Three broad classes of infrastructure interactions can be described (based on Little, 2002), and each must be considered when establishing a system understanding:

- ▶ **Cascading risk:** a disruption in one infrastructure causes a disruption in a second infrastructure, or disruption to one aspect of the supply chain can have impacts to reliant business up and down the change (with potentially global reach). Such

cascading risks can, on occasion, have a greater impact than the initial floodwater. For example, access to safe drinking water and sanitation after the flood is vital. In some places (like Bangladesh) many flood-related casualties are caused by diarrhoea after evacuation, rather than drowning.

- ▶ **Escalating risk:** a disruption in one infrastructure, or to one element of the supply chain, exacerbates disruption to another.
- ▶ **Coherent risks:** a disruption of two or more infrastructures at the same time because of a common cause (the infrastructure might be directly affected by the initiating natural disaster for example, or indirectly affected because the infrastructure where reliant on the same, failed, supply chain).

Figure 72: Dimensions for describing infrastructure interdependencies



Source: Rinaldi et al. (2001).

11.5 Modelling approaches and tools

Various qualitative and quantitative tools are available to marshal our understanding regarding the potential interactions in complex infrastructure systems. Often presented in diagrammatic or table form, such methods can be useful for analysing actual events, exploring the likely outcomes of potential 'what-if' scenarios, tracing the cascade of failures through to a final outcome (Figure 73) or marshalling high-level trade-off decisions. Such methods do however offer limited predictive capability.

Quantified modelling of the evacuation process can identify bottlenecks in the system before they are experienced in real life, and explore the options, and potential what-if scenarios, for evacuation: the impact of road closures as a result of flooding, the impact of phased evacuation on traffic loading, and many other possible consequences of an evacuation event. If used correctly, such models can help establish appropriate evacuation policies, strategies and contingency plans, and can help facilitate communication and information transfer.

Conditions in a disaster-affected region tend to be chaotic. Communication is difficult and command structures can break down because of logistical or communications failure. Human behaviour during the emergency is hard to control and predict. Through the modelling process (both qualitative and quantitative) the following can be improved (Lumbroso et al., 2008):

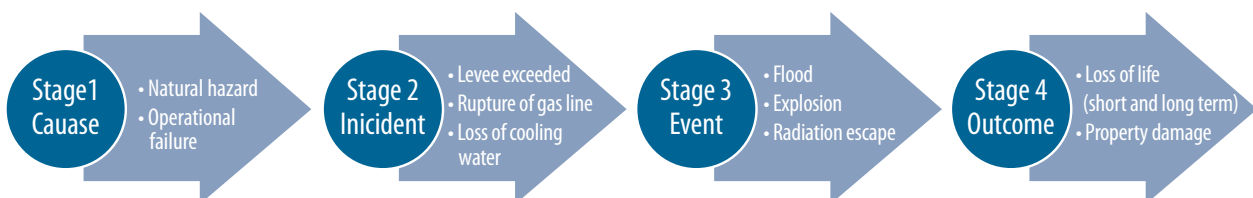
- ▶ understanding of the social side of emergency management processes
- ▶ communication between the population affected by the disaster and emergency management authorities
- ▶ preparedness through simulation, or investigation of what-if scenarios.

Different types of evacuation model are used at different scales:

- ▶ **Micro:** at this scale each individual receptor at risk (such as a person, vehicle or property) is modelled and there is a detailed representation of the evacuation routes. A complex modelling system (such as an agent-based model) is often used to estimate the evacuation times for each individual receptor.
- ▶ **Meso:** this scale is between a micro and macro scale. In meso models the receptors are lumped together. The evacuation time is estimated by assessing the demand for and the capacity of the evacuation routes, which are evaluated on a geographical basis.
- ▶ **Macro:** in a macro model the receptors are lumped together. The estimates of the evacuation times are based purely on the distance to the exit of the at-risk area, the capacity of the route and the average evacuation speed. A macro-scale model is often used to provide an initial estimate of the evacuation time for a large area. (for instance, on a regional scale).

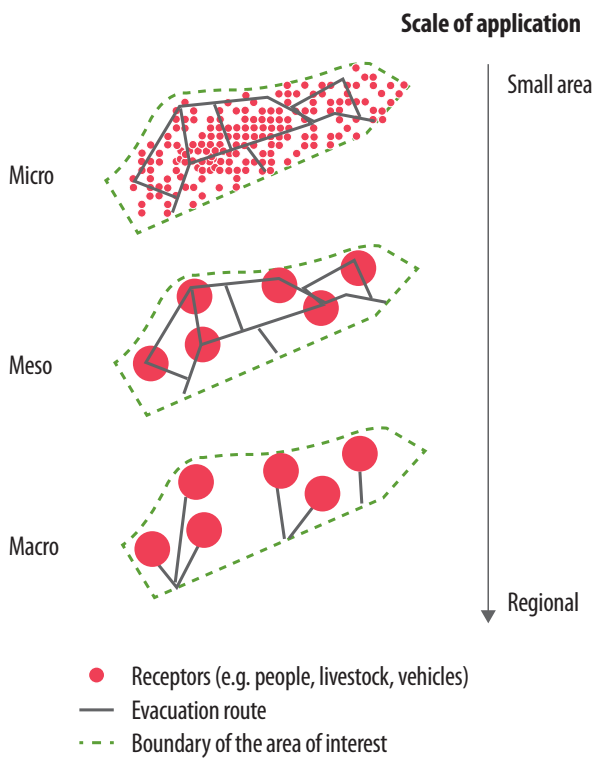
The distinction between micro, meso and macro-scale evacuation models and the typical scales at which they are applied are shown in Figure 74. The type of evacuation model that is appropriate for a particular flood risk area will depend on the level of risk and the processes which the evacuation modelling is seeking to inform. A densely populated urban area where the scale of potential evacuation is large may require a detailed simulation model where the traffic and flood hazard is modelled in a truly dynamic way. An understanding of the level of congestion delay that is inevitable under even the most effective traffic management schemes, and also the level of spontaneous evacuation that may occur in advance of an official evacuation warning are other issues that need addressing.

Figure 73: A qualitative model for depicting the linked relationships between hazards and their ultimate outcomes



Source: adapted from Baisuck and Wallace (1979).

Figure 74: Micro, meso and macro-scale evacuation models with the suggested scale of their application.



Source: Lumbroso et al., (2008).

To realistically simulate a major population evacuation, at any scale, appropriately resolved information is required on:

- ▶ the transportation infrastructure, most usually the road network and also pedestrian routes where applicable
- ▶ the spatial distribution of population, by time of day and type of activity
- ▶ vehicle usage during an emergency of the type under consideration
- ▶ the timing of people's response to the emergency, and how this timing varies by a person's location and activity at the time they find out about the threat
- ▶ evacuee route and destination selection behaviour
- ▶ traffic management controls (if any) incorporated in the evacuation plan
- ▶ nonevacuation-based protective actions (if any) taken by significant population subgroups in the area at risk
- ▶ the flood hazard in terms of extent and sometimes in terms of the spatiotemporal variability of the depth and velocity.

An increasingly effective way to investigate complex adaptive systems at all of these scales is to view them as populations of interacting agents. Agent-based modelling is becoming well established as a method for simulating complex adaptive systems: that is, those with many actors (agents) whose

behaviour both adapts to, and influences, emerging conditions. Agent-based models do not attempt to predict the outcome of decisions but rather aim to reveal the emergent properties of a complex system – enabling the most vulnerable and least resilient aspects of the system to be identified, and showing how these change with different decisions.

Agent-based methods are becoming commonplace in emergency evacuation planning (Dawson et al., 2011) – at least at a micro and meso scale – and model interactions between critical infrastructures, the organizations that manage them and the individual and communities that rely upon them (Little, 2005). Such methods, although still relatively immature, have significant potential to help make sense of the complex interactions and cascades of risk that exist at a range of scales in developing resilient communities.

11.6 A summary – reducing flood disasters through good emergency management

More specifically some key ingredients of effective emergency management, almost irrespective of the nature of the risk and the floods events that occur, are:

- ▶ good and clear arrangements for who is **responsible** for what
- ▶ adequate **legal powers** to intervene
- ▶ good agreed systems for **decision-making and prioritization** of effort during all the phases of preparation, response and recovery
- ▶ good **training** for those involved in emergency management
- ▶ good **communication** systems for those involved in rescue and recovery phases
- ▶ good management of the **media**, so that accurate pictures of the flood event are portrayed
- ▶ good logistics:
 - transport
 - equipment
 - materials (from as basic as sandbags to sophisticated demountables)
 - foodstuffs
 - shelter
 - recovery materials
- ▶ adequate power supplies and backups (otherwise nothing else works).

CHAPTER 12

FLOOD HAZARD AND RISK MAPPING

12.1 Introduction

The development and provision of flood hazard and flood risk maps has a vital role in FRM, and these maps provide a fundamental building block upon which good decisions can be made. Some of the experiences of developing maps around the world are discussed below.

12.2 The role of mapping and uses of maps

A prerequisite for effective and efficient FRM is an appropriate level of knowledge of the prevailing hazards and risks. In recent years flood maps have increasingly been used as a vehicle to support a wide range of stakeholders as well as FRM professionals. The primary uses of such maps are briefly summarized below.

AWARENESS RAISING

Flood maps can increase public awareness of the areas at risk from flooding. To be effective, the public must believe the maps to be accurate, have a clear understanding of their content and have ready access to them.

SPATIAL PLANNING

Flood maps can differentiate the spatial distribution of risk within the floodplain to support spatial planning decisions. To be effective, the evidence present in the flood maps (present day and future) must go hand-in hand with spatial planning processes (Figure 75). In the majority of the world planning guidance goes alongside the publication of flood maps. Typically, the guidance places an onus on the planning authorities to consider flooding, but does not demand the cessation of development (although it often requires 'risk neutral' development) in floodplains. Some exceptions to this exist, for example in Northern Ireland, where development is prohibited in the most flood-prone areas. This lack of strong linkage between the flood map and development is perhaps at the heart of the difficulties flood risk managers face today, and underlies the reason why, within both the developed and developing world, flood events have often become flood disasters. 'The most effective FRM strategy is damage prevention by spatial planning' (Hooijer et al., 2004; Evans et al., 2004a, 2004b).

Figure 75: Naga, Philippines: spatial variation in flood depth is used to zone development in the floodplain



Source: Tennakoon (2004).

ASSET MANAGEMENT (OF FOR INSTANCE LEVEES, DYKES AND SLUICES)

Flood maps help in prioritizing, justifying and targeting investments, in order to manage and reduce risk to people, property and the environment.

EMERGENCY AND EVACUATION PLANNING

Flood maps help in:

- ▶ informing the local risk assessment process
- ▶ encouraging professional emergency responders (police, army, fire, ambulance) to focus on 'vulnerable' sites and assets in the floodplain, and determine whether specific mitigation actions are needed to reduce the potential impacts should a flood occur
- ▶ improving the planning and prioritization of effort (location of emergency shelters and equipment) to better mitigate the potential impacts during times flood
- ▶ supporting realistic training exercises.

INSURANCE

Flood maps underpin flood insurance, and provide a critical link between state and private-sector insurers. They are often used by insurers to set premiums and to support high-level agreements between the state and insurers regarding the ongoing viability

of private insurance. For example, in England and Wales an agreement between the government and the Association of British Insurers (ABI) provides a statement of principles, noting that flood insurance will continue to be made available to all those in the floodplain on the assumption that the government will continue to invest to reduce flood risk. In this case, year-on-year comparison of the flood map provides a vehicle by which government performance can be judged. In the United States, the flood maps are actually flood insurance rate maps, and provide fundamental information on the rate zones.

DATA REQUIREMENTS AND MANAGEMENT

The credibility of any flood map is conditioned by the data on which it is based. Data collection is expensive. Therefore a key principle of good data management (not always applied in practice) is to maintain the ownership of the data used (and the responsibility for its quality and the issue of updates) with those organizations best able to manage and maintain those datasets. This has significant cost advantages and promotes the concept of 'collect once, use many times' across all government and private organizations with an interest in environmental management (one aspect of which is flood management). This does mean sharing of sensitive information that could provide a commercial advantage, but collaborative working between organizations is a prerequisite for successful implementation of FRM. A recent study by the US National Academies pointed out that investment in high-resolution topographic data provides a greater return than investments in better hydrology or hydraulic information.

Delineation of flood zones is greatly improved with high-resolution topographic data.

COMMUNICATION OF RISK

Many countries throughout the world support public publication and active dissemination of flood maps. There is however considerable debate about the detail provided and to whom (for instance individuals, organizations, planners and flood risk managers) the maps should be made available. The language used to communicate hazard, probability, risk and uncertainty remains a topic of some debate – ranging from continued use of return periods, annual probabilities of occurrence, lifetime (or as in the United States mortgage life) encounter probability or frequency. No consensus yet exists and there is unlikely to be one in the near future. It is however clear that the descriptions must be meaningful and unambiguous to the targeted user of the map (a goal that is not always easy to achieve).

One flood professional commented, 'There wasn't any standard approach in the mapping or in defining the floodplain. And to be honest maps weren't much bloody good to anybody, because the science underpinning the maps was variable in its conception and application' (Peter Bye, chairperson, Easter 1999 UK flood review team).

12.3 Analysis techniques supporting flood risk maps

HAZARD MAPPING

There are a number of options that can be used to map flood hazard at a national level. These include (but are but no means limited to) the following:

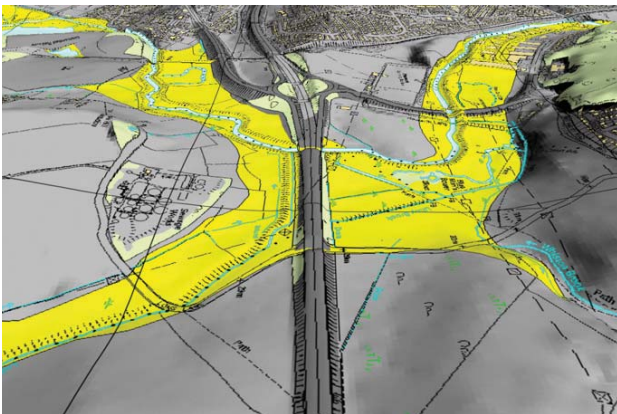
- ▶ geological and geomorphic evidence
- ▶ recent historical floods
- ▶ aerial photography
- ▶ satellite imagery
- ▶ hydraulic modelling.

Each of the main approaches is briefly described below.

Geological and geomorphic evidence

Soil maps can provide information on soil series associated with river, lake, wetland and tidal deposition. They can be useful in determining the historic floodplain at geological timescales but do not provide any indication of event probability. Raised beaches provide an example of how soil data can mislead, as these were created by isostatic uplift and may be several metres above any current flood risk. Other than being indicative of fluvial or tidal influence at some time in the past, soil maps cannot provide all the information required for the assessment of flood risk (see for example Figures 76 and 77).

Figure 76: Local-scale geological and geomorphic mapping of flood hazard for the River Rother, UK



Source: British Geological Survey.



Figure 77: Geomorphic evidence can provide an invaluable source of data particularly in remote ungauged systems



Source: Courtesy Paul Sayers taken in the Himalaya, 1996

Use of information on recent historical floods

Historical flood information from major flood events in the past can be used to produce flood hazard maps. The information may take the form of approximate flood extents for small areas (for example, parts of settlements known to have been flooded) or flood extent maps produced after the occurrence of a flood for most if not all of the affected area. Where historical flood information is used, it is normal practice to plot all available information on maps to try to obtain a first estimate of the overall national position.

A major deficiency of such mapping is that the information is often difficult to find and only covers parts of the country. The resulting flood maps are therefore incomplete. However they might show areas that have flooded in the main settlements

and therefore provide information on the main flood risk areas. A further problem is that the data rarely identifies the flood frequency associated with a flood event. Nevertheless such event mapping can assist in identifying flood-prone areas.

Historical event reconstruction: where major floods have occurred within living memory, residents in the periphery of the affected area provide useful information which helps planners to understand peak levels – for example in their homes or other fixed structures.

Looking to the future, data collated through Twitter and Facebook could be used to reconstruct flood events – using GPS-positioned photographs from mobile photos, mobile phone tracking of movements and even simple tweets.

Aerial photography

If a historical flood was particularly large and of sufficient duration to permit mobilization of aircraft, aerial photographs might have been taken by for example a river management organization or news organization. This will provide reliable information on areas that were flooded when the photograph was taken, although the magnitude of the flood (expressed in terms of probability of occurrence) might not be known. It is also difficult to capture the flood at its peak throughout a

catchment using aerial photography. In heavily forested areas it is often difficult to establish the edge of the flood extent.

Aerial photographs can be used to determine the floodplain extent. A particular problem with aerial photography is that there is often no central repository of aerial photographs, and sources are likely to be many and widespread. It can therefore be a time-consuming process to produce flood hazard maps from aerial photographs (Figure 78). An aerial photograph of flooding in Pakistan is shown in Figure 78.

Figure 78: Aerial photograph can be used as the basis for mapping Flooding in Pakistan



Source: UNICEF/mogwanja.

Satellite imagery

In many parts of the world synthetic aperture radar (SAR) has proved to be the ideal source for regional flood mapping. The resolution of the SAR image provides a dataset which can be handled with reasonable ease, and it can provide sufficient vertical and horizontal detail for most national flood mapping project requirements.

Microwave and optical satellite imaging of selected river reaches can be used to detect flood conditions. Satellite imagery will usually allow national flood maps to be produced at a scale of 1:250,000. Remote sensing methods based on optical, medium-resolution imagery such as LandsAT and the French Satellite Pour l'Observation du Terre (SPOT), are limited in their applicability. This is because they depend on cloud-free conditions and are relatively expensive. These remote sensing methods will also not penetrate flooded areas under canopies formed by trees. There is also a temporal limitation. For example the Landsat satellite only returns over any given location once every sixteen days. In a flood, when clouds frequently obscure the ground surface for several days at a time, this temporal limitation often impedes acquisition of adequate imagery for flood extent analysis.

Flooding in Sukkur in northern Sindh



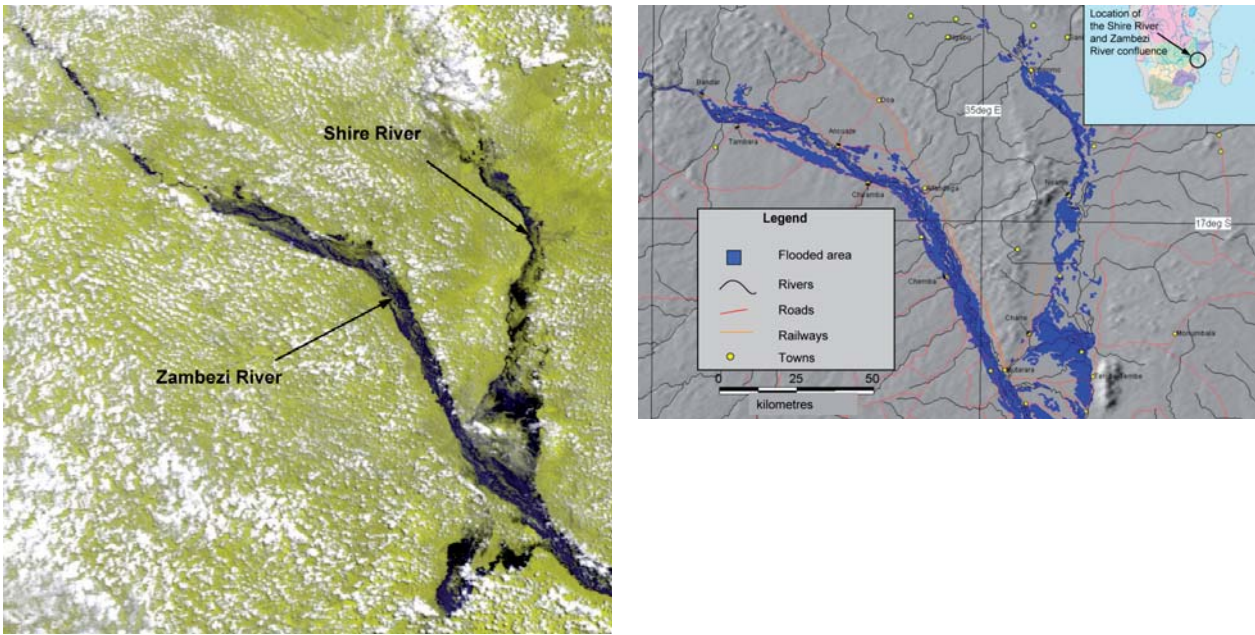
Source: DFID.

Figure 79 shows a satellite image of the Zambezi valley for a flood in 2001, and the flood map produced from it.

Flood maps can also be developed using satellite radar data. SAR can be used to acquire high-resolution large-scale images of the earth's surface (Figure 80). The advantages of a SAR device are that they can operate in all weather conditions during the day and night circles of an orbit. As well as estimating the extent of actual floods, SAR can also be used to produce digital terrain models (DTM) of large areas. These DTMs can be combined with information on flood levels to produce flood extents. It should be noted that DTMs produced by satellite-mounted SARs generally have a low vertical resolution of the order of ± 10 m. A SAR can be mounted on an aircraft and a DTM of a large area can be produced fairly rapidly with a good vertical resolution (for example ± 0.5 m). In the United Kingdom, airborne SAR has shown to be practicable in processing over 200,000 km² of terrain data, including 90,000 km of river and to produce realistic national floodplain maps.

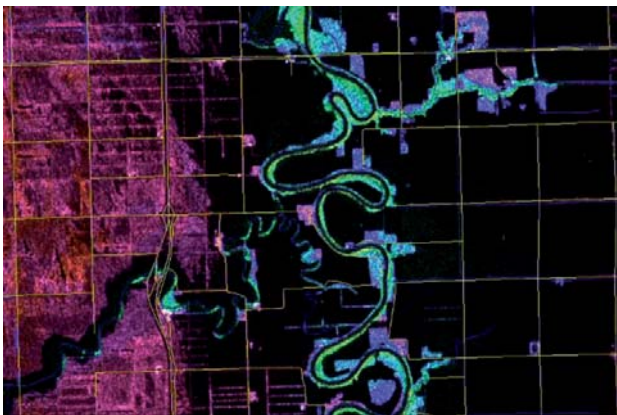
Ground truthing is always required, to distinguish between a few millimetres of inundation (for example caused by trivial local rainfall) or other anomalies and a real flood situation.

Figure 79: Use of satellite imagery: left, the Zambezi and Shire rivers in flood on 25 February 2001, and right, the flood map produced from these images.



Source: Dartmouth (2004).

Figure 80: Image produced from synthetic aperture radar (SAR) of flooding on the Red River in the USA



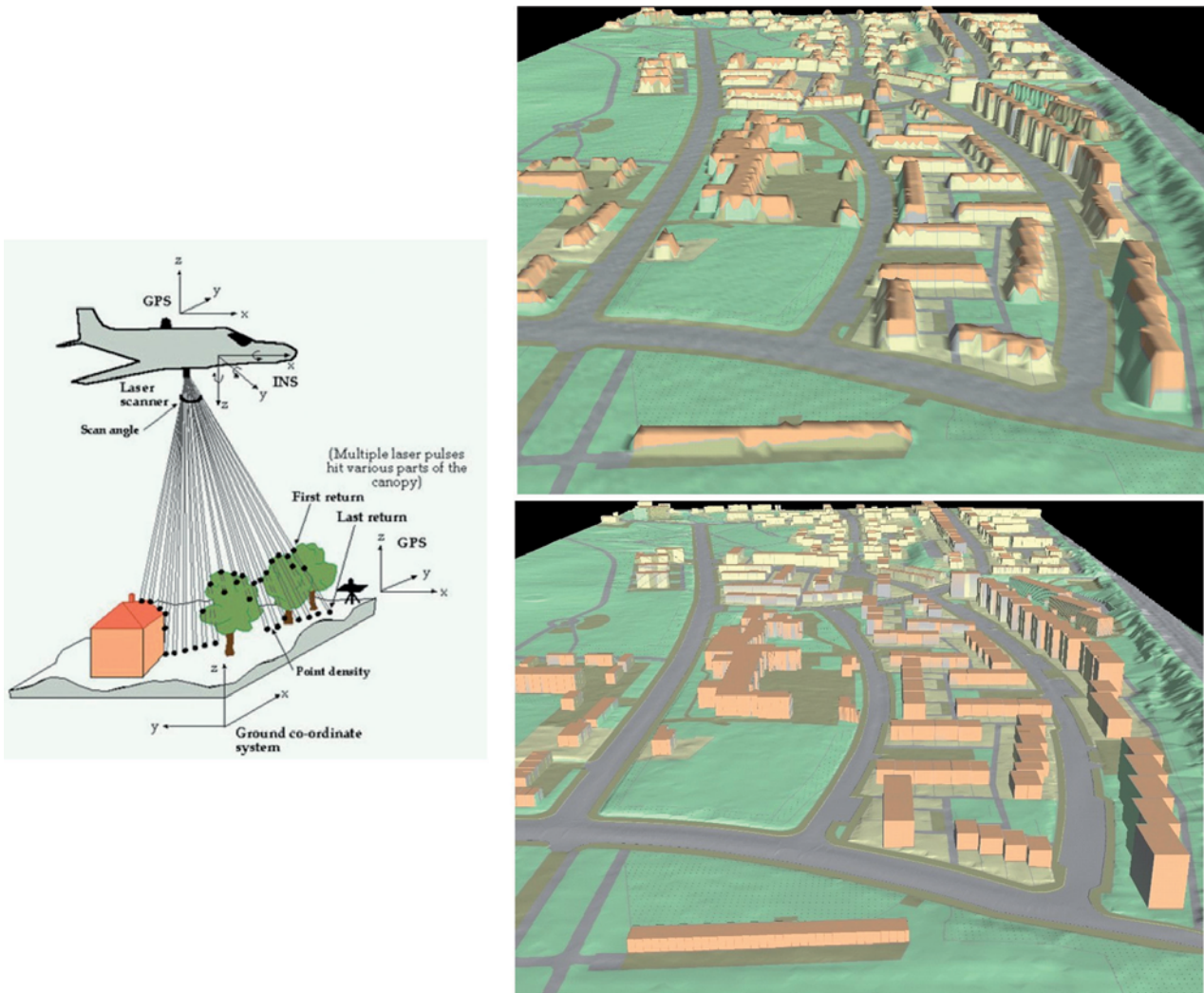
Source: DFID (2005).

HYDRAULIC MODELLING METHODS AND DETAILED DATA

A myriad of hydraulic modelling methods exist (including one-dimensional (1D), quasi-2D, 3D, and coupled above and below-ground models). If they are correctly used and well calibrated, state-of-the-art hydraulic models are capable of representing hydraulic flows and flood processes well. Allied with detailed topographic data (Figure 81), the increase in computation

speed now means such models are able to provide accurate results relatively quickly over large areas. In the context of hazard mapping such models are typically used assuming an absence of flood control infrastructure, and provide an estimate of the flood plain that would exist in the absence of such defences. As discussed in the next section, when allied to probabilistic models of the infrastructure performance, hydraulic models are needed to develop flood probability maps.

Figure 81: Developments in surface topography mapping mean it is possible to produce reasonably accurate flood mapping using hydraulic models from the coarse (GIS-based) through to hydrodynamic models



Source: Flood Risk Management Research Consortium (www.floodrisk.org.uk).

PROBABILITY MAPPING

Mapping probability requires an assessment of all plausible means by which a given location in the floodplain might be flooded. This involves consideration of:

- ▶ a range of source loading conditions (flows, sea levels and so on)
- ▶ the 'true' performance of the flood management assets – levees, culverts, barriers, sluices and so on
- ▶ the possibility of failure of these assets
- ▶ the volume of water entering the floodplain in the event of failure or overwhelming of the levees
- ▶ the propagation of the flood waters across the floodplain.

Only through consideration of the whole-system behaviour can the probability of inundation be robustly established. The

information derived from such maps is considerably more powerful than traditional flood hazard or historical maps, as they seek to reflect the actual chance of an area flooding, taking into account the performance of the infrastructure in place to manage the flood.

12.4 Example mapping – hazard, probability, risk and uncertainty maps

Flood hazard, probability and risk mapping are quite different, and all are in current use around the world. Associated with good communication, all play an active and central role to play in FRM. To be useful however, flood maps must clearly

describe and communicate information on flooding to a wide range of stakeholders, for the range of uses described above. Although this might seem obvious, it is perhaps the single largest challenge, and various organizations have implemented mapping strategies (with varying degrees of success – see for example Sayers and Calvert, 2007). Some example maps are discussed below.

HAZARD MAPPING (THE UNDEFENDED FLOODPLAIN)

This maps the nature and extent of the undefended floodplain (that is, the natural floodplain that would exist in the absence of any management activity). This type of flood map has been used around the world for many years (examples are the Environment Agency indicative flood maps in England and Wales, flood insurance maps in the United States, and major river maps in Hungary since 1977). They provide an upper bound on the potential flood hazards. Dissemination is increasingly provided through web services (with limits on resolution) as shown in Figure 82.

Figure 82: Example of an undefended flood hazard map for the 1:100 year fluvial flow event as publicly disseminated through a web service in Scotland

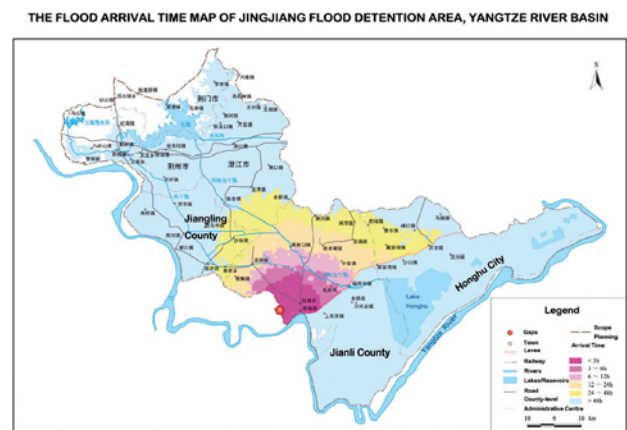


Source: www.SEPA.org, based on the methods outlined in McGahey et al. (2006).

RESIDUAL FLOOD PROBABILITY (FLOOD PROBABILITY)

The performance of flood control assets (levees, sluices and so on) can have a profound influence on the spatial variation in the residual flood probability. Residual probability maps have been made available in a number of countries, but often these simply superimpose those areas benefiting from defences onto existing maps. In England and Wales more advanced methods are applied to analyse and map the residual probability of flooding to a range of depths and at a national scale (e.g. Hall et al, 2003, Gouldby et al, 2008). On occasion predefined failure scenarios are used to explore the likely inundation areas (for example see Figure 83).

Figure 83: Likely duration of flooding within the detention areas in the Jingjiang detention basin, China



Source: GIWP.

THE PRESENT AND FUTURE FLOOD RISK (FLOOD RISK)

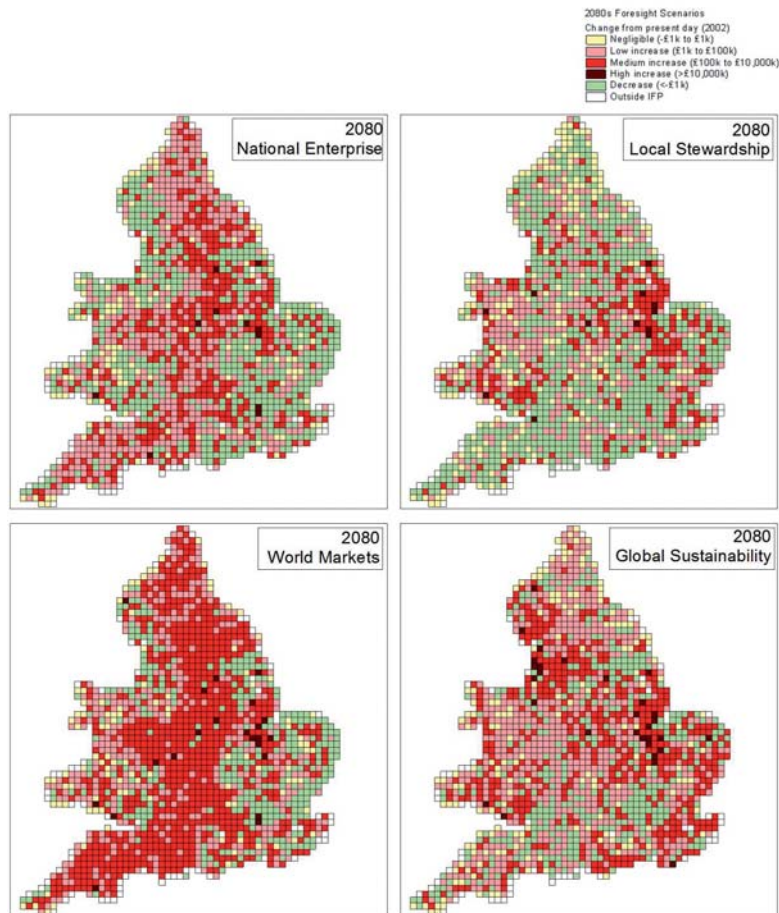
Flood risk maps include both the probability (taking account of the performance of the intervening system, including levees and other defences where they exist) and the consequences of flooding (for people, property and the environment). They perhaps have limited additional relevance to an individual (where the consequence of flooding is influenced by their own action) but they provide a powerful and compelling contribution to the flood risk manager on the scale and location of flood risk. In mapping flood risk is important to understand that it is dynamic in time, and therefore flood risk maps are often produced at different time horizons, such as the present day, thirty years into the future (circa the 2040s), and 100 years into the future (circa the 2100s). The future flood maps take account of climate change and provide readily accessible evidence on the potential change in flood risk, helping flood managers and planners to promote a sustainable approach to FRM. An example of this type of mapping taken from the UK Foresight Programme is shown in Figure 84.

Similar approaches are currently being developed in association with the Institute of Water and Hydraulic Research, Taihu Basin Authority and an expert team from the United Kingdom including HR Wallingford and a number of leading flood risk organizations.

The flood hazard is now well recognized as a function of flood depth, the velocity and the nature of the debris the water might

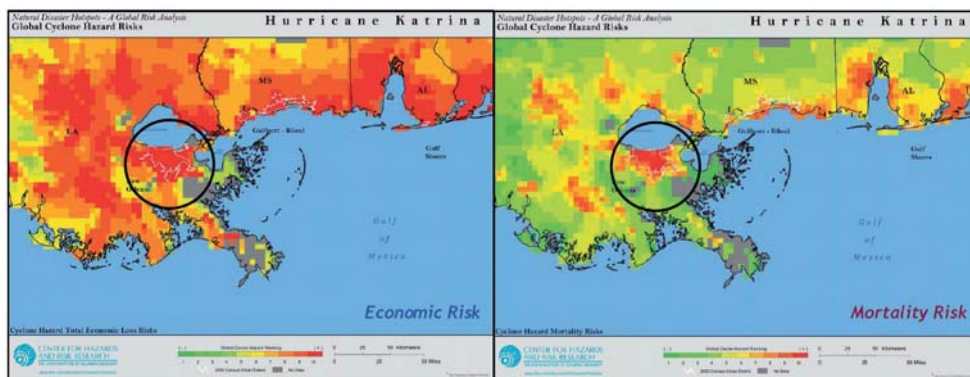
carry. A model of a simple relationship between the characteristics of the flood and the potential risk to life has been developed in various countries and used to underpin potential loss of life hazard mapping (Table 21). An example of this relationship is shown in Figure 85, and Figure 86 is an example of this kind of mapping from the United States using local methods.

Figure 84: Future flood risk mapped a national scale using the RASP methods as part of the Foresight studies: left, a World Markets future of uncontrolled development and high climate emissions, and right, a Global Sustainability future with greater development control and environmental regulation



Source: Office of Science and Technology, UK; Evans et al. (2004a, 2004b).

Figure 85: Example of regional risk maps, USA



Source: Center for Hazard and Risk Research, Columbia University.

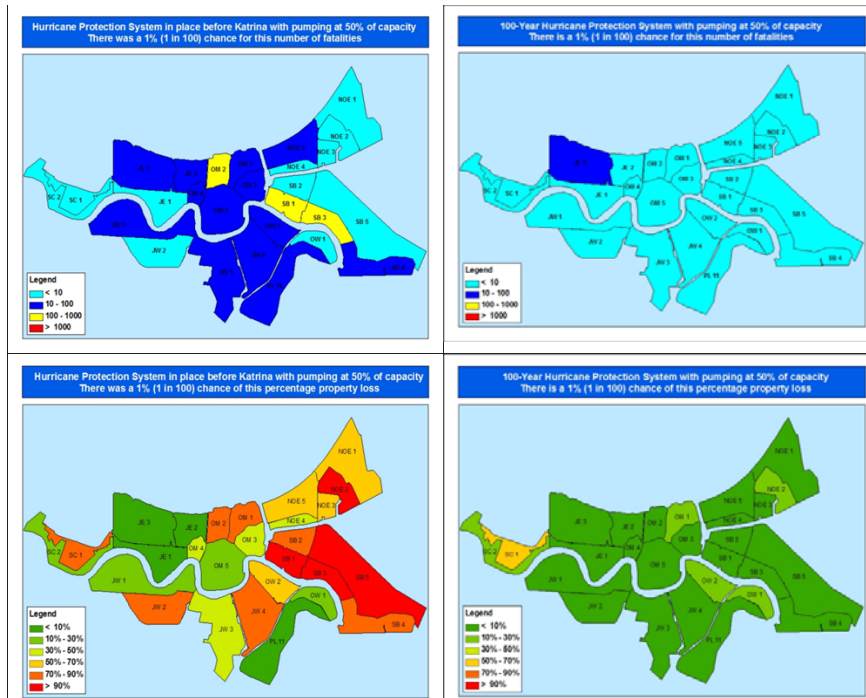
Table 21: Hazard ratings for the danger to life

d*(V+0.5)+DF velocity	Depth	20.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25		
0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50		
1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75		
1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00		
2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25		
2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50		
3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75		
3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00		
4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25		
4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50		
5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75		

Class 1	From	to	Danger for some	Class 2	1.50	2.50	Danger for most
	0.75	1.50		Class 3	2.50	20.00	Danger for all

Source: Defra (2003).

Figure 86: Example of loss of life and property risk maps from New Orleans



Source: USACE.

HISTORICAL FLOOD EVENT (HISTORICAL FLOOD MAPS)

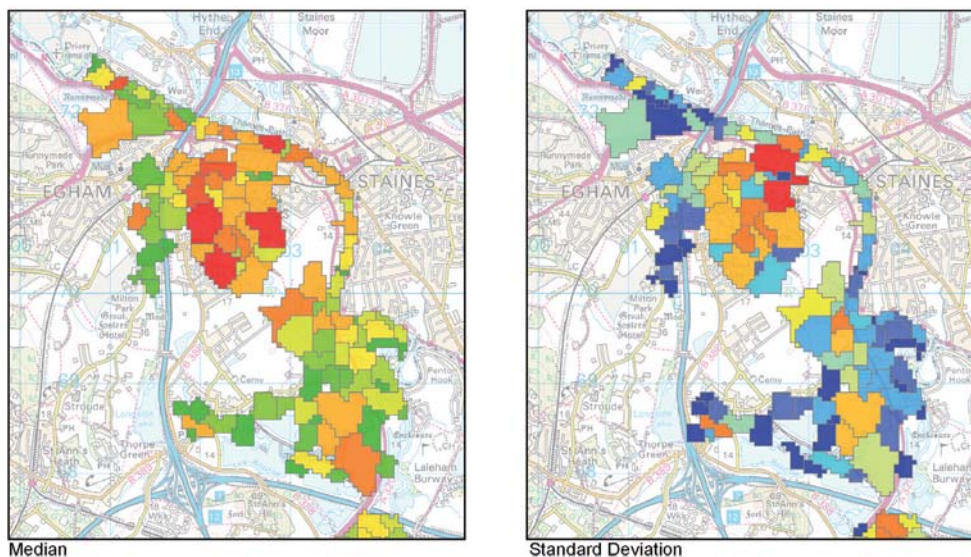
These indicate the depth and extent of flood events that have occurred in the past, (Developing confidence in the evidence present in the mapping is vital to promote uptake). Although information on past flood events is available, it is only in recent years that it has been collected and disseminated in an easy to access and detailed manner. There can be secrecy around the causes of flooding, particularly when control structures fail and blame might be apportioned, and this tends to undermine public confidence. This situation is changing, and now basic historical flood outlines are available. For example, post-event mapping of Hurricane Katrina in New Orleans is available from the US Geological Survey and the Rivers Agency in Northern Ireland highlight areas that have been flooded as part of their Historical Flood Map (available online). Although historically accurate however, such maps can give a false impression of

present-day hazard areas (due to changes in defenses or climate for example) and it should be recognized that do not necessarily provide a guide to future flooding.

MAPPING UNCERTAINTY IN THE FLOOD ESTIMATES

Flood modelling is not an exact science, so consequently there will be a degree of uncertainty in the flood mapping output. For example the data underpinning the maps will vary in quality; and it is not possible or cost-effective to seek to establish the same level of data accuracy in all areas. Data collection and model improvement need to be targeted based on the level of risk and the impact of the uncertainty on the estimate of risk. Uncertainty can be a difficult concept to convey meaningfully, and various approaches for its representation in the map products have been developed in recent times (see Figure 87).

Figure 87: Example maps showing a representation of uncertainty

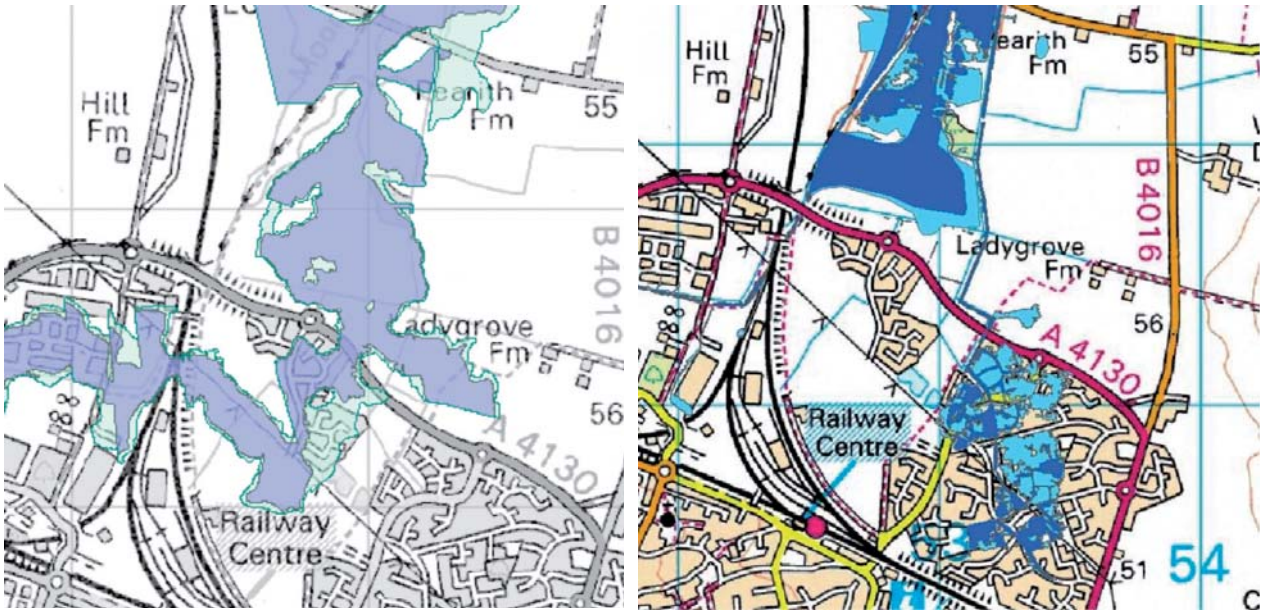


Left –The median estimate of the expected annual damage (EAD)

Right – the confidence in the estimate of risk expressed by plotting the standard deviation in the estimate of EAD

Source: Environment Agency, (2009d).

Figure 88: Changing flood maps in time.



Two maps of the same small areas, left, as known in June, 2005, and right, as remodelled in March 2007. All maps are dynamic and will change as data and the supporting modelling methods improve. This process of change needs to be managed.

Source: Environment Agency, UK.

MAPPING ALL SOURCES OF FLOODING

Flooding can be driven by a range of sources. The person flooded typically cares little about the source of flooding but simply recognizes that they are flooded. For the flood risk manager however understanding the source of flooding is fundamental to understanding how best to manage it. In Europe, North America and elsewhere there is a move towards mapping all sources of flooding. The focus of effort reflects the recent experience of flooding. For example pluvial flooding in urban areas has been the subject of significant mapping effort since the pluvial floods in the United Kingdom in 2007, tsunami mapping has received significant attention in Asia, and cyclone mapping in the United States has followed the devastating flood events there. Communicating these different forms of flooding to the public remains a challenge. Very little has been done to

map the joint probability of floods from multiple sources (such as riverine floods, pluvial floods and hurricane surges). This is an evolving science.

12.6 A summary – good practice guide to useful hazard and risk maps

A number of lessons can be drawn from past and emerging good practice in flood hazard and flood risk mapping. The development of useful well-founded and well-understood maps relies on a number of key principles. These are summarized in Table 22.

Table 22: Good practice principles for flood hazard and risk mapping

Description	
1	<p>What to map?</p> <p>It is important to be clear on what is to be mapped and why,</p> <p>Historical events</p> <p>Predicted hazards (depth, velocity, rate of rise, duration, contamination/debris)</p> <p>or</p> <p>Predicted risks (expected property damages, expected loss of life, specific event losses etc).</p> <p>Uncertainty and confidence</p>
2	<p>What source of flooding?</p> <p>Fluvial, sea, pluvial and groundwater are all sources of flooding.</p>
3	<p>Describing the map</p> <p>Historical maps: are they based on geological evidence or topography/hydrological and hydraulic analysis?</p> <p>Present-day maps: are the defences (levees, pumps, barriers etc). assumed to work to rule, ignored or has the probability of failure (of one or more defences) being included?</p> <p>Future maps: how has climate change been represented? What assumptions have been made about management practice or demographic change?</p>
5	<p>What confidence can be given to the mapped output?</p> <p>What is the expected accuracy of the mapping – in terms of both extent, depth and velocity – taking account of data, model and model structure uncertainties?</p>
6	<p>How should they be used?</p> <p>This will aid decision on scale (national, regional or local) and the method of dissemination</p>

Lesson from practice: Maps are a vital part of flood risk management but no one map is fit for all purposes!

CHAPTER 13

FLASH FLOODS – MANAGING THE RISKS

About the only thing floods have in common is water. They can be caused by rainfall, snowmelt, structural failures or ice jams. They can occur over days or in minutes, and take place in remote rural areas or in the middle of large cities.

Paraphrased from Susquehanna River Commission

13.1 Introduction

Flash floods represent a unique subset in the range of flood hazards. Flash floods rise quickly, frequently with limited or no warning, and giving rise to fast-moving and rapidly rising waters with enough force to destroy property and take lives. Flash floods are the most deadly of floods, and worldwide are responsible for the largest number of flood-related deaths and high flood mortality rates (Jonkman, 2005). Although mitigation of flash floods risks is difficult, it is not impossible. This chapter describes the flash flood threat and steps that can be taken to reduce the risks from such floods.

As with all effective efforts to reduce risk, flash FRM must account for the hazards as well as changes that are occurring to those hazards (climate and demographic) and the potential interventions (engineered structures and nonstructural responses) that may reduce present and future consequences of such floods.

13.2 Drivers of flash floods

Flash floods typically result from intense rainfall over a short period of time in a limited area. The intensity of the rainfall reduces the ability of the land to absorb the precipitation, and increases the runoff into streams and rivers, resulting in rapid rise of the stream or river level (stage). Flows in one river may join other rivers in the region affected by the same meteorological event, adding to the rapid rise. In mountainous areas where topography causes the rainfall to accumulate rapidly in valleys and canyons, the rises in river stages becomes even more pronounced – the steeper the topography, the more rapid the concentration of flows. In a matter of minutes or hours a peacefully flowing stream can become a raging torrent. In areas with steep soil-covered slopes, the intense rainfall can cause massive mudslides, which can move with such force as to wash away whole communities and landscapes below.

In high-latitude areas, particularly in the northern hemisphere, ice jams are a frequent occurrence, blocking channel and control structures. They can under some circumstances create flash flooding when they break (Figure 89). In the case of ice jam breaks, inundation may contain not only flood waters from the river but large ice boulders which themselves can cause significant damage.

Figure 89: The town of Eagle, Alaska was suddenly inundated when an ice jam break occurred on the Yukon River and forced the river into the community



Source: US National Park Service.

Flash floods may also occur following failures of dams, sending the waters previously stored behind the dams downstream as walls of water. They may result from failure or overtopping of levees, opening previously protected areas to the onrush of flood waters. Such events may or may not be weather-related. Dams and levees have failed and caused massive downriver flooding or inundation of areas behind the levees as a result of structural conditions not directly related to rainfall events. In rare cases, deliberate human actions have precipitated such failures. Under other circumstances, significant meteorological

events have created conditions that caused the failure of the dams or levees. Whether the failure has a meteorological or nonmeteorological cause makes little difference to those who are affected by the consequences of the failures.

13.3 Past flash flood events

The record of flash floods is lengthy. Many are significant in terms of their consequences, of both lives lost and property damage. The following are illustrative of such events and the disasters they brought with them:

AUGUST 2002, CHINA

On 8 August 2010, unusually intense monsoon rains triggered devastating landslides and floods which buried a densely populated area in the centre of Zhouqu City in north-west China. The slide terminated in a brown fan that extended into the Bailong River (Figure 90 and 91). Mud surrounded several of the buildings near the river's edge and branched into adjacent streets. Some of this mud may have been deposited by flood waters that gathered behind the slide as torrential rain continued to fall. More than 1,400 people were reported killed and several hundred were missing after this disaster.

Figure 90: Satellite photo of part of downtown Zhouqu City after the mudslide



Source: NASA (<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=45329>).

Figure 91: Buildings in Zhouqu City surrounded by mud as rescuers attempt to locate missing persons



Source: GIWP.

OCTOBER 2010, WESTERN HUNGARY

In October 2010, the dam of a sludge reservoir in Western Hungary failed and sent a toxic concentration of heavy metals down a nearby river and through two villages, killing eight people and injuring 92 (Figure 92). The reservoir was built to contain the residue from alumina production in a nearby factory. Over 600,000 m³ of sludge ran into the local rivers and eventually into the nearby Danube River, raising international concerns over potential significant pollution. There had been no indication of a possible failure and as a result there was no warning of the flood given to those in the nearby villages. In 2006, in the same region, another alumina sludge reservoir failed and caused a similar flood.

Figure 92: Red sludge covers a Hungarian city after a flash flood caused by a dam failure



Source: AP Photo/MTI, Gyoergy Varga.

JUNE 1972, USA

In the late afternoon of 9 June 1972, scattered thunderstorms began to develop over the Black Hills, a rugged mountain range to the west of Rapid City, South Dakota, USA. By 18.00, heavy rain had begun to fall as a line of thunderstorms moved over the area, sending rainfall into the numerous canyons and valleys of the Black Hills. At 19.15, as the heavy rainfall continued, the US Weather Service issued a flash flood warning for Rapid City, and Rapid Creek, which runs through the city, began to overtop its banks. At 20.45, a dam on the west side of the city failed, adding to the flow in Rapid Creek. By 00.15 on 10 June, a flood crest of 1,416 m³/s moved through the city, killing 238 people and causing US\$800 million (in 2011 terms) in damages in the city and the region, including the destruction of 1,335 homes and 5,000 vehicles (Figure 93). The flash flood resulted from 254 mm of rain falling over an area of 115 km² in six hours. In one area the rainfall exceeded 381 mm in the same period.

Figure 93: Cars piled up by the 1972 flash flood in Rapid City, SD, USA



Flood damage on East Blvd. at Omaha St. in Rapid City, June 10, 1972 (photo courtesy of the Rapid City Journal).

See: http://www.crh.noaa.gov/unr/?n=1972_Flo

Source: US Geological Survey.

13.3 Characteristics of flash flood events

Flash floods can be characterized by the uncertainty of their occurrence, the rapidity with which they occur, the size and velocity of their flows and the potential severity of the associated consequences.

PREDICTING THE OCCURRENCE OF A FLASH FLOOD OR LANDSLIDE

Flash floods can result from a number of causes, and forecasting their occurrence is extremely difficult. Intensive thunderstorms, dam break, ice jam break and levee failure are all impossible to predict with any degree of certainty in the context of a flash flood forecast, but of critical importance to consider. Thunderstorms develop rapidly, with chaotic processes that can only be forecast in probabilistic terms, and an associated high degree of uncertainty. Advances in radar technology and coverage in a number of developed countries are promoting the use of data-driven models to forecast thunderstorms with some success, but in many regions of the world more limited coverage and older technologies limit their usefulness. When water overflowed the levees in New Orleans, structure failure and breach rapidly followed. Similarly failure of a storm water system to be able to accept, store or convey storm rainfall can lead to local fast-rise flooding. Such failures result from the collapse of pipes and culverts and the blocking of entrances to storm sewers by debris picked up by the storm waters. Neither of these events is easily predicted but methods to help are now starting to emerge, including:

- ▶ uncertainty and levee and drainage failure with real time forecasts
- ▶ real-time monitoring of levee performance and structural condition to support a forecast of failure (floodprobe, www.floodprobe.org).

Prediction continues to be focused at identifying areas that are susceptible to flash floods and landslides. Such analysis relies on synoptic, topographic and geologic analysis, and provides good insight, but developing the probability of occurrence and more importantly, forecasts of forthcoming events, is far more complex.

VELOCITY AND DEPTH OF FLOODING

The intensity of rainfall or the suddenness of a levee or dam failure or an ice jam event creates high-velocity flows during flash floods, and the high velocities create significant threats to those in the path of the flood wave. Velocities of 10–20 km/hr are not unusual. Such speeds will move automobiles and knock humans off their feet, carrying them away. Depending on the nature of the event, flash flooding can generate fast, and occasionally deep, flowing water down a stream or river. Heights of 3 to 6 m can be expected and under dam break or extremely large rainfall events, rivers may rise as much as 20 or more meters carrying with the flows boulders, trees, cars, and debris (Figure 94).

Figure 94: Large boulder found in a river in western China following a flash flood



Source: GIWP.

FLASH FLOOD CONSEQUENCES

Flash floods frequently catch unawares those who live or work in the flood zone. Early warning can reduce the human consequences of a rainfall-generated flash flood event significantly, but it is difficult to provide early warning for structural failure that can occur without any warning, when the distance between the failure and the population is minimal. The capability of flash floods to carry large amounts of material in their flows, including soil and sand that buries people and destroys property in their paths, increases the destructiveness of these events. Similarly, mudslides may occur without warning, bring vast volumes of debris crashing down on those below. Flash flooding occurs quickly and water levels created by these floods fall equally as fast. As a result, areas subject to flash flooding are not generally subjected to the same extended periods of inundation seen in slow-onset riverine events. However the time of recovery can be slow. The sediment load in the flood flows and the destructive power can lead to damage that it can take a considerable time to recover from.

13.4 Managing flash flood risk – intervention options

The first and most important stage in developing a response to flash floods is to determine the potential flash flood hazards and the areas that would be affected should a hazard event materialize. This includes the potential for intense rainfall events and the associated meteorological conditions, but also the potential for mudslide, dam break, ice breaks, levee failure and so on. Once these factors are known, described, and potential hazard areas identified, steps can be taken to reduce the impact of the hazard on the affected population and property.

STRUCTURAL MEASURES

Given the extreme range of flash flood flows and their infrequent nature, use of structural measures frequently is not economically viable or environmentally acceptable. This does not mean structural measures have no role. Examples do exist where structural measures are used: for example in San Antonio in the United States embankment dams (dry for most of the year) are used to control the flow of the flash flood flows (alongside nonstructural measures). In Almaty (Kazakhstan) there is a known risk of flash floods/mud flows from nearby mountains, and dams are used to retain the mud flows. Structural measures are therefore typically used to redirect flows, stabilize slopes and strengthen properties rather than attempt to defend the floodplain. Nonstructural measures (see below) linked with good land use management (promoting run-off control – see Chapter 9) offer the primary response.

NONSTRUCTURAL INTERVENTION

Nonstructural measures can provide significant mitigation of flash flood consequences. These measures include the following.

Building awareness and mapping of hazard zones

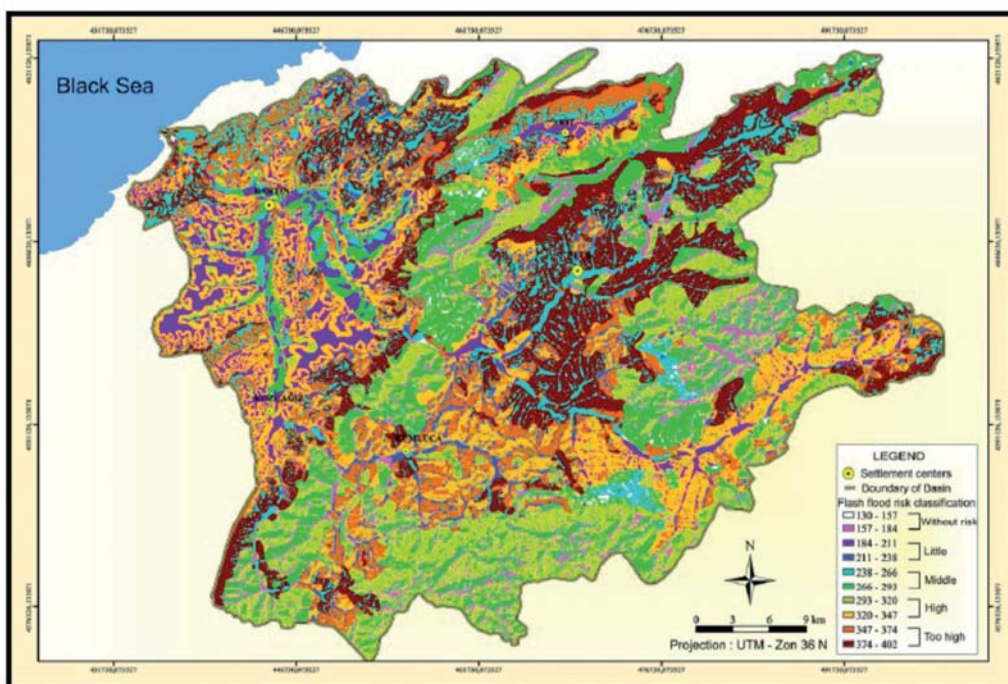
As with slow-onset flooding, calculations can be made of the areas that could be inundated by a variety of flash flood

events, and these inundation areas mapped (Figure 95). The extent of historical flash floods provides a useful addition to such maps, but they need to be presented as historical maps and are not necessarily indicative of future floods. Depending on the quality of the data available, depths of inundation and flash flood velocities can also be indicated on the maps (see Chapter 12).

The extent of the inundation from the failure of a dam also can be estimated and mapped (Figure 96). Levee failures and ice jam flooding can occur at almost any place in a floodplain, and a combination of ‘what-if’ mapping (such as the rapid inundation zones mapping produced in England, which assumes a breach in the levee) and probability mapping (which maps the residual probability of flooding taking account of the chance of levee failure) can be useful additional outputs (see Chapter 12 for elaboration).

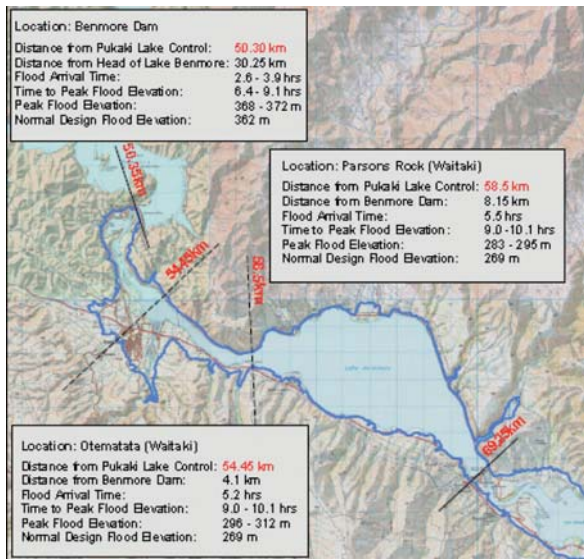
It is also possible to identify areas of potential mudslides (Figure 97) and, as with slow onset floods, maps can be developed to guide evacuation from flood hazard areas (Figure 98). As a result, in many areas of the world, when potential failure areas are identified, residents that might be in the path of the landslide are relocated to other less dangerous areas.

Figure 95: A flash flood risk map of the Bartın basin in Turkey based on analysis of the physical conditions of the basin



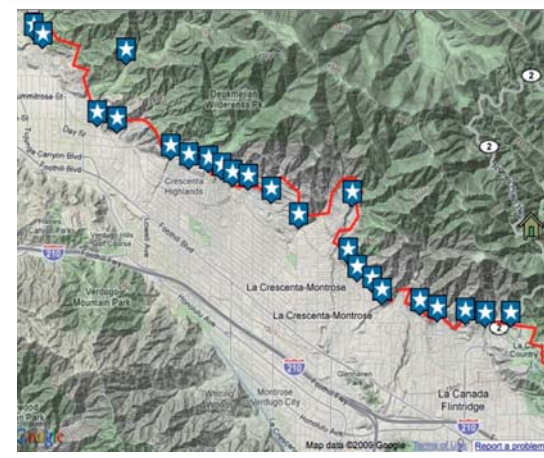
Source: H Toroglu, Istanbul University.

Figure 96: A section of a dam overtopping failure inundation map for Benmore Dam in New Zealand. Information in the boxes describes conditions concerning timing and extent of inundation at the selected cross sections of the river below the dam.



Source: Waimate District Council, New Zealand.

Figure 97: A Los Angeles Times map indicating areas subject to mudslides during storm events in August 2010.



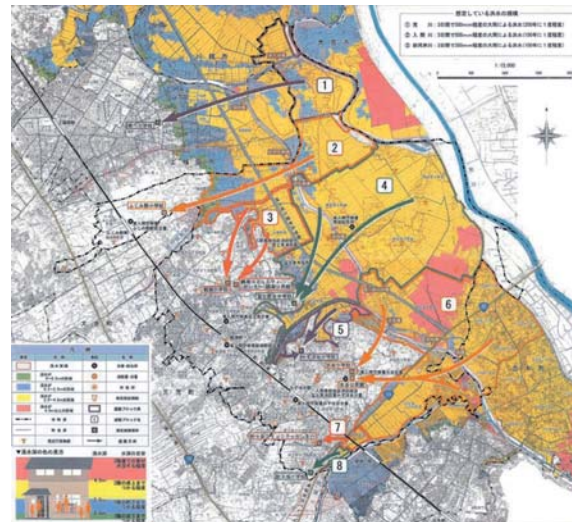
Source: These maps were based on US Geological Survey analyses of areas most at risk of mudslides (Los Angeles Times, 2010).

Better weather forecasting

Modern forecasting techniques permit the early identification of potential flash-flood-generating meteorological events. Dual-polarizing and increasingly sophisticated ground radar

and satellite systems aid in the identification and tracking of storms and the accurate determination of their rain-producing capabilities – a capability that is starting to include the ability to track thunderstorms. Forecasts using a combination of physics and data-driven artificial intelligence techniques are now starting to increase the amount of time available to those in the path of major storms and potential flash floods.

Figure 98: Map showing safety areas and evacuation routes in Koriyama City, Japan



Source: EC (n.d)..

Better early warning systems

Once information on the potential for rainfall, dam/levee break or ice jam flash floods is developed or made known to responsible officials, wider dissemination should follow. Access to information on the probability of the event and its likely severity supports those who could be affected in taking actions to protect property and to evacuate when appropriate. Sirens and loudspeakers can be used to broadcast the message to populated areas. A wide variety of modern communication systems such as television, radio, cell phones and the internet provide near-instant communication of hazard warnings to those with such systems. In France, Cemagref and Meteo France have developed AIGA, a system that provides early flood warning information about French rivers. AIGA provides maps containing information on the rainfall and runoff risks across the entire country. The effort is expanding to include links to real-time hydrologic monitoring that is linked to near real-time displays of actual and potential streamflow changes.

Box 32: Identifying potential rapid response catchments – a national screening approach

Through 2004 and 2005 two small steep catchments in England (Boscastle, 2004 on the North Cornish coast and Helmsley, 2005 in the Yorkshire Moors) experienced flash flooding. In response new national-scale modelling was undertaken to identify those catchments with the potential to respond rapidly to rainfall and produce a fast-flowing, rapid-rise flood event.

The study recognized that for small catchments the time between the rainfall event and the consequent flooding is short. This makes traditional flood warning systems that rely on monitoring river levels difficult or impossible to implement. There are characteristics of some catchments, however, that appear to place them at higher risk of flash floods than other catchments. In some locations this potential risk of rapid flooding will coincide with developed areas, which will mean that there is a risk to people and property. If such areas can be identified prior to any rainfall event, then the potential risk to people can be assessed and the appropriate response in these locations can be reviewed. In certain locations it might be possible to implement simple, quick warning systems, or information could be provided to raise awareness of the potential for flash flooding in these areas in order to reduce the risks to people.

A high-level method was applied nationally to:

- ▶ identify catchments that react quickly to rainfall events
- ▶ describe the severity of the resultant flooding
- ▶ assess the impact of the predicted flooding on people (using methods outlined in Defra, 2003).

Source: Environment Agency (2006).

The Boscastle flood arrived so quickly that owners did not have time to remove their cars. However the significant risk is to life and to fixed property (photo: Cornwall County Fire Brigade).

Example GIS image from the national application of the method showing peak flood depth during an extreme flooding event



Education

Unless people receiving the warning are aware of the risks and prepared to act, even the most sophisticated early warning systems will be ineffective. Individuals and organizations must understand the nature of the threat and what they should do in the event of receiving a warning. Community education and programmes in businesses and schools should focus on developing an awareness of the risks faced and the actions that must be taken when alerts are sounded. Education also should focus on actions that can be taken prior to flash flood events to mitigate potential damages. Such actions include relocation of utilities to upper levels of buildings and floodproofing/sealing of entrances and windows.

Preparedness exercises

In addition to individuals, organizations with responsibility for responding to a flash flood emergency must always be prepared. This includes undertaking periodic simulated exercises to practise and refine plans. Such exercises should be as comprehensive as possible, and include testing of the early warning systems, evacuation drills, and response and recovery training. (More details on the general aspects of emergency planning and management are given in Chapter 11).

Hazard identification signs

In association with education programmes, signs should be placed in flash flood hazard zones both identifying the areas subject to the hazard and providing instructions on the actions to take in the event of a flash flood or a mudslide (Figure 99). Although very simple, such signage can be powerful reminders of the risk posed.

Figure 99: Flash flood warning and instruction signs



Land use controls

Damages from flash floods can be avoided by limiting development in areas subject to flash floods and mudslides. Where population pressures do not permit the prohibition of development throughout a potential hazard area, development in those areas deemed to be the most hazardous should be restricted or limited to activities that can sustain occasional flash flood damage (such as parking lots, sports fields and parks).

Building codes

Both retrofitting and new design offer an opportunity to increase the resistance and resilience of buildings to flash floods. Where development will take place in areas that could be subject to flash flooding, new structures should be built according to standards that dramatically reduce the damages that would be sustained in a flash flood or a mudslide. In some cases, it may be necessary to mandate elevation of structures that will be subject to frequent flash flooding.

13.5 Flash flood risk management planning

The techniques and procedures described in earlier chapters for flood risk planning for slow-onset floods apply equally to planning for management of flash floods and related mudslides. Because of the nature of a flash floods, such planning, while it must take into account national and regional policies, goals and objectives, places an increased onus on clear identification of local issues and unique physical factors. It must also integrate the actions that need to be taken by individuals and businesses as well as the local emergency management structures charged with development of the pre-event planning, response during the event, and post-flood recovery. The lack of long warning periods before flash floods makes it unlikely that those on the scene can plan on support from higher levels of government prior to and immediately following the flood.

As a first step in the planning process, heavily populated urban areas that are subject to flash flooding must be identified and the hydrologic characteristics of the region closely examined. Knowing these details permits the identification of the flood forecasting and early warning tools that are most needed and where they should be located. This initial analysis also permits the development of structural and nonstructural portfolios of flood risk reduction measures. In addition to the need for more accurate and timely forecasting methods and enhanced early warning systems, considerable effort needs to be focused on educating the population at risk about what to do both if a potential flash flood is announced and during the event should it occur.

Following the 1972 Rapid City, North Dakota, USA flash flood, federal, state and local officials worked closely together to develop an integrated approach to reduce the threat of flash flooding to the community should another major event occur. Following a detailed analysis of the physical characteristics and development of the 1972 flood and an examination of land-use patterns in the Rapid City area, officials initiated a number of actions designed to address the shortfalls identified in the post-flood analysis. The size of the National Weather Service staff in the region was increased and more modern forecasting equipment was brought on site. Increased reliance was and is being placed on use of new observation systems such as satellites to provide a more rapid understanding of weather systems as they develop. Communication systems that were used to notify local officials of impending weather events were also modernized. As part of a national improvement in early warning of weather events, radio and television stations were integrated into an early warning network that permitted special alarms to sound on receivers in homes and businesses. Similar alarms are now able to be transmitted to the wide variety of personal telephones and communication devices. The four warning sirens in the region in 1972 have been supplemented by additional thirteen devices (NOAA, 2011; USGS, 2011).

Consideration was given to development of structural measures to deal with potential flash flooding, but those alternatives analysed were either not feasible from an engineering standpoint or too costly. As a result, the city, working with the state and federal government, chose instead to develop a green way –open space – along the river to reduce the potential exposure of the community to flooding and provide room for the river to pass through without causing significant damages. Extensive education campaigns have taken place in the community to remind residents of the earlier tragedy and to inform them of the actions they need to take in the event the future threat (USGS, 2011).

Similar efforts were undertaken after other flash flood events around the globe, and these have succeeded to varying degrees. Considerably more success has been obtained in improving the quality of weather forecasting, early identification of potential significant events, and development of early warning systems that educate the public about appropriate actions in the face of flash flooding. In developed areas, in spite of considerable media attention to the threat, the highest casualty rates occur as a result of vehicles being caught in floodwaters. Receipt of information about a threat does not necessarily enhance people's safety unless they are willing to modify their behaviour in response to this information, or governments are willing to move to involuntary evacuation (Montz and Gruntfest, 2002; Staes et al., 1994; Duclos et al., 1991). Efforts to better manage areas most prone to flash flooding are hampered by pressures for

development in the same areas. Following the flash flood deaths of 137 people in the Big Thompson Canyon in Colorado in 1976, plans were made to limit occupancy of high-risk areas; however, in the decades since, development has gradually moved back to take advantage of the canyon's amenities.

Following major flash floods in many large Asian cities such as Kuala Lumpur, Manila and Seoul, efforts were undertaken

to improve forecasting services and warning systems, but the concurrent growth in population, interior drainage problems and lack of public understanding of what actions should be taken during flood events created conditions that continued to generate flood casualties. The need for public education was found to be of critical importance (Sehmi, 1989). The experience of Aude, France in dealing with flash floods is highlighted in Box 33.

Box 33: Aude, France – reducing the risk from flash floods

The Aude is a region in France exposed to severe flash floods. These examples illustrate the fact that, except for camping places, evacuation is generally not recommended in France and is considered as a very last resort. A suggestion was made after the 2002 floods in the Gard region to build refuges on the roof of some houses if they are below the maximum water level so that the occupants have a place to take shelter before being rescued. If evacuation is considered necessary, the procedure is described in the municipal safeguard plan (*Plan communal de sauvegarde*). The typical procedures are described in regulation 2005-1156 of 13 September 2005, including:

- ▶ First provide a pre-alert message to the affected population to give information about a possible evacuation and explain the procedure. A second message is given at the start of the evacuation. Both messages have to be clear.

- ▶ Teams are created to organize the evacuation, with one team per area to be evacuated. If necessary, specific means are prepared to evacuate schools: for example, transport can be requisitioned. If some of the residents refuse to evacuate their location should be noted. If the situation becomes dangerous they should be forcibly evacuated. People with reduced mobility have to be identified and helped. After the evacuation, every building must be checked to be sure that there is nobody remaining in the area.
- ▶ A safe place must be designated and prepared for the evacuated people to take shelter. This is typically a public building like a school or a gymnasium. This place must be located as close as possible to the evacuated areas.
- ▶ The evacuated areas must be policed to avoid looting and vandalism.



L'évacuation

La mise à l'abri dans un refuge sur place est souvent préférables à une évacuation, notamment pour toutes les habitations qui ne sont pas fortement exposées lors de la montée des eaux.



Si l'évacuation apparaît comme l'ultime solution,

- évacuer rapidement,
- gagner un point en hauteur ou le refuge indiqué,
- suivre strictement les consignes données par les autorités.

About Evacuation

Taking shelter on the spot is often preferable to an evacuation, particularly when the buildings are not exposed to potentially destructive flood flows. If evacuation is the only option then:

- Evacuate without delay
- Move to high ground or an designated refuge
- Follow the orders of the authorities



Prévoir

■ *l'installation au-dessus du niveau des plus hautes eaux (dans les étages supérieurs, les combles ou sur le toit de l'habitation), d'une zone refuge accessible de l'intérieur et de l'extérieur (pour les secours).*



- *sur les ouvertures, des dispositifs mécaniques destinés à ralentir l'entrée de l'eau.*
- *les moyens de surélever le mobilier ou de le monter dans les étages,*
- *la mise en sûreté des véhicules avant l'inondation.*

Before the flood

- Install a refuge, above the highest known flood water level which is accessible from both inside and outside the house
- Slow down entrance of water through the openings
- Raise the furniture above the flood water or move upstairs
- Put vehicles in a place safe before the onset of flooding



Ne pas...

■ *Ne pas s'engager à pied ou en voiture dans une zone inondée: une voiture n'est plus manoeuvrable dans 30 à 50 cm d'eau; ne pas forcer les interdictions. Reporter ses déplacements à plus tard.*



- *Ne pas prendre l'ascenseur...pour éviter de rester bloqué.*
- *Ne pas aller chercher ses enfants à l'école...l'école s'occupe d'eux.*
- *Ne pas téléphoner...afin de libérer les lignes pour les secours.*



Do not...

- Do not walk or drive in a flooded area. It's not possible to control a car if the depth of water is between 30 and 50 cm.
 - Do not force pass through roadblocks. Postpone your travels.
 - Do not take the lift as it may get stuck
 - Do not go and fetch your children at school. The school will care of them
- Do not use phone as the lines need to be left free for the emergency services



Agir

- Fermer les portes, fenêtres, soupiraux, aérations...pour ralentir l'entrée de l'eau et limiter des dégats.
- Couper l'électricité et le gaz...pour éviter l'électrocution et l'explosion.
- Monter dans les étages avec: eau potable, vivres, papiers d'identité, radio à piles, lampe de poche, pile de rechange, vêtements chauds, médicaments...pour attendre les secours dans les meilleures conditions.
- Ecouter la radio...pour connaître les consignes à suivre.
- Se tenir prêt à évacuer les lieux à la demande des autorités, prendre ses papiers d'identité et si possible fermer le bâtiment.



Act

- Close doors, windows and other openings to slow the entrance of water and limit the damages.
- Switch off the electricity and gas to avoid electrocution and explosions
- Go upstairs with: drinking water, supplies, identity papers, radio, torch, batteries, warm clothes, medicines and wait for assistance under the most favourable conditions.
- Listen to the radio to get the latest instructions
- Be ready to evacuate when requested to by the authorities' request. Take your identity papers and if possible lock your home.

Source: adapted from Mens et al. (2008).

13.6 A summary of recommendations – learning the lessons from flash flood events

Flash flood events are common to all regions of the globe, and perhaps the most important lesson is that, where possible, development in flash flood risk areas should be avoided. This of course relies upon understanding those areas potentially at risk.

Success in dealing with these events rests on pre-flood identification of the potential risk in terms of magnitude and location, development of techniques to provide forecasts of events as they develop, education of those that might be affected, and implementation of early warning systems that permit those at risk to move out of harm's way. Development of plans to deal with flash floods and to respond to their occurrence will require use of the same procedures employed to deal with slow-onset floods.

CHAPTER 14

INSURANCE AND FLOOD RISK

14.1 Aims

Flood insurance is a major and legitimate activity in managing flood risk. For those insured, flood insurance provides a mechanism for them to transfer part of their risk and reduce their vulnerability to flooding; to those providing the insurance (and reinsurance) it provides a commercially viable means of generating income.

Flood insurance, when seen as part of a portfolio of measures to reduce or manage flood risk, has four main roles:

- ▶ **reimbursing** those who suffer damage, and thereby restoring them to their pre-flood financial situation
- ▶ **spreading** the costs of flooding across communities (and clients), given that floods may affect only some communities at a time; and for individuals through time by spreading the potential costs of flood damage over many years in relatively small payments rather than having a single large cost if and when a flood actually occurs
- ▶ **reducing** the costs to the government of post-event recovery since the insured will receive insurance funds (note: where a private insurance sector exists only)
- ▶ promoting a **change of behaviour** with regard to exposure to flood risk, by giving a signal of the hazard that people face and providing incentives for 'good behaviour' – joining automated warning schemes, floodproofing properties and so on.

Only the fourth of the roles listed above seeks to reduce risk; the first two simply transfer the risk from the insured to the insurer, and the third reduces government expenditures.

The way in which each of these roles is approached determines the nature of the flood insurance arrangements that are effective

and commercially viable. In descending order of general incidence, insurance policies can be bought for:

- ▶ **property damage loss**, when floods cause damage that requires the repair or replacement of buildings and their contents
- ▶ **loss of business income and profits**, for example when operational days occur or stock is lost
- ▶ **loss of agricultural production**, for example when crops are destroyed
- ▶ **loss of life and injury** during floods (life insurance).

Insurance against flood damage is a central component of a well-considered portfolio of FRM measures, but there are dangers. Many private insurance companies failed in the United States in the early parts of the twentieth century when confronted with massive claims during major floods. This failure occurred for a number of reasons:

- ▶ Few legitimate insurance companies in the early part of the twentieth century underwrote flood losses, as few considered flood catastrophes to be a natural hazard. (In part this was because the insurer had limited ability to properly access catastrophic risks – that is, those affecting many insured at once – in terms of frequency and severity, and hence premium levels and reserves were often insufficient.
- ▶ Many illegitimate insurance companies existed at the turn of the twentieth century as insurance products became increasingly popular. Because of the lack of associated regulation fraud, scandal and mismanagement were commonplace. Many of the issuing companies did not actually have the capital to pay claims, whether these claims related to flood, fire or loss of life.
- ▶ Many companies went bankrupt and the claimants did not receive their compensation.

In response the US government had to intervene to make many of these payments, so as to restore faith in insurance generally. A much tighter and more regulated industry followed to try and curb future problems.

14.2 State or private? A key decision

Any organization promoting flood insurance must be large, as claims totals can be substantial. There are basically two alternatives:

- ▶ flood insurance provided by the state, and sold to communities or individuals
- ▶ flood insurance provided by large private companies, and sold as profit-making services just like motor and other typical insurance products.

Each has advantages and disadvantages. For example, a state system requires a long-term commitment which may not fit with changing political agendas. It also requires a commitment by the government to meet periodic large claims. Private companies may fail, or may withdraw cover when it becomes unprofitable. Governments should decide for their country where the balance of advantage lies, or could decide (like most of the Netherlands) to have no flood insurance at all.

14.3 Necessary conditions for successful insurance

There are five conditions that need to be in place to ensure the sustainability of any insurance scheme, not just flood insurance (Arnell, 2000). These are:

- ▶ It must be possible to estimate the **likelihood and magnitude of possible losses**, so that premiums can be calculated that reflect this loss potential. If this is not possible, the premiums become arbitrary and the insurance agency (private or governmental) is at risk.
- ▶ Losses from individual claims must be **independent**, and no single event such as a major flood should affect the majority (or even a large number) of those insured. If this is not the case, then the insurance agency might be faced with an overwhelming claims total, and fail.
- ▶ The occurrence of any event leading to claims **must not be predictable** in deterministic terms (for instance, the dam will fail tomorrow and my house will be lost), or else those

purchasing policies will only do so when they know that a claim is certain/likely.

- ▶ There must be sufficient **demand** for insurance coverage to make a large enough market that a single event such as major flood does not lead to claims that exhaust the insurance agencies' resources
- ▶ The **premium** charged to the insured must be acceptable so that coverage is purchased.

The problem with flood insurance (compared, say, with motor insurance) is that not all these conditions are met. In particular, flood losses are not independent; a major flood affects hundreds or thousands of adjacent properties, all of which may claim at once. Regional floods may affect properties across different catchments, or even in different countries. Equally a flood event could coincide with an earthquake and /or hurricane and wind damage. Although there always will be some correlation between risks, for the most part one flood event will not affect everyone. Flood is not alone in this: brush fire, windstorm, freeze and all other natural perils have some degree of dependence and can impact multiple policy holders. A regional company might have greater exposure to dependent risks than a well-diversified international or national insurer. The potential for large single-event claims however puts insurance companies or even governments at risk. This pressure has led to the development of an active reinsurance market for natural perils, which seeks to further transfer this risk – see below.

HOW BEST TO MEET THE FIVE CONDITIONS

Failure to meet the above conditions is liable to render any insurance system fragile, and to cause it to fail periodically. This can be avoided by careful attention to information on flood risk and the nature of the insurance scheme, as discussed below:

Having adequate information on which to base premiums

What are required here are flood maps and flood probabilities. This in turn will require a hydrological database of past floods, from which to predict future flood probabilities for locations where insurance premiums are to be sold, as these premiums should ideally be related to the risk of flooding and hence of claims. This database should extend back as far as possible (say fifty years) and is likely to include, for each catchment or locations within catchments:

- ▶ rainfall records
- ▶ runoff characteristics
- ▶ river flow records
- ▶ coastal tidal gauge and surge records
- ▶ historical flood extents (for model calibration)

- ▶ structure elevations
- ▶ adequate topographical information.

The simplest way of presenting information from the analysis of this data is as insurance 'rate maps', showing where properties are located, and the extent of the 10, 20, 50 and 100-year floods. With climate change affecting the behaviour of the flood system and hence probabilities, this can be a complex operation, and modelling is usually required to produce the flood extent data, which cannot solely rely on historical records.

Insurance premiums should reflect risk, although they do not always do so. Risk incorporates the probability of flooding, and the consequences of that flooding. This means that the insurer must also know the susceptibility of the insured to flood damage, as compensation will obviously be a function of that damage. For this, data needs to be collected on:

- ▶ the nature of the property insured (for instance domestic, industrial or commercial)
- ▶ the size of that property or group of properties
- ▶ the potential damage that would result from a range of flood events (to establish an expected annual loss).

In this way the insurer can calculate an appropriate annual premium to charge which over the long term will compensate the insured for the flood losses they will incur and create sufficient profit (and hence reserves) for the insurer to be safe from failure.

Assessing exposure of individual premium payers, communities and hence the total portfolios

Given the data collected as above, the insurance company needs to set the premium to charge. If this is done correctly total claims should not exceed total premium income, over the long term.

But the exposure of the insured to risks changes over time. This might result from increased runoff from an urbanizing catchment, or increased flood flows resulting from climate change. It might also result from the changes in property characteristics, when the owners extend their buildings or purchase more valuable contents. This means that exposure needs to be monitored continuously, and premiums recalculated on a regular basis (say, every year).

Any insurance company will also need at the same time to assess its total exposure to risk, by cumulating all possible simultaneous claims within its portfolio of policies. This is necessary to ensure that the company can meet its obligations of paying compensation totals that cover its entire portfolio. It will also alert the company to excessive risk and encourage it

to spread its portfolio of cover over many communities and/or catchments.

This way makes it very less likely that all policy-holders will claim at the same time, and thus threaten the company, by ensuring that claims to the insurance company are matched by (or at least paid partly from) income from others who are not making these claims either at that time or at all.

Having adequate financial reserves to meet all claims

In a properly run flood insurance scheme total claims should not exceed total premium income, over the long term. But the scheme might be faced with many claims early in its life, or claims in any one year that far exceed its annual premium income.

This means that the scheme must have reserves (through reinsurance or capital market securities) or be backed by the country's government as the 'insurer of last resort'. The extent of these reserves will depend on the nature of the portfolio of policies the company has 'written' (that is sold) and the chance that premiums in any one period will exceed income, and by how much. There are no simple rules here, but insurers at Lloyds of London (a marketplace in which insurance is traded) are required by the UK Government to be able to cover all the claims from a 1:200-year event.

These reserves also need to be liquid. That is, they need to be available at short notice, to respond to a flood event and the claims that rapidly follow, so they cannot include valuable property that could not be sold easily or quickly. Generally they comprise government bonds that are traded regularly and are relatively risk-free investments. Holding these liquid reserves – which generally yield a low income – is an expense that the insurers must be able to cover.

Promoting a sufficiently large market to ensure the safety of the insurers

Any small market in flood insurance is liable to suffer from claims that overwhelm its income and reserves. Therefore the market for flood insurance needs to be large, so as to include at any one time far fewer claimants than the numbers that are insured. Ideally any insurance scheme will, say, have many thousands (or millions) of premium payers but only a few hundred or a few thousand claims in any one year (or any other such period).

How this is achieved is not easy in flood insurance, as property owners might only seek and therefore buy insurance if they feel that their individual risk of flooding is high (which is known as adverse selection). Most governments make it compulsory for vehicle drivers to insure against accidents. This is generally not possible for flood insurance, as the owners of risk-free properties well outside flood plains would justifiably complain, and in a

free market they will decline to buy cover or simply refuse to pay. Either incentives for insurance need to be provided (by governments generally) or other ways found whereby insurance is bought by people unlikely to claim, as in the United Kingdom (see below). In any case the market must be large, or it is vulnerable to large simultaneous claims which will lead to its collapse.

Governments have an important role here. They can either be the agency of insurance themselves (that is, act as an insurance company in insuring individuals or communities) or they can promote a private insurance market (see above). If the latter, they will need to regulate it in such a way as to minimize the risk of failure by requiring the companies to hold sufficient reserves to meet multiple claims. Often the critical tension between the regulator and the private insurers is a desire for affordability for all and a fear that regulation will suppress risk-based rates to a level where premiums would never cover losses, and hence the private insurance sector would fail to function.

Importantly, the ratio between reserves and the extent to which the companies can provide insurance cover needs to be controlled, using fixed ratios based on modelling of catastrophic floods or by some other means, so as to disallow the companies from writing excessive numbers of policies that could lead to failure if claims all come together. (Note: rating agencies routinely do this for hurricane and earthquake, and are likely to increasingly do so for flood).

14.4 The nature of reinsurance

Individual insurance companies can become unsafe or even fail if they are faced with an overwhelming claims total. Anticipating these circumstances, the company can reinsure part of its liability with a specialist insurer, which will reimburse them if the liability exceeds a certain sum (typically billions of dollars). The premium might be quite small per sum insured, given that the probability of a claim is inherently low, but it means that the insurance company is rendered fit to write more policies than would otherwise be the case.

Reinsurance companies are typically regulated with capital ratios, and to be profitable and safe they tend to be large, so they can bear the losses when claims are made, and have an international rather than just a national marketplace to realize the benefits of a diversified portfolio covering many disparate circumstances.

As pressure mounts for insurance payouts to be delivered as rapidly as possible, some reinsurance products release the insurance compensation payment based on the occurrence

of a (precisely defined) catastrophic event without a detailed assessment of the actual damage caused. This allows for speedy processing of insurance claims; the event itself can be verified in a matter of hours, whereas damage assessment can take months or years.

14.5 'Nonstationarity': a real threat to insurance?

The world is changing, in both its climate and its social and economic fabric. The past is no complete guide to the future. Insurance arrangements and premiums that are based on the past hydrological record can be unsafe, and fail if there is a 'run' of serious floods requiring huge insurance payouts.

There are several ways out of this dilemma:

- ▶ One solution is for insurers not to offer long-term policies, but to restrict them to annual cover. In this way losses one year can be recouped the next (provided as the insured can afford the higher premiums that will probably be required).
- ▶ Another strategy is more risk sharing. The insurance policy can require that the insured pays the first slice of the flood damage costs (termed an excess or a deductible), particularly for high-risk areas. In this way the liability of the insurance company is reduced.
- ▶ Insurance for floods is not offered by the private sector: this is a real option, and can bring dilemmas for the governments of the countries concerned, as they are then liable to pick up a substantial element of the bill for flood damage if they want the areas affected to recovery quickly.

Clearly, insurers need to monitor very carefully indeed the state of flood risk in the areas in which they provide cover, so as to avoid the dangers that come with unanticipated change in risk and hence liability.

14.6 Example insurance regimes

FLOOD INSURANCE IN THE UNITED KINGDOM: INSURANCE FOR ALL, IRRESPECTIVE OF RISK

Flood insurance is very common in the United Kingdom, for some internationally unique reasons. Based on the government's Household Expenditure Survey and evidence from its own

members, the ABI estimates that the take-up of insurance in the United Kingdom is such that 93 per cent of all homeowners have buildings insurance that covers their home (where this insurance is a standard condition of a UK mortgage), although this falls to 85 per cent of the poorest 10 per cent of households purchasing their own property. Some 75 per cent of all households have home contents insurance, although half of the poorest 10 per cent of households do not have this protection.

This internationally unusual situation is a product of history. Following severe floods in the south-west of England in 1960, the insurance industry agreed in 1961 to make flood insurance more widely available to private households and to commercial and industrial properties. Members of the British Insurance Association, the forerunner of the ABI, reached a 'gentleman's agreement' with government. The agreement was that they would offer flood cover to any domestic residence or small shop in Britain at an additional premium not exceeding 10 shillings (£0.50, or approximately \$0.60). But there was a key condition: this cover they would charge to all properties, irrespective of risk, as part of a general household insurance package.

Thus, the pattern of compensation for flood damages being the responsibility of individual householders and businesses provided through the market was set, as was the role of private insurance. In the 1990s, as data and techniques for mapping and modelling flood risk improved, the insurance industry focused attention on identifying properties at greatest risk; and thereby on endeavouring to ensure that the premiums charged reflected that risk, and on assessing the overall level of liability it might face in a major flood event.

This provided the industry with an argument for increased investment in flood defence. In this way, the ABI began to contribute to the debate about funding for flood and coastal defence. The flood event of 1998 also served to increase the industry's level of concern about the potential frequency, and cost, of floods in the United Kingdom, but it was the events of autumn 2000 that confirmed the industry's predictions on inland flooding. It was clear that significant flood event could result in insurance costs of between £1 billion and £2 billion (approx. US\$1.2–2.4 billion): a dangerously large sum from the industry's perspective.

In January 2001 the industry, through the ABI, agreed voluntarily that it would be a general policy to maintain flood cover for domestic properties and small businesses, but just for a period of two years. During these two years the ABI was active in putting pressure on the government, through a variety of means such as direct discussions and responses to consultation documents, to ensure that sufficient funds were made available to allow flood defences to be improved, thus reducing the potential liabilities.

The ABI was also a key actor in processes to secure a strengthening of the control of development in floodplains through changes to planning policy guidance/statements and the planning system. In 2005 it issued a 'Statement of Principles' (ABI, 2005) on the provision of flooding insurance', indicating that flood cover would be maintained for domestic properties and small businesses where properties were currently protected to Defra's minimum indicative standard or 1 in 75 years, for urban areas, or better where improved defences to at least that standard were planned by 2007.

In other locations, where risks were unacceptably high, and no improvement in defences was planned, flood cover could not be guaranteed but would be considered on a case-by-case basis. The implementation of the principles in the Statement was conditional upon specific actions from government being carried out, on funding, development control and other matters.

In summary, the UK flood insurance arrangements are designed to make the insurers safe and profitable, without which there would be no private market for compensation against loss through flooding. The consequence is that some individuals who are insured, and pay for it, do not need that insurance, and the government is required to spend more on flood defence than it might otherwise do. The merits and demerits of these characteristics continue to be debated.

FLOOD INSURANCE IN THE UNITED STATES: CARROT AND STICK

Standard US homeowners' insurance does not cover flooding. It is therefore important for those at risk to have extra protection from the floods associated with hurricanes, tropical storms, heavy rains and other conditions that impact the United States.

In 1968, Congress created the National Flood Insurance Program (NFIP) to help provide a means for property owners to protect themselves financially from unaffordable flood damage. The NFIP offers flood insurance to homeowners, renters and business owners if their community participates in the programme. Participating communities agree to adopt and enforce ordinances (zoning of land use) requiring that all new homes built after the community joined the programme to have their first floor elevation at or above the 100-year flood elevation. Communities must also meet or exceed other FEMA requirements, such as control of construction in that portion of the floodplain that passes the 100-year flood in order to reduce the community risk.

The NFIP has the following three aims:

- ▶ to provide flood insurance at affordable rates (that are reasonable given the risk faced)

- ▶ to reduce federal disaster aid by replacing such aid with the insurance system
- ▶ to slow the rate of increases in flood losses through community actions that control development in the 100-year floodplain.

In this respect the NFIP supports local communities in their efforts to reduce the risk and consequences of serious flooding. In order to participate in the NFIP, a community must agree to adopt and enforce sound floodplain management regulations and ordinances. In exchange for these practices, FEMA makes (government-subsidized) flood insurance available to homeowners, business owners and renters in these communities. Those who joined the programme in its early days and who lived in the 100-year floodplain were offered reduced or subsidized rates. Today, approximately 25 per cent of the FEMA policies are subsidized (so they are provided at a rate lower than actuarially expected).

Because relatively few homeowners purchased flood insurance early on, the US Congress established a mandatory purchase requirement (MPR) in 1973. A property owner in an area at high flood risk (defined as having a first floor below the elevation of the 100-year flood) is required to purchase flood insurance if the property is mortgaged with a federally regulated lender. The lender is required to ensure that the property is covered by flood insurance for the term of the loan, and to purchase flood insurance on behalf of the property owner if the property owner fails to do so, although this is not frequently done. Homeowners who live in a hazard area that is protected by a levee that provides protection against the 100-year flood and has been recognized by FEMA as providing that level of protection are not required to purchase insurance.

Box 34: Floodplain development and flood insurance in the United States

US Federal policy has not prevented development in high-risk areas. Since 1980 coastal county population growth rate (at 28 per cent) is consistent with the nation's average rate of increase, but the density is much greater (17 per cent of the land area holds 53 per cent of the total population). However, only about 3 per cent of the US population live in a coastal flood hazard area.

Flood insurance is available in over 21,000 participating communities nationwide. There are over 1100 communities participating in the financial-incentive-based Community Rating System implementing 'higher standards', and accounting for 66 per cent of policies in force.

There are over 80,000 insured repetitive loss properties (a number that is growing) and over 8000 severe repetitive loss properties (also growing). There is \$1.2 trillion in insurance cover, and 5.6 million flood policies are in force. About 25 per cent of the 5.6 million policies are rated at less than actuarial rates

Outstanding Treasury borrowing (debt) is \$18.7 billion.

Source: FEMA www.fema.gov accessed 1 December 2011.

Rather than purchase insurance through the NFIP, lenders and homeowners can purchase flood insurance from private insurers. In contrast to the NFIP market, in which the private sector sells the policies but the federal government underwrites them, in the private-sector market insurers both sell and underwrite the policies. Such policies must meet or exceed the coverage provided by NFIP policies to satisfy the MPR.

At present, coverage of residences under the NFIP is limited to \$250,000 and \$500,000 for businesses. Those seeking coverage above the FEMA maximum must turn to the private market.

FLOOD INSURANCE ARRANGEMENTS IN FRANCE: 'BUNDLED' WITH FIRE COVER

In France, a different model of compulsion has been developed. Since 1982 the French government has required communities to produce plans to reduce risk – not just from floods – in the form of plans d'exposition aux risques (PER), termed plan de prevention aux risques (PPR) since 1995. The insurance element is provided by requiring all those insuring against fire to pay a compulsory levy of 9 per cent of their premium for flood insurance. Insurance companies can buy reinsurance from the state's Caisse Central de Reassurance.

At the same time, mitigation was incorporated in the arrangements. A commune has to produce a plan of its floodplain areas, and divide this into zones with different levels of risk. New development is subject to conditions that are designed to reduce the build-up of risk, and existing developments must be adapted to minimize risk, paid for by the owners. Reimbursement for flood damage is only paid if the property affected meets the requirement of the PPR: new development in contravention to the plan is not covered, nor is property that had not been adapted as above.

There are similarities with the US NFIP, but suited to French circumstances. There is no need to incentivize compliance with zoning and mitigation measures, as in the United States through subsidized flood insurance, because in France these plans and measures are required by law. This more dirigiste regime does have its own limitations, in that enforcement of the mitigation measures has not always been straightforward, and this threatens to undermine the whole arrangement.

INSURING THOSE RESPONDING TO FLOOD EVENTS

As well as those directly impact by floods, local governments can incur significant additional expenditure in responding to flood events. Various 'insurance' mechanisms exist to reimburse local governments for this additional expenditure from central funds. For example the Belwin scheme in the United Kingdom

provides a central government fund that local authorities can apply to for emergency financial assistance following a major emergency in their area. If a local authority incurs costs from responding to a major incident, it can apply for a grant to recoup up to 85 per cent of the costs (over a given threshold).

The scheme is applicable where an emergency or disaster results in destruction of or danger to life or property, and a local authority incurs expenditure on, or in connection with, taking action to safeguard life or property or preventing suffering or severe inconvenience in their area. Local authorities are not automatically entitled to this financial assistance, and the grant does not cover insurable or capital costs. The decision to award a grant is taken by central government after deliberating on the disaster circumstances.

14.7 A summary – the key components of an effective flood risk insurance sector

For flood insurance to form a component of the FRM it must:

- ▶ have access to sufficient financial reserves (either directly or through reinsurance) – reflecting a good understanding of the interconnectivity and the spatial and temporal coherence of the major flood events (and associated perils) to which a country is exposed
- ▶ form part of a more comprehensive and large private insurance industry, or be run by the state
- ▶ compel individuals and businesses to take insurance (or at least in part)
- ▶ be well regulated to ensure substantial financial reserves are maintained (particularly if operated through private companies)
- ▶ set premiums that are affordable (to promote take-up) yet commercially reasonable given good data on risks faced
- ▶ promote and regulate reinsurance arrangements; ensuring providers have appropriately diversified their exposure
- ▶ promote ‘good behaviour’ but build flood risk mitigation actions into the conditions for cover to be provided
- ▶ link private and government funding with individual and business financing to promote betterment of reinstated properties (to be flood resilient)
- ▶ provide access to central government emergency funds to insure the additional costs incurred by local governments in responding to flood events.

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Flood risk management A Strategic Approach

Over recent decades the concept of flood risk management has been cultivated across the globe. Implementation however remains stubbornly difficult to achieve. In part this reflects the perception that a risk management paradigm is more complex than a more traditional standard-based approach as it involves 'whole systems' and 'whole life' thinking; yet this is its main strength and a prerequisite for more integrated and informed decision making.

This book results from an international collaborative effort to explore and distil best practice approaches to flood risk management in challenging large scale and inter-related environments. Part A provides a historical perspective on the flood events that have shaped modern approaches. Part B describes emerging good practice, including (i) the purpose and characteristics of strategic flood risk management, (ii) the goals, objectives and outcomes sought, (iii) the necessary governance frameworks, (iv) the development of adaptive strategies, (v) the relationship with ecosystem services, (vi) the barriers to, and enablers of, implementation, and, finally, (vii) the 'nine golden rules' that underpin good flood risk management decision making today. Part C presents particular techniques in more detail, including (i) risk and uncertainty analysis, (ii) spatial planning, (iii) infrastructure management, (iv) emergency planning, (v) flood hazard and risk mapping, (vi) the management of flash floods and (vii) insurance.

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