Flood risk assessment and flood risk management

An introduction and guidance based on experiences and findings of FLOODsite (an EU-funded Integrated Project)
Colophon

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Preface

About flood disasters

During the last few decades, the world has experienced an increasing number of devastating floods, and Europe has not been spared. Many people remember the Rhine and Meuse floods of 1993 and 1995, the Oder flood of 1997, the large floods in northern Italy of 1994 and 2000, the Elbe flood of 2002 and the UK floods of 2000 and 2007. Statistics show that floods in third-world countries usually cause many casualties and comparatively little damage, whereas floods in Europe and the USA cause enormous economic damage, but relatively small numbers of victims (www.dartmouth.edu/~floods). The Elbe-floods of 2002 caused about 15 billion € of damage and the July 2007 floods in England about 6.5 billion € of damage. Both events were considered to be national disasters.

The recent flood disasters in Europe were all caused by pluvial and fluvial floods. Storm surges which caused the flooding of large coastal areas date back to 1953 (southwest of the Netherlands and eastern England) and 1962 (northern Germany). They are still part of the collective memory of these regions because of their huge impacts: many hundreds to several thousands of victims died and the feeling remains of a loss of control and being at the mercy of fate. But the memory is fading as, since then, improved flood defences along the coast and huge storm surge barriers in various estuaries have reduced the probability of such events. This contributes to a – perhaps false – sense of security, which in turn provokes further population growth and economic developments in those areas.

It is unclear whether the increased consequences of floods in the last decades are caused by more frequent and more intense flooding, or by the increased vulnerability of the coastal plain and floodplain areas, which are the preferred locations for settling and economic development. It is, however, generally acknowledged that worldwide flood risks are increasing. It is also considered very likely that climate change may cause an increase of the flood hazard probability and magnitude, whereas it is certain that demographic and economic development cause a continuous increase of the vulnerability of many floodplain areas. Climate change causes the sea level to rise, even if slowly; it may cause precipitation to increase and rainstorms to become more intense; low-pressure areas may deepen and storm surges may become more frequent and higher. All these processes may aggravate flood hazards, equally in steep flash-flood catchments, as in river valleys and along coasts. Demographic and economic developments mean that even a modest 2% economic growth causes economic damage of a given flood to double each 30-35 years, unless the growth is all located outside all flood-prone area. This reflects the saying: without people there is no risk.

About what to do about it

Especially the Rhine, Meuse, Oder and Elbe river floods revealed that floods are not only a national concern, but have a pronounced cross-boundary character. Actions in one country may diminish or aggravate a flood’s impact in a neighbouring country. This triggered the European Union to put effort in research and policy making on flood risks. Research funds were made available for a large number of subsequent research projects and programmes, among which the Integrated Project FLOODsite, which was carried out from 2004 to 2009.
Meanwhile, a proposal for an EU-directive on flood risk assessment and management was discussed and adopted on 23 October 2007, to complement the Water Framework Directive. This “Directive of the European Parliament and of the Council on the assessment and management of flood risks” is now being implemented by the Member States. The purpose of the directive is stated in Article 1:

… to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community.

The directive requires:

• Preliminary flood risk assessment
• Flood hazard mapping and flood risk mapping
• Flood risk management plans.

FLOODsite, from the start, had the ambition to provide conceptual and methodological guidance on how to analyze and assess flood risks as well as on how to manage flood risk and flood events. This nicely matches the Directive’s requirements.

**About this volume**

In this volume, we open some windows on the scientific progress FLOODsite has achieved in this respect, by summarizing the main findings and by giving links for further reading.

The main goal of this volume is, however, to share FLOODsite’s view on what a comprehensive approach to flood risk assessment and management is, and what it ought to encompass. We do so by drafting the whole picture in a relatively concise text, whereas some more detail is given in text boxes. We are aware that we thus, obviously, do insufficient justice to all the scientific progress made within FLOODsite, but we wanted to restrict ourselves to the essence of what the research has concluded.

References here to FLOODsite’s task reports may, however, help the interested reader to delve deeper, which is facilitated by FLOODsite’s website (www.floodsite.net) where they are available.
The cyclic character of flood risk management

- post-flood measures
  - relief
  - cleaning
  - reconstruction
  - organisational and financial aid
  -...

- preventive flood risk management
  - spatial planning
  - flood defence
  - retention
  - preparedness
  - insurances
  -...

- flood event management
  - early warning
  - reservoir control
  - evacuation
  - rescue
  -...

The cyclic character of flood risk management

Sources and pathways of flooding, and the receptors at risk
CHAPTER 1

On the science of flood risk management: what are we talking about?

What is flood risk management?
Flood risk management is an approach to dealing with flood risk based on the notion that risks cannot be taken away entirely but only partially and always at the expense of other societal goals. The aim of flood risk management is thus to reduce the consequences of floods, in ways that balance this aim against other considerations.

Flood risk management aims at preventing losses and damages by preventing flooding and/or by preventing the exposure of people and property to flooding. This includes lowering the probability of flooding as well as reducing the vulnerability of the society in flood-prone areas. Consequently, flood risk management may involve a large number of measures, for example flood defence measures, flood control measures, but also spatial planning and measures aimed at lowering the vulnerability of people and property. This is because single-measure management approaches do not take advantage of the way that various measures can reinforce each other. For example, better spatial planning to keep urban and other vulnerable development out of hazard zones may mean smaller scale engineering works to protect towns and villages. And adequate emergency response during floods can reduce flood damage and thereby lower insurance premiums.

Flood risk management is not a one-off activity, such as building an embankment or a dam. It is a continuous process, characterised by repeated activities: analysis of the flood risk, consideration of measures and policy instruments to reduce the risk, making policy decisions, implementing measures and instruments, monitoring their effects, etc. This permits constant adaptation to changing circumstances and changing societal requirements.

Flood risk management (FRM) is essentially preventive, as it focuses on all possible floods – both frequent and rare – in contrast to flood event (or incident) management (FEM or FIM), which is about dealing with floods that are happening or are about to happen. But flood risk management (FRM) does of course involve the development of flood warning systems or of insurance schemes that are essential for flood event management, as these should operate all the time and not just during flood events.

So, flood risk management is not the same as flood risk reduction …?
Flood risk reduction is part of flood risk management; actually, it is a core aim. But it is not the only aim, for flood risk management is more a means to support sustainable development than a goal in itself. So, flood risk management does aim to reduce flood risks, but it seeks to do this in a way that is optimal from a societal point-of-view, by balancing the reduction in risk with the societal cost and effects of doing so. To influence both the probability of flooding and its consequences involves examining all aspects of flood risk management for a community, in a comprehensive appraisal, rather than just looking at some aspects.

A flood risk management policy which would reduce risk partly by transferring some of that risk from the rich to the poor, because this was economically efficient, would not be good flood risk management. A flood risk management policy which would reduce risk to people and their property but caused disproportionate environmental damage (perhaps by turning rivers into concrete channels) would also not be good flood risk management. And a flood risk management scheme which reduced risk at such a high cost that other socially valued expenditure was no longer possible (e.g. on hospitals or schools), would also not be good flood risk management.
Because a balance of economic, social and environmental considerations is important here, flood risk management can be seen as part of an overall management policy for sustainable development, which aims for a similar balance. But the nature of this balance varies across communities and countries. That is why achieving good flood risk management is so difficult!

**Before we go into details, how does this flood risk management differ from what was done in the past?**

Before flood risk management became the generally accepted approach, we have seen a sequence of dominant approaches. In the 1950s to the 1970s we talked about Flood Defence, with a strong engineering focus on keeping floods off the land. Then, we talked about Flood Control, suggesting (incorrectly) that we might control floods. And in the 1980s and 1990s we talked about Flood Management, implying that we might at least manage floods, if we could not control them, but still focussing on the flood water and on engineering measures.

This does not mean that other measures were not considered: many countries have decades of experience of flood forecasting and warning (for example, the Rhine-flood warning centre in the state of Rheinland-Pfalz started as long ago as 1986), of land use planning in flood risk areas (carried out in the UK since 1947), and of emergency planning and response (already a Departmental responsibility in France for many decades). What it does mean is that prior to the 1990s there was a dominant view that engineering measures were preferred. The focus was on reducing the probability that communities would experience floods, generally through investing in such measures as flood embankments, channel enlargement, pumping schemes, and sea walls.

Nowadays, with flood risk management, the risks to people and property are the central emphasis, and thus not only water management measures are considered, but also measures to reduce the society’s vulnerability. This development in the approach to flood risk management can be linked to two societal trends. Firstly, in the last century, there was initially a tendency towards increasing faith in technological solutions culminating in a sense of full control over the environment, but this has been followed by criticism of the negative environmental consequences of technology and a decreasing faith in its potential. This tendency is reflected by the succession of flood defence, via flood control to flood management. Secondly, since the Enlightenment, there was a slow but steady tendency of ever-increasing specialisation in science and governance, but this too has been followed by criticism and a strong call for integration in the last decades. This is reflected by the appearance of approaches such as integrated water management and also by the steady integration of water management with spatial planning and environmental management at large.

**Could you be more specific about what ‘management’ is, then?**

The verb ‘to manage’ comes from the Italian *maneggiare* (to handle — especially a horse), which in turn derives from the Latin *manus* (hand). In flood risk management we are trying to ‘handle’ the risk of flooding that we face: to achieve the right balance between the economic, social and environmental dimensions of flood risk reduction, both today and into the future.

Management includes various activities, such as investigation of the problem and possible solutions to the problem, planning of resources and timing, implementation of measures and instruments, and monitoring of the progress against the plans and the goals and effects achieved.

Again, this is a continuous or cyclic process, not a one-off activity.
The EU Floods Directive

Background
Following devastating floods in several parts of Europe in recent years, EU environment ministers agreed in 2004 that there was a need for greater European co-ordination on flood risk management. In April 2007, the Parliament and Council of the European Union agreed the European Directive on the assessment and management of flood risks. The Council adopted the Floods Directive in September 2007 and it came into force on 26 November, 2007. The Integrated Project FLOODsite is listed as one of the European actions which support the Directive.

The requirements
In essence, the Floods Directive requires member states to prepare the following assessments for the European Commission:

- Preliminary flood risk assessments to identify areas that are at potentially significant flood risk, by 2011;
- Flood hazard maps (showing the likelihood and flow of the potential flooding) and flood risk maps (also showing the potential impact), by 2013;
- Flood risk management plans (showing measures to decrease the likelihood or impact of flooding), by 2015; and
- Updates every 6 years thereafter that take into account the impact of climate change.

The assessment process must be aligned with the environmental objectives of the Water Framework Directive and carried out in consultation with stakeholders.
And what exactly is ‘flood risk’?

There is no single definition of flood risk, because the concept of risk has developed across many disciplines and these different disciplines have used the word in slightly different ways. In FLOODsite, flood risk is defined in at least two alternative ways, each of which has certain advantages in different applications.

1. \[ \text{risk} = (\text{flood}) \text{ hazard} \times (\text{exposure}) \times \text{vulnerability (of the society/area)} \]
2. \[ \text{risk} = \text{probability (of the flood)} \times \text{consequences} \]

The first definition specifies the two quintessential elements of flood risk, namely floods posing a hazard, which means that they potentially have harmful effects, as well as a vulnerable society/area, which means that it can be harmed by those floods. Obviously, without exposure to a certain flooding depth, not even a very vulnerable society/area will be harmed. So, if any one of these elements is zero, there is no flood risk.

But the word risk also refers to probability, chance or likelihood. That element is better reflected in the second definition, in which the probability of the flood(s) is specified. Obviously, probability may refer to the probability of flooding (the hazard), or to the probability of exposure or finally to the probability of consequences. The final sense suits FLOODsite’s definition of flood risk.

And so what is a flood …?

Here we are on safer ground. A useful understanding is “A temporary covering of land by water outside its normal confines”. So there are three elements:

- **Time:** Water permanently covering land, such as in a lake, is not a flood.
- **Geography:** The water must cover land, by temporary occupancy (although this may be for weeks or months).
- **What is normal:** Water is usually confined to a river, a lake or a sea. A flood is water that breaks free from those confines.

In the EU Floods Directive (see textboxes), the term ‘flood’ means “the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems”.

A flood is only not ‘normal’ in so far as it occurs infrequently. This does not mean that flooding is unnatural: all rivers cover areas away from their channels with their water for some of the time (on their floodplains), and low-lying coastal areas are often flooded quite naturally during storms.

Floods, whether normal or extreme, may be considered to belong to the perfectly natural behaviour of rivers, lakes, estuaries and the sea. But they may potentially cause harm to society, and that is where the term ‘hazard’ comes in. A hazard is a physical event or human activity with the potential to result in harm. In flood risk management, we are only interested in floods which constitute a hazard.

So if a flood is a natural hazard, when does one speak of flood risk?

Well, a flood is a ‘natural hazard’ in so far as natural processes can cause “a temporary covering of land by water outside its normal confines”. But one may dispute whether all floods are ‘natural’ hazards. If an embankment or a dam breaches and the result is the flooding of land and property, one might argue that human activity has created the potential to result in harm or at least increased the strength and suddenness of the flooding.
The EU Floods Directive: some details

Preliminary flood risk assessment (Articles 4 & 5)
It is essential that flood mitigation actions are only taken in areas where potential significant flood risks exist or are reasonably foreseeable in the future. If in a particular river basin, sub-basin or stretch of coastline no potential significant flood risk exists or is reasonably foreseeable in the future, Member States can identify them in the preliminary flood risk assessment. For these river basins and/or sub-basins no further action need be taken.

Flood hazard and flood risk maps (Article 6)
Flood hazards and risks are to be mapped for the river basins and sub-basins with significant potential risk of flooding for three scenarios:

• Floods with a low probability or extreme event scenarios
• Floods with a medium probability (likely return period > 100 years)
• Floods with high probability, where appropriate

The maps may show information on flood extent, depths and velocity of water, and the potential adverse consequences.

Flood risk management plans (Article 7)
Flood risk management plans are to be developed and implemented at river basin or sub-basin level to reduce and manage the flood risk where identified as necessary in the preliminary flood risk assessment. These plans are to focus on the reduction of potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity, and, if considered appropriate, with non-structural initiatives and/or on the reduction of the likelihood of flooding. They are to address all phases of the flood risk management cycle but focus particularly on:

• Prevention (i.e. preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas or by adapting future developments to the risk of flooding),
• Protection (i.e. taking measures to reduce the likelihood of floods and/or the impact of floods in a specific location such as restoring flood plains and wetlands) and
• Preparedness (e.g. providing instructions to the public on what to do in the event of flooding).

Boundaries and international basins (Article 8)
Article 8 covers the boundaries of plans and in particular the need for collaboration between Member States for international river basins which extend across several Member States or beyond the boundaries of the Community.
But as for the question: the definition of flood risk we gave requires (1) that the probability or likelihood of flooding is taken into account as the essential hazard characteristic and (2) that a vulnerable society/area is actually exposed to experience the harm which the hazard only potentially poses. If a flood occurs where there is no vulnerability (i.e. no property; no people; no fragile environments) and hence no harm, than this hazard results in no risk.

In one sentence: the essence of flood risk in contrast to flood hazard lies in taking into account the probability distribution of all flood levels and the likely consequences of all possible floods.

**What different kinds of floods can be recognised?**

Different types of floods can be recognised on the basis of:

- Origin of the water (source)
- Geography of the receiving area
- Cause
- Speed of onset

With **origin of the water**, one may differentiate between water from the sea (coastal floods), from rivers (fluvial floods), from above (‘pluvial’ floods) or from below (groundwater floods and sewage overflow). This partly coincides with a differentiation in **geography**:

- Coastal and estuarine flooding: when the sea invades the land (as in Hurricane Katrina in 2003)
- Fluvial flooding: when rivers overflow their banks (as in Cologne in 1995) or cause the breaching of embankments (as along the Elbe in 2002).
- Areal flooding of catchments, urban areas or polders: when drainage capacity is insufficient to carry rainstorm water away fast enough (as in large parts of the south of England in 2007)

With **cause**, floods can be distinguished resulting from excess rainfall (inland), storms (coastal), earthquakes (tsunamis) and floods resulting from dam break (man-induced).

With **speed of onset**, one may distinguish “flash floods” from slower flooding types. Flash floods can occur in mountainous area during intense rainstorms; they are characterised by high flood water velocity. Rapid onset can also occur where flood defences are breached (e.g. a dam or dike failure). Low speeds of onset generally occur when flood waters accumulate slowly over days or weeks in large catchments like the Po or the Elbe, or where the drainage regime (natural or artificial) cannot accommodate even low rainfall intensities, so that localised ponding results.

**Do these different floods pose comparable risks?**

No, the characteristics of these floods are quite different, which influences their consequences; their probability of occurrence differs too, which again affects the risk they may pose.

- Coastal flooding through storm-surges may affect large areas and have enormous consequences, both in terms of fatalities and in economic damage. The 1953 flood disaster which hit the Netherlands and the UK, and the 1960 flood in the German Bight are examples, as is Hurricane Katrina (2003). Such coastal floods are relatively rare, can be foreseen between a few days to 24 hours ahead, can affect large areas and large numbers of people, and happen during weather conditions which disrupt evacuation and rescue.
Meuse flood 1993 at Roermond
• Fluvial floods along large rivers occur in large catchments. They tend to cover the largest areas by flooding large floodplains at the lower end of catchments during prolonged periods, but can be foreseen days ahead – allowing time for warning – and are characterised by slow rise. They bring about huge damage and may affect many people, but generally cause few fatalities.

• ‘Pluvial’ floods in upper catchments, urban areas and polders may be localised when resulting from summer storms, but can also be large-scale when caused by weather conditions related to huge low pressure areas (e.g. Elbe, 2002; England, 2007). They can have devastating effects on densely occupied urban areas, but the consequences are usually limited to damage and seldom include fatalities.

• Flash floods, instead, are small-scale killers. They are very localised in size, but occur frequently, especially in southern Europe. They are difficult to forecast, as they relate to local convective thunder storms. Flash floods never appear in the statistics for great disasters, but are responsible for large mean numbers of fatalities each year and cause great damage owing to their high flood water velocities and debris load.

So the greatest consequences, in general, may come from extensive fluvial floods, the breaching of coastal defences without good warning, urban areas flooded by intensive and sudden rainstorm events leading to rapid runoff and high flood water velocities, and floods in small steep catchments. But ‘may come’, as these are only the hazard characteristics. The actual risk, of course, depends on the vulnerability of the area.

Ah, ‘vulnerable people or property’. Does that mean that there is no risk without vulnerability?
Correct! Central to ‘hazard’ is the potential for harm, and risk only arises where vulnerable populations (human or otherwise) or property are exposed to this hazard. We can have a hazard without risk, but no risk without both exposure and vulnerability. It’s simple, really!

And what about this simpler definition of flood risk (probability x consequence)?
Well, as already said, one can simplify the definition of risk, firstly, by substituting the two terms ‘exposure’ and ‘vulnerability’ by ‘consequences’. A ‘consequence’ results when a vulnerable person or property is actually exposed to a flood and suffers some actual harm. Secondly, the hazard should then be characterised by its probability distribution. This yields:

Risk = probability x consequences

Hence, a large risk may arise because there is a high probability of a flood (say every winter) with only modest consequences. Or, a large risk may arise because there is a very small probability of a flood – such as 1 / 1,000 per year – but with high consequences, such as if central London were to be flooded from the North Sea.

Conversely a small risk could result from a small probability or minor consequences, or a combination of both (e.g. the infrequent flooding of playing fields, unoccupied car parks, or rough grazing land).

This idea of risk seems very logical and rational; but is this also how people experience and view risk?
Not really! There has been a lot of research on this subject in the 1980s and 1990s, and nowadays it is generally acknowledged that there is a discrepancy between how risks are formally quantified and how people perceive risk and whether they accept risk. This needs to be taken in due account, but it has not affected the way risks are formally being
quantified. For the above definitions of risk allow comparison of different situations on a
formal basis and benefit/cost analyses for risk reduction measures, despite the fact that we
know that lay people take other aspects into account when they ‘assess’ risk.

Firstly, lay people distinguish between risk from natural hazards and hazards caused by
human activities. Natural hazards are accepted far more easily. But not all flood hazards
are perceived as natural, because flood defences and engineering works suggest that
‘authorities’ have control over the floods. Then there is the possibility – and tendency – to
blame these authorities.

Secondly, in the perception of lay people, the consequences of events are not only easier
to grasp, but also more important than their probability. The consequences are therefore
given more weight in the judgment of risk. This means that lay people judge 100 fatalities
with a 1/100 per year probability as being worse than 1 fatality every year.

Thirdly, the acquaintance of lay people with an event influences their perception. People in
flood-prone areas often know how to act, whereas people in flood-protected areas may
panic when confronted with the danger of flooding (experience in the Netherlands in 1995
when some 200,000 people were evacuated).

Fourthly, the sense of self-control is important: what possibilities do people see to evade
the risk, to reduce it, or to otherwise cope with it. Some risks are those that we can
control (e.g. smoking cigarettes; driving fast cars). Others we cannot control ourselves
as individuals (aeroplane crashes; air pollution induced diseases). Yet others cannot be
controlled at all (e.g. meteorite strikes). The (often false) sense of self-control explains
why many people fear flying more than driving a car. Individuals are often quite optimistic
about what they can do themselves in case of floods. And many flood risks are generally
regarded as manageable to a large extent.

Finally, in their actual behaviour, people take into account the personal advantages of
running a certain risk. This also explains why people accept very high risks in traffic, of
smoking cigarettes, of drinking and eating too much and too fat, etc. In the context of
flood risk management, personal gains are seldom obvious, except perhaps in the case of
restaurant owners on the coast, but still many people settle in floodplains. Flood risks are
in practice, however, regarded as unsought risks.

**How are flood risks viewed in relation to other risks in life then?**

Well, some general characteristics of flood risk in relation to other risks have been
addressed above, and these are relevant for such a comparison.

Floods can largely be regarded as natural hazards, except for dam breaks and failing flood
defences. Therefore, flood risks are more accepted than risks from accidents in industry,
chemical transports or nuclear power plants. And floods are seldom on purpose, in
contrast to acts of terrorism. But, obviously, flood risks do not classify as risks taken
voluntary, like smoking, drinking or bungee jumping. This makes them less accepted.

Floods may have enormous consequences in terms of many fatalities and billions of Euros
of damage, but floods may also be small and manageable. This strongly influences how
flood risks are viewed and it explains geographical differences between countries, but also
within countries. Floods may cause disasters affecting a whole country’s sense of control
and the views of a whole generation, like the 1953 disaster did in the Netherlands. Flash
floods are real killers, but on a small spatial scale, whereas pluvial and slow-rise fluvial floods often merely cause material damage, but for large numbers of people.

Floods with large consequences generally elicit a call on the authorities to take responsibility.

**What does the peoples’ view mean for flood risk management?**

All people, whether aware or unaware of the actual flood risk they run individually, have their own rationality, and this is not necessarily the same as that of the scientist or the flood risk manager. It is not sensible to judge that one is ‘correct’ and the other is not; they are different. But this variability does mean that in many cases action cannot be delegated to individual people.

When, for example, people judge that “it will not happen to them”, the state may have to intervene instead, taking collective responsibility for mitigating the hazard or its consequences. For many individuals this is a rational response: serious floods are rare events.

Or when, again for example, people are not even aware that they live or work in a flood-prone area and consequently take no action, this may also be the trigger for collective action by government or its agencies, in the face of public apathy or complacency.
Thames barrier at London

Flooding of the active floodplain along a branch of the Rhine at Deventer

Cause-effect chain or SPRC model (Source – pathway – receptor – consequence)

**Source**
- e.g. rainfall, wind, waves

**Pathway**
- e.g. overtopping, overflow, flood plain inundation

**Receptor**
- e.g. property, people, environment

**Harm**
- e.g. loss of life, stress, material damage, environmental degradation
CHAPTER 2

On flood risk assessment: how big is the risk?

How does one assess flood risk?

As we have seen, a hazard has the potential to cause harm. A hazard does not automatically lead to a harmful outcome, but the identification of a hazard does show that there is a possibility of harm occurring. The actual harm depends upon the exposure of vulnerable receptors to the hazard.

The actual risk can be analysed by identifying a chain of causes and effects: rainfall or storms causing high water levels; high water levels causing either a load on flood defences or the immediate flooding of floodplains; the load on the defences causing failure of, for example, an embankment; the failure causing breach growth and inundation; the inundation drowning people or devastating property. A specific form of such a cause-effect chain is the Source-Pathway-Receptor-Consequence model, which originates from environmental research. It was meant for the analysis of pollution problems, where a substance moves from a distinct source to distinct receptors. But the more general form of the cause-effect chain can be applied to almost any problem, and therefore also to flood risk analysis. It allows the distinction between flood hazard, pathways resulting in exposure of ‘receptors’, and flood consequences to people and property.

When all these elements have been analysed and quantified in objective terms, the results (‘risk metrics’) can be evaluated in normative terms: the final assessment.

How does one usually analyse flood hazard?

An analysis of flood hazard should focus on the characteristics of all possible floods, small and frequent as well as big and rare. This means one needs to establish the probability and magnitude of all floods, by investigating:

1. The probability distribution of floods of different magnitudes at a particular location;
2. The geographical extent of all these floods;
3. The depth and duration of these floods;
4. The velocity of the flood water’s flow

To determine these characteristics, one may use knowledge of floods in the past, but for rare events this may not suffice and the circumstances – for example the floodplain area – may have changed. Therefore, it is necessary, by research, to investigate the probabilities and magnitudes of all possible floods.

Is such an analysis the same for flash floods, lowland rivers, estuaries and coasts?

Yes, in essence. No, in practice. The same four hazard characteristics mentioned above may be important; but not equally important, as every flood type is different. Also, there may be large differences in these characteristics between protected areas and unprotected areas.

- In flash floods, velocity is very important, and debris concentrations are generally higher than is the case for other floods. Extent is often easy to establish, because the floods are constrained in narrow valleys. The analysis of flash flood hazard usually focuses on probability and prediction, as flash floods are local scattered phenomena in small catchments resulting from showers and thunderstorms which may develop locally in a few hours in summer (convective clouds);
An example of a relationship between flood frequency (expressed in return period (years)) and magnitude (expressed as the flow discharge (in cubic metres per second)).
• Lowland floods tend to cover much larger areas than floods in upland areas and may last very long. They result from prolonged rainfall over large areas associated with warm or cold weather fronts drifting in from the ocean (advective clouds);
• Floods in estuaries can result from a coincidence of river floods meeting high water levels in the sea generated by storm surges or high tides; their particular characteristics are thus related to the joint probability of the two flood water sources;
• Coastal floods are a function of tides, storm surges and wave conditions, so again their character is a function of joint probabilities. Coastal floods are, in practice, unlikely floods of large extent.

Obviously, the flood characteristics described above will also be very different in protected and unprotected areas. In unprotected areas it will be natural for flows to exceed channel discharge capacity at times of high precipitation, and the resulting flood water will enter and occupy the river’s floodplain; the same will happen at the coast when high tides and storm surges coincide to flood coastal lowlands. The probability of flooding is then equal to the probability of the water level exceeding the bank level or land level.

In protected areas, in contrast, flooding also depends on the probability that flood defences are overtopped or breached. This depends on the reliability of the defences in relation to different loading conditions, particularly from the pressure or impact of the water on the defence structures. The flood probability must then be established as the probability of failure of the defence structures as a function of the combined exceedance probabilities of water levels and wave heights.

**So probability is an essential feature? How is the probability of floods defined and determined?**

Floods are episodic events. Large floods are rarer than medium sized or small floods. The probability of each size of event can be characterised as the chance that it will occur in any one year (its annual probability). It is important to realise that this is not the same as a recurrence interval. Floods do not, as earthquakes or volcano eruptions, recur periodically after building up tension, but instead have the same probability of occurrence each year. A very large flood might have an annual probability of only 1% or 1:100 per year, whereas a moderately large flood may have an annual probability of occurrence of 10% or 1:10 per year. Thus, within a 100 year period, on average only one ‘very large’ 1% flood should occur but we might expect 10 ‘moderately large’ 10% floods. And so on.

For events that occur repeatedly, the probability is usually estimated from the relative frequency of occurrence of that event in the past. In each case, the event in question has to be precisely defined, and clear reference has to be made to the time period, for example, the annual exceedance probability. For example a 1:1,000 annual probability of flooding can also be expressed as a 99.9% protection level (‘that sounds good!’) or as an 8% chance to experience it in a life-time (‘that sounds less good!’).

We can estimate the probability of floods by examining the record of flood events in the past, using what are essentially statistical interpolation techniques. This is easiest for lowland rivers and at the coast, where there may be decades or even centuries of river flow (discharge) and water level records available. If, say, 100 years of fluvial flow records are available, as on the Thames, the Rhine or the Po River, it is possible to assess the discharge that corresponds with the 10% probability flood by interpolation between the data.
Overflow

Wave overtopping

overflow and overtopping
erosion
sliding
piping
Establishing the size (discharge or height) of the more rare events, for example the 1% or the 0.1% flood, is more difficult. This used to be done by statistical extrapolation to derive a full magnitude-frequency relationship beyond the available data (Figure 2.2). Statisticians state that extrapolation of homogeneous data is only allowed up to 3 times the measurement period. Thus one cannot say anything about more rare events, which is, obviously, unacceptable from a flood risk management point of view. Therefore, extension beyond these limits is still common practice. Against this background it is obviously essential to show the ‘error bands’ around the central estimate, which results from interpolation and extrapolation, showing the degree of uncertainty.

At the coast, there are locations with decades and even centuries of tide records. Wave data are also collected. By statistical analysis, involving both interpolation and extrapolation, the water level associated with the 10% or the 0.1% event can be determined. Where there are no tide gauges, one may have to resort to extrapolating from nearby locations where there are records that can be used. Again, ‘error bands’ around the central estimate are required to show the degree of uncertainty.

With flash floods, the starting point is often the probability of rainfall events that can generate such floods. This is because rainfall statistics for small catchments are generally more plentiful than flow records. However the chance of the fluvial flow occurring is not the same as the chance of the rainfall event that causes the flood, because catchment characteristics intervene between the two.

Recently, for rivers, extra discharge data derived from modelling exercises are sometimes added to the recorded data. This so-called ‘synthetic’ approach involves the computer-generation of weather conditions over prolonged periods by randomly picking from measured data for individual days, followed by rainfall-runoff modelling to produce extra discharge data. Similarly, for the coast, modelling the effects of certain weather conditions on storm surge and waves may yield data on extreme water level probabilities.

In every case - for flash floods, for lowland rivers, for estuaries and coasts, and for urban floods (where interactions with sewer systems will be important) – the result is a percentage chance of a particular event of a particular size within a given time period at a given location, e.g.:

- a 1% flood
- within any one year
- at Cochem on the river Moselle
- would have a flow discharge of approximately 4,000 cubic metres per second.

Is the probability of particular flood levels the only issue; or is there something else we should know?

Yes, there is something else. Many areas are protected from flooding by embankments and other flood defences. For example the majority of the Netherlands lies below sea level and is protected by embankments, dams and storm surges; most of central London is protected against storm surges from the North Sea by the Thames Barrier; the same applies to the large floodplains with embankments and polders along the main rivers of Europe, such as the Rhine, the Rhone, the Elbe, the Danube or the Po.

The probability of flooding in such areas is more difficult to establish, as it is also a function of the probability of the failure of the defences (the embankments; dams; sea walls; dune systems, etc). So, for flooding to occur there has to be, firstly, a hazardous flood level, and
Example of a fault tree of a section of an embankment in the German Bight for the relevant failure modes.

Flood hazard areas (blue) in the Ebro delta when sea level would rise with 0.25 m (left) and 0.5 m (right).
then, secondly, a failure of the defence. The probability of flooding behind the defence is a function of both probabilities (the ‘joint probability’ of the flood’s causes). To calculate these probabilities we need to know about the reliability and the strength of the defences for various failure modes.

These are not easy to determine and, notwithstanding important Floodsite research in this field, it remains hard to accurately establish the probability of floods caused by defence failures. Given that many areas of Europe’s floodplains are protected to some degree or other from flooding, this makes these risks difficult to manage because the probability of flooding there is very uncertain.

I guess flood probability is not constant in time; nowadays everybody talks of climate change and sea level rise, development in catchments, etc ..? That’s right. Flood probability can change if the sea level or the precipitation regime change, or if the characteristics of the catchment (source area) or river valley (pathway area) change from which floods originate or by which they are conveyed. This may influence the amount of discharge or the shape of the discharge wave which runs through the valley.

For example, if sea levels rise (as they are forecasted to do worldwide), then the probability of sea walls or dune systems being overtopped or breached will rise. If precipitation amounts rise (as they may do in northern European winters over the next century), then the probability of a flood at any riverine location will rise too, as will the probability of embankments being overtopped in protected areas.

For pathways, land-use change – and in particular urbanisation – may increase the rate and volume of flood runoff in small catchments, increasing the probability of local floods. This affects the rainfall-runoff relationship. In other situations, increased vegetation growth in floodplains may slow the river’s current and cause backwater effects and higher flood levels, altering the discharge-water level relationship.

The key message here is that the past cannot be the sole guide to the future: we live in a ‘non-stationary world’. Given that many flood risk mitigation measures take years or even decades to implement (e.g. embankments, dams, flood barriers or sophisticated flood warning systems), the implication is that one has to plan these for the flood probabilities of the future, not for what has been experienced in the past. Complex modelling may be required to determine the likely probabilities of future floods.

And what about exposure then? How is that analysed?
Exposure refers to people, their activities and their goods, threatened by a hazard. Actually, it is most easily expressed as a spatial ‘overlay’ of hazard characteristics (extent, depth, duration, rise rate, flow velocity) and the vulnerability characteristics of an area. In its quantification it is, for example, the number of people exposed, or the number and type of properties exposed to a hazard of a certain size. Clearly in this analysis one needs to distinguish between protected and unprotected sites: both may have the same extent of exposure, but the probability of flooding as well other hazard characteristics – such as depth and rise rate – will be very different.

To assess exposure one should first analyse the geography of the flood hazard: its areal extent and other characteristics (depth; velocity; time to peak, etc). This can be done at least partially with reference to historical records, maps, photographs, remote sensing data, and other information on floods that have occurred in the past. Often, however, it
Hazard characteristics as established with a 1D-2D flood simulation model (Task 8)

- moment of first inundation computed with a coarse grid (left) and a finer grid (right)

- water depths computed with a coarse grid (left) and a finer grid (right)

- flow velocities computed with a coarse grid (left) and a finer grid (right)
is also required to investigate exposure to more rare floods and/or possible future floods. This will normally require some form of hydraulic computer simulations (i.e. modelling) in order to characterise a number of typical floods. It will also be necessary to look at exposure when defences are overtopped or fail; this requires the modelling of (or assumptions about) breaches in flood embankments or walls, or the effects of the failure of moveable structures such as flood barriers or gates.

Many computer models are available on the market, at research institutes and at universities. These allow many different kinds of simulations to be made. Which model is most suitable depends on which processes are important for the type of flood event being modelled and the objective of the modelling (e.g. for real time flood forecasting; spatial planning; embankment design, etc), but also on available time, money, computer capacity and data.

Next, we need to establish the number and kind of receptors that may be influenced by a flood: the degree of exposure. One common way of achieving this is to produce an overlay of the hazard map with a map of the receptors: the demographic, socio-economic and environmental characteristics of the area. The resulting overlay maps are sometimes referred to as risk maps, even when they do not give any information about probabilities of consequences. As such, they are only a first approximation. They can, however, help delimit areas where flood warnings are needed, spatial planning for flood risk mitigation should be exercised, and where other risk reduction measures should be targeted.

**What information is needed about these receptors?**

Information is needed about the number, location and type of receptors exposed, encompassing people, property, etc.

As far as **people** are concerned, data must be collected on the number of people who reside, work or travel in the area liable to flooding (and their demographic characteristics, as these affect their personal vulnerability). Data on the number and types of residents can often be obtained from national censuses, although the geographical units used to collect census data may not match the flooded area. Those working in the exposed area can be assessed by field surveys or from secondary sources of data on industrial and commercial enterprises located there. Assessing the number of people who travel through the area liable to flooding may need special surveys or data from state transport departments.

As far as **property** is concerned, data are needed on the number or area of different types of property (houses; factories; etc), as well as on their value and their susceptibility to flooding. There are two principal ways to obtain this required land use information: by carrying out field surveys (primary data) or, more usually, by relying on existing land use data (secondary data).

The advantage of **primary data** is that all required land use and property information can be collected at the level of detail that is needed. This means, for example, that a more detailed classification of land use and property types can be used than is usually available from **secondary data**. The disadvantage is that field surveys are time-consuming and costly, whereas secondary data such as national censuses of land use are often readily available. The main disadvantage of secondary data is that it is almost never solely produced for the purpose of flood risk assessment (often it is collected for local property taxation purposes) and, therefore, it will probably not contain all necessary information at the required level of detail.
<table>
<thead>
<tr>
<th>Form of consequence</th>
<th>Tangible</th>
<th>Intangible</th>
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<tbody>
<tr>
<td><strong>Direct</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physical damage to:</td>
<td>buildings</td>
<td>loss of life</td>
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<td></td>
<td>other property</td>
<td>adverse health effects</td>
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<td></td>
<td>infrastructure</td>
<td>loss of ecological values</td>
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<td></td>
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<td>loss of cultural values</td>
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<tr>
<td><strong>Indirect</strong></td>
<td></td>
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<tr>
<td>- loss of industrial production</td>
<td>- inconvenience of post-flood recovery</td>
<td></td>
</tr>
<tr>
<td>- traffic disruption</td>
<td>- increased vulnerability of survivors</td>
<td></td>
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<tr>
<td>- emergency costs</td>
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Types of flood consequences, with examples
How does exposure relate to an estimation of consequence?

As explained above, the analysis of exposure is usually a simple overlay of (a) hazard characteristics and (b) characteristics of those areas that are vulnerable to flooding: the receptors (principally people and property but also ecosystems). The degree of exposure is important for analysing and assessing flood risk, but being exposed does not automatically mean being affected. Not all exposed people die or get ill, not all exposed property is lost or turned useless. And, quite differently, significant consequences of floods may be felt in areas which are not directly exposed. For example, it is difficult to portray on an exposure map the indirect effects of a flood, such as the business interruption for firms affected when their offices or factories are flooded or – more complex still – when such factories are not themselves flooded but their supply routes are affected by flooding and this forces them to close.

For the quantification of all direct consequences of flooding, exposure is a key factor. After all, depth, rising speed, flow velocity and other factors determine the chance to survive a flood, whereas water depth is the paramount factor which determines the damage to property. Estimating the consequences for people and property in terms of loss of life, health, wealth, etc, thus requires knowledge about exposure characteristics.

If exposure can be incorporated in the quantification of the hazard, how is that done?

Hazard maps may be specific about flood probability, depth, speed, onset, flow velocity, etc. They may do so not only for natural floodplain area but also for areas protected by embankments. Thus, such hazard maps – or data – actually provide information on exposure probability. This is common practice in most European countries. It suits the definition of risk as hazard x exposure x vulnerability, which is best suited for mapping exercises.

In some countries with many protected areas, for example the Netherlands, hazard analysis focuses on flood probabilities for combinations of load conditions and defence failure, whereas anything after that point is covered by damage modelling and loss-of-life modelling using the results of 2-dimensional overland flow models as input. Exposure is then implicitly incorporated in the quantification of consequences. This suits the definition of risk as probability × consequence. And it is well-suited for quantitative risk analyses.

How are flood consequences quantified, in general?

Generally, flood consequences are quantified as the monetary losses and the intangible effects that occur if an area is flooded. Flood consequences come in several different forms.

It is common practice to distinguish between direct and indirect consequences. Direct flood consequence covers all harm which results from the immediate physical contact of flood water with humans, property and the environment. This includes, for example, damage to buildings, economic assets, loss of standing agricultural crops and livestock, loss of human life, immediate health impacts, and loss of ecological and cultural goods.

Indirect flood damages are damages caused by disruption of physical and economic linkages of the economy, and the extra costs of emergency and other actions taken to prevent flood damage and other losses. This includes, for example, the loss of production of companies affected by the flooding, induced production losses suffered by their suppliers and customers, the costs of traffic disruption and the costs of emergency services.
Formulae for injuries and loss of life in floods from the UK

The number of injuries and loss of life in floods are calculated as functions of 3 ratings:

- **Hazard Rating** = function of the flow characteristics of the flood, i.e. depth (m) and velocity (m/s) and the ‘debris factor’ (score).
- **Area Vulnerability** = function of the effectiveness of flood warnings, speed of onset, type of buildings
- **People Vulnerability** = function of the number of very old people (over 75) and long term sick/disabled/infirm. This factor is expressed as a percentage.

The number of injuries caused by a single flood event is calculated as:

\[ N(I) = \frac{2N_Z \times (\text{Hazard Rating} \times \text{Area Vulnerability}) \times \text{People Vulnerability}}{100} \]

Where:
- \( N(I) \) = number of injuries
- \( N_Z \) = population living in the floodplain

The number of fatalities from this flood event is then calculated from the injuries formula as this is considered to be a function of the number of injuries and the hazard rating.

\[ N(f) = \frac{2N(I) \times \text{HR}}{100} \]

Where:
- \( N(f) \) = number of fatalities
Damages which can be easily quantified in monetary terms, such as damages to assets, loss of production etc. are called tangible damages. Fatalities, health effects or damages to ecological values and to all kind of goods and services which are not traded in a market are far more difficult to assess in monetary terms. They are therefore categorised as ‘intangibles’ and generally quantified via social surveys of those affected, or simply assessed with rating scales (‘severe’; ‘moderate’ or ‘minor’).

So, this means that although flood risk management aims to reduce risk, and risk covers all the consequences of flooding (damages; other losses) some of the most important of these losses cannot satisfactorily be quantified. In FLOODsite this issue has been addressed by applying Multi Criteria Analysis to achieve overall risk classes in two pilot areas (Mulde River and German Bight).

**Could you clarify how potential loss of life can be quantified?**

Well, this is surprisingly difficult, but also of great importance because many flood risk management policies and measures are aimed at public safety (e.g. flood forecasting and warning systems; evacuation). In order to be able to prioritise activities to promote this safety one needs to know where injury and loss of life in floods are likely to be greatest. But it is very difficult to estimate numbers of fatalities, because these not only depend on physical characteristics of floods and area affected, but also on the people’s behaviour. And this behaviour is very difficult to predict.

Various countries have loss-of-life models available or are developing these, for example the UK and the Netherlands. The FLOODsite project has attempted to develop for wider EU application a UK model for prediction of injuries and deaths in floods. Loss-of-life models usually relate the probability of injury and death to a number of relevant factors, such as:

- The flood’s hazard characteristics (depth, velocity, debris load, etc.)
- The area’s characteristics which influence exposure (building type, warnings, etc)
- The population’s characteristics which determine vulnerability (age, health, etc)

Records of injury in floods are very sparse, and even data on flood deaths is not collected systematically in any EU Member State. When it is collected, there are definition problems: for example, a large proportion of deaths during floods occur in vehicles that are washed away, but these deaths are often officially recorded as road traffic deaths rather than flood deaths. This poses difficulties to the calibration of any loss-of-life model. The output of such models should therefore be regarded as indicative only; very useful for comparisons between different areas or when assessing the relative effect of measures. But the predicted absolute numbers of injuries and deaths are very uncertain, as they rely on many assumptions, and not only about the behaviour of water but also about the behaviour of people.

Given the problems with this type of approach one might fall back on simple look-up tables. This relies on a simpler yet more reliable approach based on the factors that affect loss of life in floods. It can be used to identify where the risk to life in European floods is likely to be greatest.

**Could you clarify how economic damage of floods is quantified?**

Monetary losses are usually quantified as the loss of value of the receptors in question, or as the cost of restoring these receptors to their pre-flood condition. The loss of value can be expressed as a percentage (or fraction) loss of total value as a function of water depth, flow velocity, etc. This is expressed in ‘depth-damage curves’ and similar dose-effect curves.
We know that flood duration is also important (long duration floods cause extra damage), and that flooding from the sea also causes extra damage owing to the salinity of the flood waters. However, less good data are available on these relationships, and the precise effects of flood duration and salinity on flood damage are less well understood.

A piece of complex electronic equipment may be damaged beyond further use in a flood: even when partly submerged its damage is already 100% (a ‘total-loss’, although the components may have some scrap value). On the other hand goods such as bricks in a builder’s yard may be resistant to flood damage and only require cleaning after a flood: their damage might be only 5% of their value.

By multiplying the percentage loss with the value of the object one obtains the loss of value in monetary terms. Obviously, this must be done for all objects in a flooded area to obtain total damage. Depending on the scale of flooding and the availability of data this can be done on the basis of detailed knowledge on individual objects or on land use types from topographic maps only. Depth-damage curves will need to be available for these objects or land use types or will have to be prepared.

The thus-established damage covers the direct damage of a flood, but sometimes indirect losses (e.g. due to business or transport interruption) also need to be considered.

**We have discussed loss of life and economic damage now, but what about other effects?**

Indeed the consequences of floods are more than just economic or financial losses and loss of life, important though these are. Some of these consequences are the adverse effects of floods on people’s health, the loss of their treasured possessions, and the time taken in reacting to and recovering from a serious flood event.

The health impacts of floods on people depend on the following:

- Personal characteristics: age, social status, employment status, gender, home ownership, single parent status, prior health or long-term sickness;
- Characteristics of the context: the recovery process and associated household disruption, the efficiency of insurers and builders.

It has been established that the psychological effects of floods affect more people than do the physical health effects, and that they last longer. These psychological effects include anxiety, stress and depression, and flood victims are known to suffer from Post Traumatic Stress Disorder.

Floods also have ecological effects, not only adverse, but also favourable; ecosystems and species can therefore also be considered as receptors. The favourable effects will include, for example, the benefits from the water and sediments that floods bring to wetland areas, thereby enhancing these locations as bird habitats. Floods thus help to maintain the natural character of these areas and the biotic diversity that they support. The unfavourable effects will be where floods invade areas where the ecosystems are not water-tolerant, or where floods lead to erosion or deposition of sediments to the detriment of the species normally based there, or where flood waters disperse pollutants that adversely affect floodplain habitats and/or their species.
Calculating overall risk as expected annual damage (EAD),
with \( D \) = damage and \( p \) = probability

\[
EAD = \int_0^1 D \, dp \approx \sum_{i=1}^{N} (D_{i+1} + D_i) \cdot (p_{i+1} - p_i) / 2
\]
Common to these other consequences, like loss of life, is the difficulty of measuring them in monetary terms, although for some consequences it is being done. Insurance companies, for example, put monetary values on loss of life as a matter of routine. The health effects of flooding can be assessed by gauging the resources needed to restore people to their pre-flood condition, in terms of medication, hospital treatment and other needs. Remediation costs can be attributed to pollution incidents. Despite these exceptions, these consequences are normally expressed using their own metrics.

**Have I understood well that risk analysis is the combination of probability analysis and consequence analysis?**

Yes. We cannot just consider the probability, extent, duration and depths of a flood in isolation, because that flood might have no detrimental effects, by not negatively affecting any valuable receptor. Were that to be the case, in risk management terms, we would not be concerned.

In turn, just to know the socio-economic effects of one flood in terms of damage or loss of life is not sufficient: we need to know how often floods of different magnitudes might occur (i.e. their annual probability of occurrence). For example, if a flood were to be very rare indeed (say with an annual probability of 0.01%) then the flood risk management measures that one might consider implementing would be different to those to be considered if the same flood were to have an annual probability of occurrence of 10%.

So the flood risk that we are concerned about is the combination of both the probability distribution of all possible floods and their likely consequences.

**How can that be expressed then?**

Risk has a probability and a consequences dimension and thus is scaled as the probability of certain consequences. This can be represented either by a graph of consequences against probability – termed a ‘magnitude-frequency diagram’ – or by calculating the average annual consequences. The latter gives the Expected Annual Damage (EAD), the Expected Annual Number of Affected persons, and/or the Expected Annual Number of Fatalities (EAN). When large numbers of fatalities are expected with very small occurrence probabilities, a common way of expression is to use a so-called FN-curve. This shows the exceedance probability of large numbers of fatalities.

The way to calculate risk is always a more or less sophisticated variation on a theme, namely by calculating the consequences of a certain flood of known probability. Take, for example, a flood on the river Elbe in Germany that results in 1 Million Euros of economic losses. If that flood has a probability of occurrence of 4% or 1:25 per year, the risk contribution of that specific flood in terms of expected annual damage is:

\[
\text{Expected Annual Damage} = 1 \text{ Million Euro } \times 1/25 \text{ per year} = 40,000 \text{ Euro/year}
\]

This kind of calculation would be useful to compare different floods. If, say, another flood in an adjacent area had a probability-times-consequences value of Euros 100,000 Euro/year, we could say that the second flood was “two-and-a-half times as bad” as the first, assessed as its calculated risk.

The full flood risk at a site consists of the effects of all floods that can be experienced at that site, not just those of one single event. This can be represented by a graph of damages (or other consequences) against probability. This yields a ‘magnitude-frequency diagram’. The overall Estimated Annual Damage (EAD) is then the area under the curve, which

-
Multi-Risk Analysis of the Mulde River

The Mulde River pilot study (Task 10) drafted risk maps for the present situation as well as for the situation after implementing all measures planned within the Flood Protection Conceptual Plan (HWSK). The difference in the standardized risk value between the situation with and without measures is the benefit of the planned measures.
can be accurately calculated as the integral of the probability-consequence curve, or approximated by the sum of a number of 'representative' flood events. This value, and the shape of the curve, characterise and summarise all aspects of flood risk at that site.

If the EAD for one site were to be 2.5 times the EAD at another site, we could say that the economic flood risk at the second site was two-and-a-half times greater than at the first site. Similar calculations can be made for number of fatalities and number of affected persons. And, of course, more specific risks can be calculated in a similar way too.

Many things seem uncertain, both regarding probabilities and consequences. Could you elaborate on uncertainties a bit?

Indeed many things are uncertain. We already discussed that floods are infrequent phenomena for which it is difficult to establish the exact probability distribution. Next, the reliability of flood defences is difficult to define, and so is the location where defences may fail. The consequences of frequent floods are rarely well documented, but the consequences of more rare floods can often only be established by calculation because they may never have occurred yet. And the results of such calculations cannot be validated by empirical data because of a lack of such data. All in all, we have to work with uncertain figures and, since we multiply these with each other, this results in risk metrics that are even more uncertain.

Within FLOODsite special attention was given to determining the uncertainties associated with the variables that contribute most to the probability of failure of defences. But FLOODsite has also identified all the uncertainties that affect the analysis of risk and decision making about risk management and gives guidance as to how to deal with these.

Uncertainties can be divided into three main groups:

1. Natural variability: Natural variability can be subdivided into natural variability in time and natural variability in space;
2. Knowledge uncertainties: uncertainties that come from basic lack of knowledge, for example about the behaviour of defences;
3. Fundamental uncertainties: uncertainties about things we cannot know, for example the distant future.

An important difference between these groups of uncertainty is that natural variability is a matter of fact which cannot be reduced, in contrast to knowledge uncertainties that can be reduced by further research. Natural variability can be known, however, and represented as probabilities. This allows taking them into account in risk analysis. Some statisticians (cf. Bayesian decision theory) maintain that knowledge uncertainties can also be represented as probabilities and can hence be included in the calculation of flood probability and risk. Others (‘frequentists’) prefer a clear distinction between variability and uncertainty, and plea for showing uncertainty in terms of error bands or alike.

Now we know about some facts and their uncertainties, could you explain about the (e)valuation of risk? When is risk ‘tolerable’ and when isn’t it?

Analysing and quantifying risk as discussed above is a technical matter, but flood risk assessment involves a normative judgement. Assessment thus needs to take account of human understanding, emotions and tolerances; of individuals and/or society as a whole. And since floods are episodic events, and people forget about their adverse impacts in between events, this is not straightforward. Therefore, it is necessary to distinguish between an individual perspective and the perspective of responsible authorities.
From an individual perspective it is important whether floods are life-threatening or just a nuisance; whether they cause huge material losses and immense stress or are just a matter of life people are used to ‘live with’. This largely depends on the type of flood. But additionally, individual people and communities also have different levels of tolerance of floods related to personal or community characteristics and circumstances. Those living off the natural resources of wetland will see floods as beneficial. Those losing their jobs if the factories in which they work are flooded and have to close will see the same flood as highly disadvantageous. People injured in the same flood will again have different views and emotions, as will the relatives of those who die in floods.

These individual ‘tolerances’ appear to be a function of at least the following:

• The perception and understanding of possible flood risks, and the other risks that the same people face;
• The benefits and costs to the communities concerned as a result of the floods;
• The ability of individuals and communities to help themselves or reduce the consequences;
• The degree to which a flood is seen as an ‘Act of God’ or as the ‘fault’ of someone who can then be ‘blamed’.

This is a complex research field and FLOODsite has only investigated some aspects of it. But it is nowadays understood that a risk assessment is incomplete without thoroughly understanding how the risk is perceived by those running it. Risk is not absolute: it is a social or mental construct that varies according to the social context.

For the responsible authorities, it is necessary to ‘integrate’ or ‘generalise’ the views of individuals, communities and others at risk, but also to take into account the view of other parts of society in their judgement of acceptability. Authorities may also be expected to forget less easily and hence to have – or at least apply – a more steady opinion on acceptability of flood risks than individuals. Moreover, responsible authorities also need to take into account the impact of a possible flood disaster with large numbers of fatalities for the image of the region or entire country – or for their own image, for that matter.

When performing a flood risk assessment, it is essential to express flood risks in terms which are relevant from an individual point of view as well as from the point of view of authorities. This requires that one is very explicit about the criteria used, about how they are calculated or estimated, and about how they are judged. This enables well-informed discussions between stakeholders and responsible authorities.

Are the views on tolerable/acceptable flood risk the same in different countries?
No, they are not. But they also differ within countries. Obviously attitudes to flood risk differ according to the different risks associated with geographical differences (low-lying coastal plains, large river valleys, gently undulating hillside or steep mountainous areas with flash-floods), but they also differ because of different views on the responsibility of authorities.

For example, in the Netherlands the flood hazard that the country faces is given a very high national priority, owing to the memory of the 1953 disaster and the fact that much development has taken place below sea level. Moreover, for decades the authorities have given the impression of being able to fully control flood risks, which means that the Netherlands’ public now hold them fully responsible for flood risk. This can be partly understood by the fact that only floods resulting from the failure of defences are expected to be really dangerous, whereas floods resulting from heavy rainfall are usually addressed as ‘water inconvenience’.
Protection standards in the Netherlands

Thames river flood 2007 at Wittenham
In the UK, recent flooding in 2007 has heightened public awareness of flood threats, as has government attention for future climate change. Nevertheless, in the UK floods are still mainly regarded as a natural hazard and less as the result of failing management. Virtually all floods are caused by heavy rainfall and nobody expects government to prevent rain from falling. The geomorphology of the country unfortunately causes the water to concentrate in valleys, but this again is not something which can be changed. Spatial planners are being blamed, however, for allowing development in flood-prone areas.

_It seems we now know what flood risks are, their magnitude and their societal importance; I suppose we proceed towards what can be done about those risks ...?_

Yes. Let us proceed to the next chapter. But, remember, we now see the need to regard risk as the result of flood probability and societal vulnerability. And we also see the need to use a range of tools and involve various scientific disciplines in flood risk assessment – not only the natural and technical sciences but also the social sciences.
CHAPTER 3

On management measures and policy instruments: how to reduce flood risk?

When risks result from a combination of flood hazard and societal vulnerability, which one should be addressed to reduce the risk?

Flood hazard and societal vulnerability can both be relevant, depending on the local situation. In other words, flood risk can sometimes be best reduced by managing hazard characteristics, such as flood probability or extent, whereas in other situations reducing exposure and/or vulnerability of people or property is preferable. It is down to the site-specific situation whether flood probability reduction, exposure delimitation or vulnerability reduction is the most effective or the most desired. One of the key notions of flood risk management is that we at least consider both hazard and vulnerability while searching for the best solutions. This means that one should take into account natural sciences and engineering as well as social sciences and spatial planning.

There is a wide range of measures and instruments to reduce risk in different ways, such as flood alleviation, early warning, flood defences, flood zoning, flood proofing, insurance, etc., etc. All these measures and instruments may be effective in their specific manner. Their relevance, though, depends on the main causes of risk in the first place. Moreover, the national or regional traditions of flood risk management, the availability of money and other factors determine which measures and instruments are favoured. There is no standard repertoire of the ‘top-ten actions’ for reducing flood risk all over Europe. But, of course, the question what measures and instruments to choose requires some knowledge about their performance.

Pause, please. You introduce so many new things now. Please first explain what you mean by measures and instruments?

Measures and instruments are the actual ‘tools’ by which risk can be reduced. Measures are physical interventions in the environment, which exercise effect directly through their existence, for example embankments. They are usually implemented by the flood risk managing authorities. Instruments – or policy instruments –, in contrast, are no direct physical interventions in the environment but rather means to influence the behaviour of other parties who co-determine the flood risk. For example: communication to warn inhabitants, insurance fees to make companies aware of the flood risk they run, or regulations to force local planners to better take into account flood risk.

Measures traditionally include all kinds of permanent structural measures, i.e. river and coastal engineering works, such as dams, flood walls, embankments, or river training works. Over the last few decades attention for non-structural measures gained ground – beyond the field of river and coastal engineering – such as catchment management to enhance water retention, erosion control by reforestation, river rehabilitation, temporary defences, etc..

Policy instruments are intended to influence the attitude and/or actions of others than the immediate responsible authorities themselves. Three main groups of instruments can be distinguished, namely communicative, financial and regulatory instruments. Communication may, for example, enhance the people’s risk awareness and preparedness. Financial instruments may influence people’s investments or may encourage them to flood-proof their property. Regulatory instruments, such as land-use regulations, allow or prohibit certain activities. A popular way of addressing these three groups of policy instruments is as ‘chatter’, ‘carrot’ and ‘stick’.
<table>
<thead>
<tr>
<th>goal</th>
<th>aim</th>
<th>character</th>
<th>name</th>
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<tbody>
<tr>
<td>flood probability reduction</td>
<td>physical measures</td>
<td>conservation tillage, dams/reservoirs, reforestation, restoring meanders in brooks and rivers, retention in upstream catchment, retention of water in cities, wave breakers</td>
<td></td>
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<tr>
<td>Flood defence &amp; control</td>
<td>physical measures</td>
<td>embankment construction/strengthening, flood barrier, mobile flood wall, coastal sand supply, by-passes, connect rivers to existing lakes, dredging rivers, embankment relocation/realignment, floodplain lowering, removing obstacles to lower hydraulic roughness, river bed widening</td>
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<tr>
<td>control of flood patterns</td>
<td>physical measures</td>
<td>compartmentalisation of areas, detention areas/calamity polders, floodway, ring dikes along villages/cities, mounds</td>
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<tr>
<td>adaptation &amp; regulation of use of flood-prone area</td>
<td>physical measures</td>
<td>flood proofing</td>
<td></td>
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<tr>
<td>regulatory instruments</td>
<td></td>
<td>building restrictions, land use zoning, regulations on storage of toxics/chemicals, adaptation of recreation functions, adaptation of agricultural practices</td>
<td></td>
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<tr>
<td>financial instruments</td>
<td></td>
<td>fines for damage, increasing behaviour, subsidies for flood proofing or other measures</td>
<td></td>
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<tr>
<td>distribution of flood impacts</td>
<td>financial instruments</td>
<td>damage compensation, governmental relief funds, insurances</td>
<td></td>
</tr>
<tr>
<td>preparedness</td>
<td>communicative instruments</td>
<td>crisis management, education of inhabitants, evacuation plans, flood forecasting, flood risk maps, flood warning systems, radio/television information channel</td>
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Examples of measures and instruments and their character
In practice, measures and instruments are not so separate as represented here. It is virtually impossible to implement any structural measure without appropriate regulations, without communication about the reason for its implementation and without some financial compensation for those affected by it. And the other way around, policy instruments influence the behaviour of others which may materialise in a physical form, for example, by moving to another area, by flood-proofing the houses, by raising the ground before development, etc.

**Could you give some examples of measures?**

The best known measures are the so-called structural measures, i.e. concrete, earthen or other engineering structures. These may be aimed at flood prevention by reducing the amount of discharge running down a river, for example through reservoirs used for retention purposes. They may also be aimed at flood protection, as is the purpose of flood defences of various kinds, such as embankments, flood walls, storm surge barriers and temporary defences. Along rivers, structural measures may also be aimed at the rapid unhindered discharge of water through a river by installing training works, such as normalisation or canalisation. And along coasts many structures aim at reducing the destructive power of waves, e.g. by wave breakers or groynes. Such structural measures are still the most commonly applied measures. They aim at flood prevention, flood defence or flood control, i.e. in all instances some kind of control of the hazard.

Different flood types call for different kinds of measures. The largest variety of measures is probably applied to rivers, because the amount of water in rivers is finite which allows the application of not only flood defences but also measures aimed at influencing this amount per unit of time by upstream retention, temporary storage or of measures that lower the water level by increasing the discharge capacity of the river. For example:

- **Reservoirs** may be used for the retention of water in the upper catchment. They are constructed mainly in the headwaters of rivers and tributaries in mountainous and hilly regions. Though usually primarily intended for power generation, they may also be used to delimit the discharge through the river by reserving capacity for the retention of water during heavy rainfall. Stored flood water can then be released after the rainfall peak to restore the capacity of the reservoir.

- **Retention polders** along rivers can be used for the temporary storage of water once a critical level of discharge is exceeded, whilst allowing other land use, such as agriculture, for the majority of the time. Whilst also providing a reduction in discharge, retention polders generally have less ecological side effects than reservoirs. Retention polders differ from normal polders because they have controlled inlets and outlets, e.g. by spill-overs or sluices. Thus the moment of inlet and the flow rates can be controlled much better than when embankments are opened by blasting, which destroys the embankment. Thus, flood peak ‘shaving’ becomes more effective at lower costs. This was established for the Havel polder system, which could have performed better during the August 2002 flood in the Elbe River in Germany.

- **River training** is applied to increase the conveyance and hence the discharge capacity of rivers, which in turn means lower flood water levels. River training requires little space, but has significant ecological impacts. River training can involve straightening, widening, deepening and hard-lining of river channels.

- **Embankments and flood walls** are installed along rivers, estuaries and coasts to protect parts of the natural floodplain from frequent flooding, thus allowing agriculture or more intense development. Embankments and floodwalls do allow intensive use of the floodplain, but may be exposed to considerable loading during floods. They require maintenance and surveillance during flood events and are susceptible to failure. This is
'Room for rivers' measures

1 - lowering of gravel beds
2 - deepening low flow channel
3 - removing hydraulic obstacles
4 - lowering flood plains

5 - locally setting back dikes
6 - setting back dikes on a large scale
7 - retention reservoir
8 - reduction lateral inflow
particularly important as dike failures can increase losses as breaches cause sudden and rapid flooding of often intensively used floodplain areas where people had expected to be safe. Nevertheless, embankments and floodwalls effectively protect some important economic centres such as London or Rotterdam.

**These measures all seem quite conventional, if not old-fashioned. Aren’t there more innovative measures?**

Well, yes. Especially the ecological side-effects and the perceived ugliness of many structural measures have triggered a great deal of creativity to identify more environmentally-friendly measures. Many of these still focus on flood control and defence measures, but aim to minimise environmental impacts. For example:

- Local, small-scale retention in small catchments or storage of water in urban areas can reduce runoff (often termed ‘Sustainable Urban Drainage’ or SUDS). This is particularly important for the management of urban flooding caused by the overflow of sewer systems. It is effective for small to medium scale floods.

- ‘Room for rivers’ measures aim to increase the available floodplain area or the channel dimensions in larger rivers, whilst allowing natural developments and enhancing the perceived ‘spatial quality’ of the environment. Measures include removing obstacles from the floodplain, setting back embankments (or ‘managed realignment’ as it is called in England), the lowering of floodplains, or the construction of bypass channels or ‘green rivers’. The aim is to provide more room for discharge or storage along rivers while allowing more natural ecological development in the floodplain. It is a very mild version of what in Germany is intended with *Renaturierung* (re-naturalisation) of river corridors.

- *Temporary defences* combine requirements of accessibility with necessity of flood protection especially in urban areas.

**So far you have talked about structural measures, but what about other measures?**

Non-structural measures also imply physical interference in the environment, but without building obvious engineered structures. Examples are re-afforestation programmes in catchment areas, adapted agricultural practice aimed at limiting the runoff, or the cutting of trees and the dredging of channels to enhance the conveyance capacity of rivers.

Such measures are sometimes referred to as ‘soft’ measures. Although they involve physical interference – and hence technology – these measures do not rely on the introduction of large technical structures. Instead, they focus on changing the natural conditions of the catchment (source area), the channel (pathway area), or the floodplains (pathway or receptor areas).

Catchment measures are mainly designed to reduce the discharge. This can be achieved through increasing the infiltration and retention capacity of the soils by adapted agricultural practice, for example conservation tillage, ploughless cultivation, avoiding bare soils, etc., or by re-forestation. The contribution of such measures to the reduction of extreme discharges and flood levels is much more limited than commonly assumed, but they can play a role in reducing low and medium size frequent floods which may contribute substantially to overall economic flood risk.

Next, measures can be directed at changing the properties of channels and active floodplains. For example, a river’s discharge capacity can be enhanced by enlarging the channel’s width and depth and by removing plant growth. Some ‘Room for rivers’ measures can – in this sense – be regarded as non-structural, for example the lowering
Relation of dike location and usability of floodplains

- Increasing usability of flood-prone areas
- Decreasing damage potentials

Principles of dry and wet flood proofing

- Surrounding defences
- Sealing of openings
- Unsusceptible construction

Examples of flood-proof building and stabilisation
how to reduce flood risk?

of floodplains, or the dredging of the channel. Also re-naturalisation of rivers, which causes the slowing down of the discharge, is a non-structural measure. This provides more room for discharge and storage along rivers while allowing a more natural ecological development of the floodplain. At the same time the wave load on defences is tempered by the trees.

This is still all about hazard control, are there also measures to reduce vulnerability?

Indeed, most measures mentioned so-far are aimed at flood control or flood defence. But there are also structural and less-structural measures which aim to reduce the impacts of floods by either reducing the exposure of the receptors or their vulnerability.

With respect to exposure reduction, one might think of:

• Overtoppable, fail-safe embankments, for example through spill-overs, which guarantee gradual and foreseeable overtopping of dikes when the design level is exceeded, thus reducing the speed of onset and the inflow volume of the flooding process. The danger of surprises – sudden breaches in unexpected locations – can thus be reduced, while allowing for better prediction and easier evacuation. The expected damage is reduced through the reduced volume of inflow.

• Compartmentalisation of large polders into smaller ones can also reduce the impact of flooding, as the flooded area is delimited. In combination with some differentiation of the heights of the embankments, the when and where of flooding can be influenced.

Reducing the vulnerability proper of an area usually requires changing the land use. Housing, industries and services can, obviously, be best located on higher ground, i.e. outside the flood prone area. But within this land-use category one may distinguish further, by taking into account the capacity to self-help which is much less among elderly people, the disabled and children. Also emergency services need special attention in this respect. Of course, it is easier to not develop a floodplain than to replace the existing land use by something less vulnerable. Although in particularly exposed situations the relocation of whole villages has been implemented – as exemplified by the village of Röderau Süd on the Elbe River close to Dresden after the August 2002 flood.

In most existing situations, however, the principle of do things elsewhere cannot be easily applied, whereas the principle of do them else may apply. That brings us to measures such as individual mounds or stilts or flood proofing, the last of which can also be applied to existing buildings. Flood proofing should be done by private property owners to reduce the exposure of buildings or their susceptibility to damage from flood water. This may include the sealing of doors and windows, the waterproofing of walls or the use of waterproof construction material. Up to a certain flood level, and if properly implemented and maintained, flood proofing measures can contribute considerably to the reduction of damage to buildings.

Other possibilities to permanently or temporarily reduce the exposure of property include the moving of susceptible goods to upper floors, or entirely out of the area. A recent study in the City of Dresden showed that this is particularly effective.
Relationship between measures and instruments
If I understand correctly now, measures can be aimed at the reduction of both flood hazard and vulnerability; but what about those instruments then?

As you may have noticed in the answer to the former question, we have gradually come to measures which are in practice seldomly implemented by flood risk management authorities themselves, but which rather require action of communities, housing developers, property owners and individuals. Influencing their decisions and behaviour is what policy instruments are intended for.

Measures and instruments fulfil different roles in the reduction of risk. Measures directly influence the flood’s generation and propagation as well as the inundation, but also the exposure and vulnerability of people and property. Many of these measures can thus be implemented by public authorities within large scale programs. As, however, flood risk depends on the presence of people and property, any policy instrument which may influence this presence may also be relevant for flood risk management. Instruments, against this background, may thus be regarded to serve two distinct purposes, namely:

• supporting the implementation of measures by the authorities themselves;
• influencing the behaviour of other actors, including the implementation of measures by them.

Often risk reduction cannot be achieved solely by adjusting the physical properties of the flood risk system, or through the implementation of public measures. The vulnerability of an area is largely determined by the behaviour and decisions of people at risk, such as decisions about development of land, building or people’s behaviour during flood events. However, people are often not sufficiently aware of the risk they run or their own vulnerability, nor of the options they may have to reduce the risk to themselves, others and their property. Their individual interests may even conflict with the public interest of flood risk reduction by the authorities, for example when they can have the benefits of living in a floodplain, whereas the authorities cover the costs.

There are a number of possibilities to influence the behaviour, decisions and action of others through policy instruments. Policy instruments are usually distinguished by the degree of their bindingness to the individual:

• Regulatory instruments are backed by the legal framework and can be enforced by public administrations. They can be applied to influence land use and development, for example by risk zoning, building regulations and permits.
• Financial instruments are positive or negative financial incentives supporting decisions and behaviour by appealing to the individual’s economic interests. Compensation – a special kind of financial instrument – can mitigate incurred losses by distributing the losses across the wider society.
• Communicative instruments aim to raise awareness, immediate response or promote certain decisions and behaviour by appealing to a person’s sense of responsibility. Examples are raising risk awareness, flood alerts and or informing about options for risk reduction.

Policy instruments can thus regulate, stimulate (financial), or merely promote (communicative) desired behaviour, decisions and actions which reduce flood risk.

I guess not all these measures and instruments are equally effective, or are they?

No, they are not. But it is very difficult to give a simple and definitive answer to this question, as the effectiveness of measures and instruments depends to a large degree on the situation. Different measures perform differently in different situations.
Firstly, what may be effective along a river, for example the temporary storage of water to lower the water level, may not be effective along an estuary or the coast, where the amount of water is infinite. The same goes for policy instruments, for example flood warning. When a flood can be foreseen hours or even days ahead, warning can be very effective and even full evacuation of villages or larger areas is possible. In the case of flash floods, however, there is very little time. And coastal plains may sometimes require the evacuation of millions of people – e.g. in the Netherlands – which is virtually impossible in the available time. So the kind of hazard and the physical geographical context are important for a measure’s or an instruments’ effectiveness.

Secondly, the effectiveness of measures or instruments strongly depends on the socio-economic situation and the possibility of changing this. As remarked before, it is easier to not build in a floodplain area than to move existing villages or even cities. Thus, it may be theoretically effective but practically impossible to reduce the vulnerability of, for example, London, Hamburg, Rotterdam or Venice, by regulatory measures aimed at influencing the land use such as flood hazard zoning. Moreover, these cities are in these locations not only for historical reasons but also for good actual reasons; lots of money is being earned here thanks to their location!

Thirdly, whether structural measures can be implemented at all also depends on the institutional situation in a country. Usually, it is impossible to implement any structure without a sound backing through the legal regulatory framework, without sufficient money and without people’s support. This means that structural measures can only be effective when also the policy instruments required for their implementation are effective. So, measures can be effective only as far as they are supported by the associated instruments. In such cases, it is difficult to attribute a degree of effectiveness to a single individual measure or instrument.

Summarising, effectiveness can only be established for a measure or instrument in the context of a concrete problem situation and in relation to other measures and associated instruments. This requires a thorough assessment of a measure’s or instrument’s performance.

**How can the effectiveness of measures and instruments be assessed, anyway?**

The term effectiveness refers to the degree to which aims of flood risk reduction are achieved. Ideally, these aims are expressed in terms of avoided flood risk, i.e. in terms of expected annual damage, expected number of fatalities, expected number of people affected, or such like. In practice, however, the aims of flood risk reduction often refer to more down-to-earth variables, such as to a reduction in water level, to a decrease in flood probability, to a reduced area at risk, or to fewer potential flood losses. These kinds of effectiveness are easier to establish but also – principally – less relevant from a flood risk management point-of-view.

For the assessment of effectiveness one thus needs to establish two things: the achieved effect in comparison to the intended effect. First, one needs to know what the objective of the intervention was, in terms of a targeted difference between the situation with and without the measure or instrument in place. For example, if an area suffers a mean annual flood damage of 100,000 /yr and the aim is to avoid all damage, the objective is to reduce damages by 100,000 / yr. Next, we need to know the actual effect, which is the achieved reduction of flood losses, for example, a reduction of the mean annual flood losses of 80,000 / yr. With these two figures it is possible to calculate effectiveness, which in this case is 80%.
During floods weirs open (Rhine River, the Netherlands)

Bypass channels can discharge part of the flood water. Pannerdensch Kanaal, the Netherlands
The effectiveness of individual measures and instruments can be assessed before (ex-ante) or after (ex-post) implementation. Assessment before implementation requires that the effects of a measure or instruments are quantified as accurately and reliably as possible by applying the best scientific knowledge and technical means. Usually extensive modelling and advanced statistics are involved, but also quite a few assumptions may need to be made.

The assessment of effectiveness after implementation is one of the key issues in ‘learning from the past’. This requires that the performance of measures and instruments in place is evaluated, which is by no means easy for various reasons. Partly, this is because it is difficult to establish what the situation would have been without these measures and instruments as the present situation has evolved in response to the level of flood protection provided as well as in response to recent historic events. Along the Loire in France, for example, the vulnerability has strongly increased because the last ‘1:100 per year’ floods happened as far back as 1844, 1855 and 1866, whereas the Elbe in Germany experienced a ‘1:100 per year flood’ as recently as 2002. Evaluating the success of measures in place is also difficult because this irregularity of flood events in many cases makes it difficult to ascertain that a measure or instrument has been effective at all; how can we establish effectiveness when no flood event has happened to prove it?

So, effectiveness is a difficult but key criterion in assessing the performance of measures and instruments.

**But effectiveness is not the only important criterion?**

No, effectiveness is one of several important criteria to assess the performance of measures and instruments. Of course, achieving the intended reduction of risk is very important. But it is obviously also important to consider costs of implementation and maintenance — if it is possible to achieve the same effect for less money this deserves consideration. And also side effects of measures and instruments on the environment, the economy or social equity are important. Certain measures and instruments for flood risk reduction may conflict with other societal goals, such as nature conservation or economic development, so one should always balance the benefits of risk reduction against the losses in other areas of societal interest. This calls for a full consideration of all side effects, i.e. all tangible and intangible costs to society.

The ratio between the effect and the monetary costs of the implementation and maintenance of a measure or instrument is called its **efficiency**. Efficiency is usually assessed through **Cost Benefit Analysis** (CBA). The output of a CBA is the overall Benefit-Cost Ratio (BCR) or the ratio between the Net Present Value (NPV) of the effect and the costs of interventions at different points in time. Establishing the efficiency of various measures and instruments allows ranking them for the purpose of rational decision making.

Some sophisticated CBA methods not only include monetary implementation and maintenance costs, but attempt to include also other costs and benefits, tangible and intangible, by assigning financial values to them. However, the monetarisation of intangibles is quite controversial. Moreover, not only do the intended effects of measures depend on the situation in which they are implemented, the same applies for the costs and the unintended side-effects. This complicates an assessment on full societal costs and benefits of individual measures and instruments to such an extent that it is difficult — if not impossible — to formulate any generic conclusions on the performance of measures and instruments separate from the context of their application.
Flooding the Havel polder along the Elbe to lower the flood peak
Perhaps we should come back to this fundamental problem later. But did I understand it correctly that along coasts other measures are better than along rivers?

Yes, some generic judgements are possible, namely where these relate to the type of flood. And coastal floods are obviously very different from river floods.

Coastal floods are normally caused by storm surges in combination with high tide and huge waves which demolish flood defences. The amount of water in the sea is practically unlimited – excluding flood water storage options which perform so nicely along rivers –, but the water level that can be reached is restricted, which allows defending against it. The causes, forces and volumes of water require hazard reduction to focus particularly on flood defence. The large-scale nature of coastal plains requires exposure reduction to consider compartmentalisation. And vulnerability reduction can be attained by land-use planning and the provision of escape routes from the flood-prone coastal plains.

Typical defence measures are:
• Breakers or groynes installed along the coast to dissipate the wave energy;
• Offshore reefs or artificial reefs to dissipate the wave energy;
• Embankments and sea walls which can resist the forces of the waves and remain intact during overtopping;
• Sand/sediment nourishment to the beach to attenuate the energy of the waves and to the dunes to counteract or compensate for erosion.

Typical measures to reduce the vulnerability of the coastal plains are:
• Compartmentalisation;
• Elevation of roads to be used for evacuation;
• Safe havens.

Against the background of climate change and sea level rise, both historic and innovative measures are nowadays being proposed for coastal flood risk management. These include elevated construction on mounds, or the retreat from high-risk areas. Such measures may do well for isolated buildings or small villages in sparsely populated areas, but appear less conceivable for large cities and economic areas such as London, Rotterdam or Hamburg, which are all at risk from coastal flooding.

And are estuaries also different?

Estuaries, like coasts, are also mainly at risk from storm surges but experience less large waves. In addition, however, in estuaries storm surges meet with the discharge of rivers. From an analytical point-of-view this is very complicated, as joint probabilities must be taken into account in establishing flood-level probability. From a management point-of-view estuaries need protection during storm surges, but should also allow fluvial discharge to the sea.

Thus, in addition to the commonly applied defence structures along river channels, such as dikes and walls, so-called storm surge barriers can be important, particularly in exposed estuaries. This type of barrier is constructed across the estuary mouth to prevent surges from extending into the estuary and causing floods in harbours and cities. Well-known examples of storm surge barriers are the Thames Barrier downstream of Central London, the Eastern Scheldt barrier and the Maeslantkering near Rotterdam. These apply mobile gates which can close or open the river mouth within hours.
Necessity and challenges for flash flood detection and forecast

Flash floods, which occur in watersheds of up to a few hundred square kilometres usually with steep slopes and relatively impermeable surfaces, allow for response times of a few hours or less. Because of dispersed urbanization and transportation and the expansion of tourism in mountainous regions, human lives and property are increasingly exposed to flash-flood hazards. Therefore, even though physical measures and regulatory instruments are frequently used to reduce flash flood risk, residual risk may remain high. The suddenness of flash floods requires a complementary response, primarily through timely forecasting and effective warning. However, this imposes major challenges for further improvements of rainfall detection, flood forecasting and flood warning.

The flash-flood hazard is spatially defined by the thunderstorm scale. Such a small space and time scale cannot be effectively monitored by conventional observation systems of precipitation and river discharge, as these have too few gauging locations. For most flash-flood catchments discharge extremes are not known. Moreover, flood warning has traditionally focused on only some local communities and on the management of reservoirs. As a result, every river section can be considered as a potential target for flood warning. Flash-floods, therefore, pose three main problems: (i) the downscaling problem due to the differences in spatial and temporal scales between atmospheric models and the flash-flood triggering processes, (ii) the ungauged basin problem which requires that catchments must be modelled without calibration being possible and (iii) the limits of the water retention capacity of soils under the considered range of rainfall events.

Consequently i) prediction of flash-flood producing rainfall events is critically dependent on meso-scale storm monitoring, and specifically for processes conducive to slow movement of convective areas and ii) assessment of flash-flood hazards necessitates some form of real-time hydrological modelling. The same may apply to isolated convection over watersheds of some tens of km², in particular over urbanized areas.
And what about mountainous rivers with flash floods?

Flash floods are exceptional firstly due to their extreme dynamics and destructive forces and secondly because of their very rapid onset. By far the largest number of flood fatalities results from flash floods.

Areas prone to flash floods are not only endangered by water, but also by the destructive forces of high flow velocities and entrained sediment and debris. These forces mean that flash floods are difficult to control; only the course of the water can sometimes be slightly influenced in order to protect some property, but even this is very difficult. It is of utmost importance that the discharge channel is kept free of whatever obstacles, such as too narrow bridges, in order not to induce the choking of the channel which will inevitably cause overflow. All in all, one might judge that hazard reduction is not very effective. It is rather advisable to keep out of the way of possible flash floods and thus reduce exposure.

Flash floods are mainly generated in small catchments of up to several square kilometres, with steep slopes, impermeable surfaces or saturated soils. These catchments respond very rapidly to intense rainfall, causing floods within a few hours. This leaves little time for warning and evacuation. Therefore, the timely prediction of flash floods is a main challenge. There are a number of atmospheric and hydrological factors which are important for the generation of flash floods. FLOODsite has advanced the understanding of these factors and their interaction. This has improved the real-time modelling of possible flood waves.

Even when provided with the best possible forecasts, the response to flash floods must be well organised and rapid. Action must be fast and specifically adapted to the extreme dynamics and forces of flash flooding. Task forces for forecasting, warning and assistance must be sustained and kept operational around the clock. People at risk must be made well-aware about the risks and should know what to do, how to use the time available, and which routes are available at which time.

Against this background, a particular combination of measures and instruments may be regarded typical for flood risk reduction in flash flood basins, including engineering works to protect individual areas and objects; warning networks; preparedness raising among public services and land users; and rescue.

Could you now explain a bit more about the policy instruments. For example, those regulatory instruments, when do they apply?

The three main groups of policy instruments are characterised by different degrees of ‘bindingness’. They may aim merely to convince or tempt people to act and behave as desired, as is the intention with the communicative instruments; they may stimulate such behaviour by addressing the people’s economic rationality as intended by financial instruments; or they may oblige people to act and behave as desired, which is the aim of the regulatory instruments.

So regulatory instruments are the most binding instruments which authorities may apply to influence the actions and behaviour of others. Regulations are usually founded in a statutory and legal framework which can be used by public authorities to enforce compliance. Regulatory instruments may imply, for example:

- environmental designations and regulations (e.g. Coastal Zone conservation, Catchment protection);
- Flood Hazard Zoning, with regulations on allowable land use, cultivations, etc.;
- spatial planning;
- building regulations on constructions, technical layout of installations, etc;
- regulations on timely evacuation;
- etc.
Protection of installations and inventory below expected flood level

Communication on what one can do personally: leaflets

In many EU member states individuals are held partly responsible for minimising flood consequences. Communication of how this may be done is then issued by the authorities, e.g. the Environment Agency in the UK or Bundesländern in Germany, in the form of leaflets, guidelines, pictures, etc.

There are various options for home owners, dwellers and businesses to substantially reduce their losses, e.g. by different methods of flood proofing and/or relocation of property. Flood proofing measures can be incorporated during construction, or can be retrofitted to existing buildings. It may involve preventing flood water entering the building (dry flood proofing) by sealing openings or the installation of fixings for demountable flood barriers. Flood proofing may also involve the use of water-proof construction materials (wet flood proofing).

Relocation implies the temporary or permanent removal of susceptible and valuable goods, within a building (Figure 3.18, Figure 3.19) or to another place. Options include moving things to the upper floor or attic or the disconnection of electrical and electronic equipment and the central heating. For frequently affected buildings it can be worthwhile to adapt the whole installation.

Such actions require the acceptance of responsibility by the property owner and the preparedness to act before and upon warning. Communication aims to persuade people to do so, but may be supported by financial incentives or even regulations.

Moving technical installations and inventory to floors above expected flood levels
Flood Hazard Zones are often designated with the aim of preventing inappropriate development and influencing land use at large. Such designations usually restrict housing or industrial developments and can thus limit potential losses. Typically, Flood Hazard Zones restrict construction, the storage of hazardous substances and other susceptible and risky use of the area. However, in most European member states Flood Hazard Zones can seldomly be used to enforce moving existing properties, nor prevent their increase over time, if not accompanied by financial compensation to the property owners.

Whilst the designation of Flood Hazard Zones aims to reduce flood risks in receptor areas and along flood pathways, there are also regulatory instruments which can influence land use management in the catchments and headwaters of rivers. One example of such an instrument has recently been developed and applied by the Authorities of the Free State of Saxony (Germany), with the aim to improve the water retention capacity in flash flood catchments. The instrument prohibits land management practices which negatively influence the natural water retention capacity, but also provides financial compensation for, for example, afforestation.

Many regulatory instruments in the fields of spatial planning and environmental conservation are usually not specifically aimed at flood risk reduction; their impacts on flood risks are usually merely a side effect. But they can be very effective in influencing land use, such as, for example, the landscape protection according to German legislation which applies to the Elbe river valley in the City of Dresden. Although not aimed at risk reduction, this has prevented any construction in the floodplain during the time of the highest development pressure in the 1990’s. This may lead us to the recommendation to thoroughly investigate the potential effectiveness of existing regulations for environmental protection and spatial planning with respect to risk reduction. Such existing regulations may prove sufficiently effective and much easier to implement than any newly-to-be-created regulations.

As for the bindingness of regulatory instruments, it needs stressing that regulations without fines are seldomly effective, as are fines without a legal basis.

**And financial instruments, such as insurances. What about those?**

Financial instruments appeal to the economic rationality of the people by providing positive and negative incentives. These are a much weaker instrument than regulations as they leave the final decision to the ‘actor’. Positive financial stimulation can be realised by providing allowances or tax reductions for certain behaviour. Negative financial stimulation can imply fines for certain behaviour.

As for insurance, this is not primarily intended to influence the people’s decisions or behaviour, but rather to distribute losses over the wider community by involving many more members than can be affected over a period of time. We may distinguish between commercial and public insurance systems or solidarity funds. The advantage of insurance systems is that they can considerably improve the recovery capacity of flood victims and thus whole regions. This may also result in less disruption of business activities, loss of markets, etc.

As a result, however, the individual risk to property owners may lose its deterrence and may even encourage further investment (a so-called ‘perverse effect’). Interestingly, research conducted within FLOODsite indicated that private flood risk reduction measures were sooner applied in cases where no flood insurance was available to those at risk.
And now I guess communication is just explaining why all those measures and instruments are needed?

Communication is indeed about explaining all the rest, but not only; communication entails much more. Communicative instruments can also be effective in reducing risks by themselves. As independent policy instrument, communication may have two general aims. Firstly, it may aim to enhance the awareness and preparedness of people at risk, and even persuade them to change their behaviour and decisions. This primarily requires the sharing of knowledge through disseminating information from the authorities to the public. Secondly, there is warning in case of expected or ongoing flood events, which may require the action of both other – often local – authorities and the people at risk themselves.

Dissemination of information on hazards, risks, vulnerability and options for reducing risk or preferred behaviour may involve:

- Flood hazard maps displaying flood extent, flood frequency, flood depth, etc.;
- Leaflets or circulars containing information on what to do and when to do it, and preferred behaviour;
- Public events, etc.

Information is only useful when it reaches the target audience and shows options for action. Research conducted in FLOODsite showed that, while the quality and penetration of flood warning is improving considerably, a large part of the vulnerable population is often still not informed about the risk or about the options available to them to reduce the risk.

Warning conveys urgent information about expected or ongoing flooding, which may require evacuation or other action. It is particularly important to trigger the deployment of demountable defences or evacuation. Various traditional and modern media are used for warning, including sirens, radio, telephone, fax, text messaging (sms), etc.

So, communication is also about sharing responsibilities? Who then is responsible for flood damage in the end?

Well, both in preventative flood risk management and in flood event management, authorities play an important role, but so do all stakeholders, i.e. the people and property owners at risk. The authorities determine the opportunities – by regulations, financial stimulations, etc. – based on which developers, industries, and individuals decide and act. The interaction among all these actors causes risks to increase faster or slower, determines the protection level asked for, determines the management strategy opted for through various combinations of protection and land use regulations, etc. It is, therefore, difficult to establish to what extent the authorities, to what extent developers, and to what extent individuals are to be held responsible. In practice, their decisions and actions are completely interwoven and change constantly over time. The present risk situation is thus partly a heritage of earlier balances of power, and this may also determine how people perceive their own responsibilities in risk management as well as those of ‘the’ authorities. Consequently, this differs with the different cultures in Europe.

In practice floods, of course, always cause losses to individuals. This requires that people at risk must – and are likely to – take some responsibility themselves; for example by reducing their own exposure and vulnerability either by moving or by taking appropriate measures before and during flooding. Actually, this is increasingly being required by legislature in various European Countries. And in many countries people can buy insurance, like in the UK, which is also a kind of putting down responsibility with individual stakeholders.
Strategy making as multidimensional phenomenon

Strategy is a consistent whole of long-term goals and aims, of measures and instruments to achieve these, as well as of ideas about how to implement these measures and instruments, which is continuously adjusted to the changing societal context. In that sense, strategy is a multidimensional phenomenon which encompasses the dimensions of:

- content ("deciding what to do"),
- process ("deciding how to do it"), and
- context ("aligning strategic decisions with internal and external conditions").

The figure shows these three dimensions and lists some important categories within each.
In contrast, some other EU member states have a tradition of arranging flood risk management through collective organisations based on solidarity among stakeholders, for example the water boards in the Netherlands. And the national authorities will – in the end – financially stand for (part of) the losses resulting from dike breaches, as insurance against floods resulting from dike breaches is not possible here.

It seems many measures and instruments are available to reduce risks, but how should one decide on which measures and instruments to apply and which not? Indeed this is the key question in the difficult task of designing flood risk management strategies for the future for specific areas at risk.

Now you use the word strategy in relation to flood risk management. What does that mean?

A strategy can be understood as a frame of reference, which helps in making decisions on which measures and instruments to implement, as well as on how to implement them in the course of time. FLOODsite defined a strategy as: a consistent whole of long-term goals and aims, of measures and instruments to achieve these, as well as of ideas about how to implement these measures and instruments, which is continuously adjusted to the changing societal context. This understanding encompasses three crucial elements of what a strategy is about, namely the content (‘deciding which measures and instruments to apply’), the process (‘deciding how to apply them’) and the context in which decisions are taken (‘constantly adjusting decisions to changing internal and external conditions’).

The contents of a strategy are often addressed to as a strategic alternative, which term refers to a coherent set of flood risk management measures and instruments.

So a strategy is about acting in the course of time ...?

Yes, strategies relate to a situation which is bound to change over time. That is why the old-fashioned blue-print planning does not suffice, as this does not allow for adjustments to be made. On the other hand, the goals and aims of a flood risk management strategy must be kept in mind continuously and not be wandered away from.

Also, a strategy should take into account acting in the course of time to prevent that somebody simply judges: ‘Great strategy, but lousy implementation’. Instead, it should be recognised that if strategies are formulated without considering their implementation, they are lousy strategies from the start and likely to fail.

In practice, this means that it is often best to begin flood risk management planning by taking small steps. Sometimes, however, it is feasible to formulate and implement a great new strategy for reducing flood risk, for example after a flood disaster has happened, because people are then more willing to accept flood risk management measures and instruments. This new strategy should be thought-out and ready to implement then, which requires that it was thoroughly studied beforehand.

All right, and now about this process. Who are the relevant actors in flood risk management?

That is difficult to answer, as it entirely depends on the situation. Large rivers often have a dedicated authority for their management, but this does not necessarily cover flood risk – which resides in the floodplains –, and sometimes not even the flood defences. Countries with huge flood-prone areas, such as the Netherlands, Hungary or the Italian Po Valley have institutions which were especially installed to manage water and water-related problems, including flood risk. But in countries with only small flood-prone areas
how to reduce flood risk?

– without coastal plains and with primarily small rivers – flood risk management is usually just one task among many others of institutions with a general responsibility for the environment.

In many countries there is a division of tasks between institutions who are responsible for water management – including flood hazard reduction – and those who do spatial planning – including vulnerability reduction. This requires horizontal co-operation between those institutions.

Besides, in most countries there is also a division of tasks between national, regional and local authorities, but often they all have to be engaged in some way. This requires vertical co-operation, especially when there is a danger of transfer of costs (or problems) to another scale level.

Thirdly, preventive flood risk management may usually be the responsibility of water managers and spatial planners, but during a flood event usually other parties altogether know what to do and take charge: contingency planners, police, fire brigade, first-aid teams, etc. This also requires co-operation through time, as these parties are sometimes not aware of how the flood will behave.

Finally, as the flood risk management measures and policy instruments affect all kinds of property owners and other stakeholders, many other authorities and various public, semi-public, and private agencies may have to be involved in one or another moment. Again, this will require much co-operative effort, as well as needing someone to be ‘in charge’.

In short, for each specific situation the relevant actors must be discovered and mapped. This can be pursued by a so-called actor analysis. Such an analysis is often restricted to formal relationships between institutions with formal responsibility. The usefulness of actor analysis can, however, be greatly improved by also investigating where the real decisions are being made and which institutions or persons have real influence.

You mention differences between European countries. Could you give some examples and general trends?

Indeed, different European countries have different institutional arrangements and governance traditions. These are too many for a thorough treatment. Therefore, we give only a few examples.

Above, the Netherlands was already mentioned as an example of a country where a dedicated national authority, Rijkswaterstaat, is responsible for setting protection standards and managing the main water bodies for more than 200 years already, but the waterboards are held responsible for maintaining many embankments, which they sometimes do for more than 800 years already.

In the UK, in contrast, flood risk management is co-ordinated by the Environment Agency under the responsibility of DEFRA. The assessment of flood risk management schemes is thus co-ordinated at national level by many acts and regulations, as well as the national funding of these schemes. The actual measures and instruments, however, are implemented and maintained at lower level.

In Germany, the arrangement of flood risk management differs per region (‘Bundesland’), but the responsibility generally lies with the regional ministry of spatial planning or environment. In practice, however, many initiatives to take measures are taken at local or regional level.
<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>empowerment</strong></td>
<td>people have mandate to act</td>
</tr>
<tr>
<td><strong>ownership</strong></td>
<td>people feel involved / committed</td>
</tr>
<tr>
<td><strong>participation</strong></td>
<td>people are fully participating (two way)</td>
</tr>
<tr>
<td><strong>consultation</strong></td>
<td>people are consulted (one way up)</td>
</tr>
<tr>
<td><strong>informed</strong></td>
<td>people are informed (one way down)</td>
</tr>
<tr>
<td><strong>awareness</strong></td>
<td>people know that something is happening</td>
</tr>
<tr>
<td><strong>ignorance</strong></td>
<td>people do not know what is happening</td>
</tr>
</tbody>
</table>

Seven levels of stakeholder involvement
The increasing contact between countries through regional and European research co-operation as well as the influence of the EU-Directive on flood risk assessment and management result in some convergence in approach in the various countries, also affecting the national institutional arrangements and governance. For example, the shift towards flood risk management and away from mere flood defence or flood control requires countries to co-ordinate water management and spatial planning.

And what about stakeholders: what kind of stakeholders should be taken into account?
Preferably, one should take all stakeholders into account which means all people, property owners and organisations who have a stake in reducing flood risk or who may be affected by the implementation of the measures and instruments. Many people have a stake in short- to medium-term planning, because this really affects them. Long-term strategic planning, in contrast, is primarily intended for generations to come. The then-stakeholders are difficult to involve, but various non-governmental organisations (NGOs) are often willing to stand in for them.

Stakeholders can be traced by means of a so-called stakeholder analysis. This is somewhat similar to an actor analysis, but primarily aims at identifying all stakeholders while being less interested in how they are related to each other.

The question of how to take stakeholders into account is quite a different question, however, which is not so easy to answer.

Nowadays, we hear a lot about public participation: what about that?
Public participation is one the various ways to involve stakeholders and more remote actors in the planning of flood risk management. It is promoted in the EU-Directive on flood risk assessment and management. Participation implies a more close involvement in the planning of a flood risk management strategy than mere consultation does. Many countries are now gaining experience with this kind of stakeholder involvement. FLOODsite gave little attention to this issue, as other EU-research programmes had already thoroughly addressed it (e.g. HARMONI-COP).

Okay, back to the key question of how to design the best solution for areas at risk then: how should one decide on which measures and instruments to apply and which not?
In the foregoing, we have already discussed a number of relevant criteria by which one might select measures and instruments, for example on the different effectiveness of measures in different physical geographical situations, and on differences in cost-effectiveness in different socio-economic contexts; a very vulnerable area may justify more expensive measures. Important additional issues to decide on relate to questions such as whether to opt for retention upstream or rather for on-site measures such as flood defence or reducing the vulnerability in the floodplains. This pertains to the spatial transfer of benefits and costs – or negative effects of measures – to other areas.
We also acknowledged already that the present situation often reduces the possibilities of spatial planning in the sense that villages and cities cannot easily be moved, but that future development may still be influenced effectively. And we did establish that some measures are real alternatives, in the sense that it is either one measure or the other, but that other measures and instruments only perform well when combined. And some measures exclude each other or are otherwise incompatible.
How measures and instruments exactly interact – counteract each other or instead yield synergy – can only be found out by assessing combinations of measures and instruments. This requires that measures and instruments are combined in a sensible and coherent way into so-called ‘strategic alternatives’ for flood risk management. These alternatives should then be assessed, where we need to recall that flood risk management is not a goal in itself, but rather a means to achieve sustainable development, which requires balancing social goals, economic goals and goals pertaining to ecological integrity and cultural heritage.

Actually the issue of designing and assessing strategic alternatives for flood risk management is so fundamental, that it deserves a more thorough treatment. Let us devote a whole chapter to this issue….
Conclusions of FLOODsite research on the design of strategic alternatives

A FLOODsite review (Task 14) led to the following conclusions for practical applications:

• design strategic alternatives by content (of goals, aims, measures and instruments) only; in contrast to strategies which also comprise process (institutions, responsibilities, timing, etc.).

• design no more than 4 strategic alternatives; perhaps 3 will suffice, but a zero-alternative ('do nothing' or 'continue current practice') is quintessential for reference purposes.

• design strategic alternatives according to a top-down approach, defining clear and opposite guiding principles, such as resistance versus resilience, and/or by specifying different objectives (economy versus ecology, people versus material damage, etc.).

• If scenarios are being developed related to perspectives, then name (and design) the strategic alternatives according to these perspectives as well: a controlist’s, an egalitarian and a market-optimist’s strategy.

• All strategic alternatives should consist of combinations of structural and non-structural measures/instruments; and all alternatives should aim at both hazard control and vulnerability reduction – although their respective shares may deviate substantially.
CHAPTER 4

Flood risk management for the future: how should one decide what to do?

So, how does one decide what to do, in risk management?
Well, this is not easy, but this chapter explains some of this complexity. Basically one has to sort out and then adopt those interventions that reduce the risk the most and at the least societal cost (in money terms, in environmental terms and in social terms). This is a ‘balancing act’, weighing up within some form of Decision Support System (DSS) the different ‘strategic alternatives’, assessing their costs and benefits, whilst looking forward as much as possible to the possible ‘futures’ (i.e. scenarios) for which one is planning. Research in FLOODsite has helped in all these respects.

In the previous chapter we learned that a strategic alternative consists of a set of related measures and instruments. But how should one design strategies for the future?
First, we need to establish that research is not policy making and that its primary goal is not to design the best flood risk management strategy but to inform policy makers. Research should thus focus on providing policy makers with information about the performance of different strategic alternatives and their effects and further implications. Policy makers, with their responsibility, may then design a ‘best strategy’ for the area concerned, taking into account financial constraints, political acceptability, etc. Policy-making may thus be helped most by research which shows how different alternatives perform, what they cost, and what are their positive and negative effects. This requires that strategic alternatives are designed which differ significantly, or even as much as possible, as the objective is to explore the consequences of alternative long-term management policies (say for 30 -100 years). In other words: research should design and assess a number – not too many – of very different strategic alternatives in order to help decision makers mould a practical and realistic alternative for real-world implementation. These alternatives should span the ‘playing field’.

Indeed, there are many ways to compile different strategic alternatives from the enormous portfolio of all available measures and instruments for a certain area. But there is a clue in the definition of a ‘strategic alternative’, being ‘a coherent set of flood risk management measures and related policy instruments’. This clue is in the word ‘coherent’.

If one were to just combine measures and instruments which do not conflict in space or effect, one might be able to design hundreds of sets of measures and then combine them with related policy instruments. In research for policy-making, however, such a ‘bottom-up’ approach is not very practical. It is like building a house from materials that may be conveniently to hand, instead of first asking an architect to make a design and advise on materials to use. This does not yield anything coherent, whereas in a ‘top-down’ approach guiding principles may function as ‘grand design’ and promote coherence.

In a ‘top-down’ approach aims or objectives are made explicit at different related levels, from the highest level of the foundation of western societies (e.g. democracy), via basic principles (e.g. sustainability), down to the more practical guiding principles for flood risk management. Usually, at the higher levels, people in European cultures tend to agree – e.g. on the fact that sustainable development should be aimed for –, but when asked how to achieve this, different opinions arise. This is the level of guiding principles. At this level
Resilience and resistance

Resistance can be quantified by establishing the ‘reaction threshold’ at which negative flooding consequences become significant, related to a discharge, water level, or precipitation event. The resistance of a system can be increased by raising this reaction threshold. In systems with a high resistance extreme events will not cause floods. However, events which are beyond the reaction threshold may cause disasters.

Resilience can be described and quantified by three aspects:
The magnitude of the reaction, or, in this case, the flood impacts;
The graduality of the increase of reaction with increasingly severe disturbances;
The recovery rate.

The resilience of a system can be increased by reducing the impacts of flooding, by reducing the rate of increase in impacts with more severe events, and by increasing the rate of recovery after flood events. In general, in resilient systems no sudden catastrophes will occur but damage will increase gradually with disturbance.
people may have clear and very different preferences and views on what is important in the relationship between humankind and its environment. Related to this they may have very different views on how this relationship should be managed (e.g. by liberalizing the world’s markets or in contrast by strong governmental intervention or instead again by local self-organization). One way of dealing with such different ‘perspectives’ is by designing alternatives which correspond with these different management styles.

Another approach is to design alternatives related to clearly distinguished and straightforward principles, such as ‘hold-the-line’, ‘retreat’ or ‘advance the defence line’ in coastal plain situations, or by enhancing the resilience instead of the resistance of the flood risk system along large rivers or estuaries.

How do these concepts influence the design of strategic alternatives?
Resistance and resilience are two different responses of a system to external stress, for example a flood event. A ‘resistant’ system does not respond at all to the event, whereas a ‘resilient’ system will give in to the stress (flooding) but allow immediate recovery. Both may yield a system which is robust in the sense that it can cope with external stress: a flood risk system which is not vulnerable but instead robust (robustness = 1/vulnerability).

Thus in flood risk management, resistance strategies are aimed at prevention of flooding until a certain threshold, primarily by flood defence, whereas resilience strategies principally allow flooding but try to control the flood area and flood depth as well as land use within the flood-prone area in an attempt to achieve proportionate impacts with increasing flood magnitude, to maximize recovery capacity, and thus to prevent catastrophes.

The combination of resistance and resilience determines the system’s ability to cope with high water levels or discharges. The two strategies apply different combinations of measures, although the same measures may be used in both. In a resistance strategy, measures are preferred which aim at flood defence, such as embankments and barriers. In a resilience strategy measures are preferred which focus on controlling flood patterns in such a way that primarily the vulnerable areas are protected by giving room to the water elsewhere. In resistance strategies structural measures tend to dominate, whereas resilience strategies involve more of a mix of both structural and non-structural measures.

Could you give examples of some different strategies for the same location?
A resistance strategy for lowland rivers such as the Rhine River, lower Elbe River, Oder River or Po River would consist of defence measures along the river and river training to enlarge the discharge capacity. Dike strengthening would be the main measure, whilst at some locations also removing obstacles, lowering the bed of the main channel, or lowering the floodplains to increase capacity could be considered.

A resilience strategy for the same area might involve a differentiation of flood protection levels and compartmentalisation of the protected floodplain area and polders. The least vulnerable parts of the area could be used for water detention whilst the most vulnerable areas would have the highest protection levels. Land zoning would further reduce the vulnerability of people and property and thus the flood impacts. The most frequently flooded areas might be subject to building restrictions or land use changes, whilst in the least frequently flooded areas all types of land use could be permitted. Preparedness measures would be added to reduce flood impacts and enhance recovery.
Perspectives and flood risk management strategies

In research for policy making, flood risk management alternatives and future scenarios can also be related to ‘perspectives’ as recognised in social sciences (the so-called ‘Cultural Theory’) (Task 14). Thompson (2002) gave the following characterisations of what the four perspectives imply (and as these texts are difficult to improve, we prefer to give a literal citation):

• “For individualists, nature is benign and resilient—able to recover from any exploitation—and man is inherently self-seeking and atomistic. Trial-and-error in self-organizing, ego-focused networks (markets) is the way to go, with Adam Smith’s invisible hand ensuring that people only do well when others also benefit. Individualists trust others until they give them reason not to and then retaliate in kind (the winning, “tit for tat” strategy in the iterated Prisoner’s Dilemma game), and see it as only fair that those who put the most in get the most out (as in the joint stock company). Managing institutions that work “with the grain of the market” (getting rid of environmentally harmful subsidies, for instance) are what are needed.

• Nature, for egalitarians, is almost the exact opposite—fragile, intricately interconnected and ephemeral—and man is essentially caring and sharing (until corrupted by coercive and inequitable institutions such as markets and hierarchies). We must all tread lightly on the earth, and it is not enough that people start off equal; they must end up equal as well. Trust and levelling go hand in hand, and institutions that distribute unequally are distrusted. Voluntary simplicity is the only solution to our environmental problems, with the “precautionary principle” being strictly enforced on those who are tempted not to share the simple life.

• The hierarchist’s world is controllable. Nature is stable until pushed beyond discoverable limits, and man is malleable: deeply flawed, but redeemable by firm, long lasting, and trustworthy institutions. Fair distribution is by rank and station or, in the modern context, by need (with the level of need being determined by expert and dispassionate authority). Environmental management requires certified experts to determine the precise locations of nature’s limits and statutory regulation to ensure that all economic activity is then kept within those limits.

• Fatalists find neither rhyme nor reason in nature and know that man is fickle and untrustworthy. Fairness, in consequence, is not to be found in this life, and there is no possibility of effecting change for the better. “Defect first”—the winning strategy in the one-off Prisoner’s Dilemma—makes sense here, given the unreliability of communication and the permanent absence of prior acts of good faith. With no way of ever becoming in sync with nature or of building trust with others, the fatalist’s world (unlike those of the other three solidarities) is one in which learning is impossible.”

The first three of these four perspectives can be used to develop consistent and coherent ‘world views’ (descriptions of how the world is supposed to function) and ‘management styles’ (how policy should be carried out). The world views can be translated into scenarios and the management styles into policy strategies, as the perspectives determine the primarily subjective perceptions on the world’s functioning and development, as well as the preferred approach to policy and management.
Do I understand well that different strategies are preferred by different kinds of people?
Yes. Some people, for example, have strong faith in authorities and structural measures, whereas others are more distrustful and prefer personal independence and back-up systems. In addition, some gain from certain measures whereas others primarily suffer from negative side-effects or prefer to have their tax money spent on something else. Developing and assessing strategies for flood risk management therefore cannot be left only to technical and natural sciences but needs to take into account such cultural aspects as different perceptions (e.g. between local flood risk managers and planners), diverging interests (e.g. embracing uncertainty versus restoring order), etc. Research for policy making can do no better than show what such preferences mean for strategic alternatives for flood risk management and what the effects of these alternatives are for society and the environment as a whole – or, in other words, hold a mirror to the policy makers.

Different people may have different interests and different views. There may be historically-based differences in attitude to risk, and different institutional and private interests (insurance companies, developers, etc.). There are also different views among scientists from different disciplines. Engineers, ecologists and social scientists may differ in their views on how a strategy should be designed and what it should include. Furthermore, a local government representative (such as a Member of Parliament) may well have a different view on what should be done than a building developer would have, or an economist. Each will prefer a strategy which suits his or her interests, or which matches his or her disciplinary viewpoint best.

So, one might expect different strategies in different countries with different cultures and also changing strategies with changing views over time?
Yes, different societies apply different risk management strategies which match their culture and the prevalent balance of perspectives - and indeed the balance between what is highly valued changes over time. Obviously, any current flood risk management strategy is a product of historical evolution, tuned in response to the societal and physical characteristics of the region involved, but it also matches cultural preferences which can change with time.

As for cultural differences within Europe we may exemplify these by referring to some general differences between countries which can be traced back to their history: wars, revolutions, the organization of state and other institutions, just to mention some. France, for example, still has a relatively centralistic state arrangement which influences decision making on flood risk management, whereas in Germany with its federal structure many things are instead decentralized and arranged more through co-operative regional planning. By comparison, in the UK, more responsibility is incumbent upon individuals and insurance companies. In terms of the cultural perspectives one might observe a tendency towards hierarchism in France, towards egalitarianism in Germany and towards individualism in the UK, although these are of course gross generalizations which do not adequately reflect the wealth of cultural diversity in reality.

As for changing views over time we may refer by example to the fact that in much of Europe in the 1950s economic recovery and the production of food through agriculture prevailed in decision making on flood risk management, whereas from the 1970s ecological considerations gained momentum because of environmental degradation and pollution - followed again by concerns about social aspects in the 1990s. Nowadays, sustainable development is the common goal, which tries to balance the three aforementioned goals.
Guiding principles for flood risk management strategies along coasts in response to sea level rise

Along coasts, four principles of flood risk management strategies can be distinguished, namely advancement, defence, adaptation and retreat. All of these strategies have already been applied along European coasts. The strategies imply:

**Advance:** This principle means that land is reclaimed from the sea. Usually, it requires that flood defences are built well in front of the existing coastline, and subsequent emptying and drainage of the land between the coastline and the new defence line is needed.

**Defend:** Flood defences have been built along coastlines for many centuries now. In the case of storm surges, they protect people and assets by providing a sufficiently high and stable structure which is able to withstand high water levels and wave attack. This strategy is very common around the European coastline.

**Adapt:** This principle includes a large variety of individual mitigation strategies such as elevated construction on land fill (so-called ‘Warft’) or on piles. Here, buildings are constructed on mounds or stilts above the expected storm surge level to avoid exposure - even in the event of failing flood defences (e.g. typical of construction on the Wadden Sea islands off the German coast).

**Retreat:** This strategy means the relocation of people from, and a change of land use in certain low-lying areas along the coast as a response to rising sea levels and/or increased overtopping of defences. It induces the abandonment of large parts of flat coastal hinterland.

Examples of resistance and resilience strategies for the Westerschelde Estuary in the Netherlands.

FLOODsite researchers investigated different strategies for the Schelde Estuary in the Netherlands. Three strategic alternatives were designed along an axis of primarily resistant to primarily resilient. As the current strategy qualifies as a resistance strategy, one other resistance alternative was designed, and two more resilient alternatives.

<table>
<thead>
<tr>
<th>Name</th>
<th>Guiding principles</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 current policy</td>
<td>resistance along long lines</td>
<td>maintaining the once in 4000 years protection level by raising embankments</td>
</tr>
<tr>
<td>1 flood surge barrier at Middelhagen</td>
<td>resistance concentrated at one location</td>
<td>providing a once in 10000 years protection level by a barrier</td>
</tr>
<tr>
<td>2 risk approach &amp; no spatial planning</td>
<td>increase of resilience, spatial developments occur autonomously, flood protection levels following</td>
<td>flood protection level differentiation based on flood consequences, spatial developments occur autonomously</td>
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<tr>
<td>3 risk approach &amp; spatial planning</td>
<td>increase of resilience, flood patterns central, spatial developments</td>
<td>protection level diff and spatial planning are combined in order to lower flood risks</td>
</tr>
</tbody>
</table>
These differences are recognised in the European Floods Directive which recognises the relationship of flood risk with the local or regional context. It states: “Throughout the Community different types of floods occur, such as river floods, flash floods, urban floods and floods from the sea in coastal areas. The damage caused by flood events may also vary across the countries and regions of the Community. Hence, objectives regarding the management of flood risks should be determined by the Member States themselves and should be based on local and regional circumstances.”

The Directive also advocates that flood risk management plans provide for solutions tailored for specific areas according to the needs and priorities of those areas.

**I suppose the decision as to what strategic alternative is best should be based on some assessment ... ?**

Yes indeed - an assessment is needed. This is not the same as a risk assessment or the assessment of individual measures or instruments. Strategic alternatives must be evaluated on all implications for society and the environment, including their costs of implementation and maintenance, their implications for socio-economic development and their impacts on natural and cultural heritage - not only in the short term, but also from a long-term sustainability point of view. This suits the overall goal of strategic flood risk management planning which is -- we repeat -- contributing to sustainable development by balancing risk reduction with other societal goals.

In FLOODsite strategic alternatives have been subjected to a so-called sustainability assessment. To do this one needs assessment criteria as well as a method for integrated assessment. In this sense, there is no real difference with the assessment of individual measures and instruments, although the focus may shift away from criteria such as effectiveness and cost-effectiveness from a risk-reduction point-of-view - towards a more broad assessment of a strategy’s overall contribution to the sustainable development of an area.

So first of all we need a set of criteria for sustainability assessment, and then we need methods to integrate the scores of those criteria in order to achieve an overall judgment. Assessments of strategic alternatives usually involve a comparison against a ‘base case’, which may be a ‘zero alternative’ or the ‘do-nothing option’, or instead, continuation of the current strategy.

Assessment criteria of two distinct groups are relevant in this context:

- **FLOODsite** Task 14

  - criteria related to the **intended** effects of a flood risk management strategy, namely the reduction of flood risk in terms of prevented damages and losses;
  - criteria related to the **unintended** side-effects and other implications of the strategy and its implementation (i.e. the wider costs and benefits to society, economy and natural and cultural heritage of each strategic alternative).

Any strategic alternative will have unintended side-effects, for example by allowing industrial development of an area which is better protected thus enhancing economic growth, or by causing deterioration of estuarine ecosystems thus causing loss of biological diversity. Such unintended effects should be included as far as possible in a full sustainability assessment of strategic alternatives for long-term flood risk management.

Depending on whether assessment criteria are expressed in monetary terms, other quantitative terms, or descriptive qualitative terms, they may be used in existing methods for integrated assessment, including Cost/Benefit Analysis (CBA) or Multi-Criteria Analysis (MCA).
The procedure to assess the sustainability of strategic alternatives for long-term flood risk management (Task 14).
What is the difference between Cost/Benefit Analysis and Multi-Criteria Analysis then?

The main difference is that CBA is principally an economic approach, whereas MCA allows the inclusion of other criteria than mere costs and benefits. Thus, an MCA also allows a non-soley anthropocentric view. With Cost/Benefit Analysis the overall economic risk reduction (in €) can be compared to the costs of applied measures. However, it is difficult to express loss of life or ecological effects in monetary terms. Multi-criteria Analysis (MCA), in contrast, allows a comparison between different alternatives by a broader set of criteria which can all be expressed in their own different dimensions, be it qualitative or merely ranked (- - to + +).

In CBA the costs of adopting any particular measures are compared with their benefits in terms of risk reduction. The aim of CBA is primarily to assess the ‘return on investment’ of implementing measures. The benefits arising from the implementation of measures are the net differences between total present value of the damages with and without the proposed measures (i.e. the damage avoided in comparison with the ‘do nothing alternative’). Any negative benefit arising from the measures represents a loss to society and hence should be considered as a cost. The benefit-cost ratio is the present value of benefits divided by the present value of costs. Different alternatives can thus be compared on this basis.

Because CBA relies on consequences that can easily be measured in monetary terms, social and environmental consequences are often neglected. MCA, in contrast, is a non-monetary tool. It can incorporate all relevant kinds of consequences without measuring them on a monetary scale. It provides an alternative to the complex monetary evaluation of intangible consequences by allowing criteria to be taken into account that have different units of measurement. The aim of MCA is primarily to rank alternatives.

MCA requires weighting of the criteria with regard to their respective importance. This significantly affects the outcome. Hence, it is one of the key steps in an MCA. It is also where stakeholder and decision-maker participation may be crucial. Once the weighting has been decided on the overall value (utility) of each alternative, a score can be calculated by summing the weighed values (utilities) of each criterion. The alternatives are thus ‘ranked’ according to their aggregate value (utility). The influence of different weighting can be established by sensitivity analysis.

But, as I understand it, both kinds of assessment include benefits in relation to costs of measures?

Yes that is correct. From an economic point-of-view almost all effects of implementing a flood risk management strategy can be regarded as benefits to society or costs to society. For example, reduced risks and enhanced economic opportunities are obvious benefits - whereas implementation costs, ecological degradation or an increasing social inequity can be regarded as costs. This is in the broad meaning of costs and benefits. In a more narrow meaning of costs and benefits, however, it is common practice only to take into account monetary costs and benefits. This allows the direct comparison of costs and reduced risks in €. It requires that all effects be quantified in monetary terms, which is disputable from an ethical point-of-view (e.g. when one fatality is valued at 2 million €) and indeed is heavily disputed.

The costs of risk reduction measures and instruments considered in a strategic alternative are obvious costs to take into account. The costs of different measures vary greatly. For structural measures such as dikes or embankments, normally the planning, construction,
maintenance and operation costs are included. For non-structural measures such as spatial planning, relocation, installation of warning systems, the costs can be more difficult to establish. Often omitted are the transaction costs of flood mitigation measures, or the costs for decision-making and implementation of measures – i.e. the cost of adopting a particular strategy and implementing it.

The primary benefits of flood risk management alternatives lie in the reduction of flood risk. One of the most common economic variables included in Cost/Benefit analyses is the reduction in ‘expected annual flood damage’ (or EAD). For each strategic alternative the risk reduction or benefit against the reference alternative can thus be calculated (this is often called the ‘annual average benefit’). The same can be done for other – ‘non-monetary’ – risk categories, such as the number of expected casualties (casualties/yr) or the number of people affected (affected persons/yr).

The criteria mentioned above all relate to the intentions of a flood risk management strategy, namely reducing the risks to people (life, health, stress) and property (expressed in economic terms against the costs of implementing the strategic alternative). As we said above, however, from a sustainability point of view one also needs to take into account the unintended side-effects – positive or negative, i.e. beneficial or costs – on society, economy, and natural and cultural heritage.

Sustainability is a widely accepted basis of policies at all levels within the European Union, which is achieved when there is a balance between these three value realms. It is logical therefore to fully connect any assessment to all three realms and to incorporate criteria to enable such an evaluation.

For the assessment of such side-effects many procedures and methods exist, such as Environmental Impact Assessment (EIA), Economic Impact Assessment and Social Impact Assessment. Depending on national obligations, scale, kind of measure etc. these impacts can be quantified, qualified and assessed. In this assessment of side-effects special attention should be given to off-site effects, i.e. effects elsewhere, and from a sustainability point-of-view also to delayed effects, i.e. effects in the long-term. Special attention is also needed for the effects of induced activities. For example, after the flood protection works in the estuarine southwesterly part of the Netherlands, rapid development of the area followed because of the improved accessibility of the formerly isolated islands and the enhanced attractiveness of the newly-formed lakes for recreation. This ‘induced development’ had equal or even larger impacts on the area than the closure of the estuaries itself.

All these costs and benefits to society can be included in a Societal Cost/Benefit Analysis or an MCA.

And what other criteria are used for such an assessment?

Apart from the criteria which relate to the three sustainability aspects, two additional and relatively new criteria are relevant for a sustainability assessment, namely, ‘robustness’, and ‘flexibility’. ‘Robustness’ informs us as to whether a flood risk management strategy will function under ‘all’ circumstances, i.e. also when unforeseen events occur (e.g. if there is a flood on a national holiday, or if operational managers of structures cannot be reached, or if people refuse to evacuate, etc). ‘Flexibility’ informs us as to whether a strategy can be easily adapted when the future develops quite differently than foreseen. This is assessed by questioning whether the measures can be phased easily and whether their implementation does not result in irreversible losses in terms of damage to environment or socio-economy, or in terms of high investment costs.
Conclusions from FLOODsite research on the (criteria for) assessment

A FLOODsite (Task 14) review led to the following conclusions for practical applications
• Adopt the three domains of sustainability – Economic, Environmental and Social – as guidance for the selection of criteria for a full assessment of flood management strategic alternatives under various scenarios.
• Add the criteria robustness and flexibility to the other sustainability criteria in order to cover the issue of ‘coping with uncertainty’.
• Equally distribute criteria and associated indicators over the three sustainability fields, so that they receive a balanced treatment in the assessment.
• A general level of abstraction of the indicators and a simple and practical method to obtain indicator values – for all indicators – will suffice for the purpose of evaluating long term flood risk strategies for the far future.
• Use a Delphi method or similar to obtain scores for qualitative/semi-quantitative criteria/indicators which rely on expert judgment.
• For the integrated assessment, use balanced score cards or some very explicit form of Multi Criteria Analysis.
• Present the results in a visually attractive way.

<table>
<thead>
<tr>
<th>sustainability aspect</th>
<th>related to the reduction of loss and damage</th>
<th>related to the implementation of the strategic alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>social and health effects (&quot;People&quot;)</td>
<td>annual number of casualties number of affected people</td>
<td>equity</td>
</tr>
<tr>
<td>economic effects (&quot;Profit&quot;)</td>
<td>economic damage</td>
<td>costs of implementation economic opportunities</td>
</tr>
<tr>
<td>economic effects (&quot;Planet&quot;)</td>
<td>damage to cultural heritage damage to natural heritage robustness flexibility</td>
<td>landscape quality nature values</td>
</tr>
</tbody>
</table>

Sustainability aspects and related evaluation criteria for an assessment of flood risk strategies
Against this background, FLOODsite tested and advocates the use of the set of criteria which together cover the sustainability realms of social equity, economic efficiency and ecological integrity, in such a way that intended and unintended affects are covered in a balanced way, without overlaps, and of equal level of abstraction (not requiring weighting).

A formal method to score the ‘new’ criteria – robustness and flexibility – does not yet exist. Therefore, one might rely on some kind of expert judgment, for example through the so-called Delphi method. In this method hypotheses and a questionnaire are prepared by an administrator and sent to various experts. Scores and arguments provided by the experts are summarized by an administrator and a summary is returned to the experts who then may change their opinion in a second round after having read the opinions and counter-arguments of other experts. When consensus is reached after two or more rounds the process is stopped. The advantage of this method is that consensus may be reached quite quickly even though the subject is complex, and that ‘groupthink’ is avoided, so that unforeseen ideas get the attention needed. In the original Delphi method all participants remained anonymous, but recently face-to-face Delphi methods have been applied.

**How does one combine the results for all those criteria?**

In a Cost/Benefit analysis the aim is to achieve one figure, namely for the benefit/cost ratio. The higher this is, the better the alternative - in theory at least. In practice, societal Cost/Benefit analysis usually provides a relatively compact table with quantitative costs and benefits of each alternative.

In an MCA, in contrast, a large number of criteria and indicators can be included, which can be weighted in order to produce a ranking of alternatives. In formalized and computerized MCA tools, of which there are many available off-the-shelf, the number and character of the criteria can be adapted, the weighting can be adapted and so on. Thus, it is very difficult to trace back how and why a ranking has resulted. Nor can a policy-maker easily underpin the opinion to not adopt the alternative which ranks best – because the ‘story’ behind the ranking is lost.

An alternative is to use so-called ‘balanced score cards’. These are just simple tables in which all the indicators can be scored qualitatively as well as quantitatively or by ranking. Effect sheets and score cards are often used when very different criteria are included but the number of criteria is limited.

**Are there general protocols (or even computer-tools) for such assessments?**

Well, yes. When planning ‘for real’, there are many protocols prescribed and sometimes even computer tools – be it through European directives or national legislation –, for example on environmental impact assessment procedures (EIA), on CBA, on MCA, etc., etc. But each member state has specific preferences and uses its own language(s) for good reasons: the actual planning is namely done for an actual location with actual stakeholders who need to be able to understand and participate in the discussion.

From a research point of view, the key idea is to make the results of research on risks, costs and all the other criteria available in such a way that the actual decision makers and all the stakeholders who want to influence the decision making process have equal access to all the relevant information so that they can participate on an equal basis. Preferably, there should not be any dispute about the facts or distrust about their trueness/adequateness, so that the discussion can focus on the appreciation of those facts and on the policy decisions derived from them. This requires that all stakeholders are equally well informed.
Lately, much effort has therefore been focused on the production of computer-based tools which aim to fulfill exactly this function of equally informing all stakeholders. These so-called decision support systems (or DSS) are computer tools which support individual decision makers or groups in exploring different solutions for semi-structured problems. They allow strategic alternatives for flood risk management to be defined, and can rapidly calculate the effects of these alternatives for assessment purposes. DSSs use databases, models and a graphical user interface to provide results in various graphical ways.

FLOODsite reviewed 24 European DSSs which have been developed in the past decade for various flood risk management purposes. These tools can be divided into three categories:

1. project-specific tools not designed for application in other areas;
2. educational tools to familiarise people with flood related issues; and
3. generic tools for ongoing use in the strategic planning for any site.

These different categories of tools were designed for different objectives and for different target audiences. This obviously requires a diversity of functionality, structure and layout, which conflicts with the desire to produce one all-purpose DSS. When this is duly accounted for, DSSs can be promising.

This approach to DSSs recognises that each member state may want to have its own simulation models, protocols and procedures included, to be applied by its own institutions and industries according to its own preferences: which is exactly what the EU-Directive on Flood Risk Assessment and Management also recognises. It can be summarised as: European flood risk assessment and flood risk management should be performed in a similar way, but this need not be the same way.

In FLOODsite’s ambition on generic DSSs this resulted in a strive for agreement on the conceptual framework, on basic elements and on the type of output, whilst allowing ample freedom to choose from the available simulation models, assessment protocols and criteria. In other words: convergence of approach in DSS development is being sought in arguments and merits (‘good practice’) rather than in prescriptions.

**So, decision support systems are the future? But what about earlier experiences with DSSs in the past then? These have not been used very often, have they?**

In the past DSSs were often far too difficult for practitioners to use – not to mention stakeholders –, because they were developed by experts for experts. Nowadays, it is recognised that one should first establish who the end-users of a DSS will be, what their skills are and what they require of a DSS.

Users should be central to the development of any DSS. After all, the user’s skills and expectations determine whether a DSS will be accepted and thus whether it will be utilised to assist in finding better solutions. DSS development is thus very different from ‘model’ development. It requires close contact with a real user group – wanting to solve real problems – to prevent it from becoming an academic exercise.

To prevent confusion and disappointment amongst users it is advised to limit the ambitions when developing a DSS to:

- providing a collective knowledge base for all interested parties and stakeholders;
- through structuring information, whilst preventing information overload.
Conclusions from the review of DSS tools

- The DSS should be decision specific i.e. not try to support / solve too many things.
- The evidence provided to the user should be “rich” e.g. enabling the user to explore the basis of the evidence presented.
- The DSS should be appropriately flexible for its task.
- The system architecture should be appropriately open/closed for the decision at hand and the mode of use.
- A modular approach is recommended where possible.
- The DSS should be independent of temporal and spatial scale.
- The DSS should reflect the policy context within which the decisions will be made. (e.g. a risk-based analysis)
- A probabilistic approach to risk is strongly advocated across all aspects of the source, pathway and receptor elements of the flood risk system.
- The representation of output risk metrics should be sufficiently clear whilst reflecting the complexity of the underlying analysis. Uncertainty should be explicitly handled and appropriately disaggregated.
- Uncertainty should be expressed in a manner which is accessible.
- Guidance should be provided on the interpretation and use of uncertainty information.
- Training and user support for the DSS should be provided.
- Software maintenance of the system should be offered (including the release of new versions, upgrades, bug fixing, changes resulting from feedback from user group meetings etc).
- The DSS should be able to access and utilise national data sets such as Digital Terrain Models, river network maps, social vulnerability indices etc.
- The DSS should be advocated by the appropriate authority or agency.
- The analyses should include a variety of calculations e.g. agricultural damages, coastal erosion metrics etc.
- It should automate otherwise tedious calculation processes.
At present, DSS tools are increasingly being regarded as being very good discussion support tools, however their adequacy as decision support tools is disputed. Consequently, one of the desirable characteristics of DSS tools is that they help improve communication – and hence participation in decision-making – by ensuring that all stakeholders have access to the same information and can understand it. When discussion and informed participation of all stakeholders is the main goal of a DSS, however, the target group of end-users becomes very diverse indeed. This requires due consideration in the design of DSS tools.

For the purpose of ‘discussion support’ it is also essential that all users have confidence in the results or outputs of the DSS. A DSS will only be used when there is user confidence in the method and the results. Thus it is important not only to apply tested and proven methods to calculate effects, but also to highlight and explain uncertainties and confidence levels.

And what about public participation in design and assessment of strategic alternatives?
The EU- Directive on Flood Risk Assessment and Management endorses the active involvement of all interested parties in the production, review and updating of flood risk management plans. But in the context of research one should distinguish between the design and assessment of plans ‘for real’ for the short to medium term, versus exploratory research on flood risk management strategies for the long term.

When planning for real, it is obvious that public participation is desired; people will either benefit from the plans or be negatively affected by the implementation of measures, so they have a real stake and should be genuinely interested in participating. In exploratory research on the sustainability of flood risk management strategies, however, public participation is not really required, as this kind of research rather investigates whether fundamentally different strategic alternatives for flood risk management are sustainable or not. This kind of research focuses on the far future, for generations beyond our own.

Designing and planning for the far future … That sounds a very uncertain road. Could you explain how to take uncertainties into account?
Well, the uncertainties we have to deal with in this context are obviously of quite another kind than those resulting from a lack of knowledge or an inadequate representation of the real world in our models. Uncertainty about the future is uncertainty of a kind which cannot be reduced by more research. It requires not only reflecting on the probable, but also on the possible. A way of tackling this kind of uncertainty is the use of scenarios.

Recently, in exploratory research on long-term flood risk management strategies, the recognition of possible future developments in terms of scenarios is becoming a recognised technique which allows the consideration of such uncertainties about the future. The motives for the use of scenarios in research for long-term flood risk management include:

- The rate of climate change and its impact on floods is uncertain, the demographic and socio-economic developments of societies and their impact on vulnerability are uncertain, and the normative views of future generations are uncertain.
- As the future is inherently uncertain and cannot be predicted sufficiently accurately, it is important to develop strategies that are adequate for a range of different futures or which can be adapted as the situation evolves.

For some of the uncertainties with which flood risk management is concerned trends can be analysed. For example climate change, or population growth. From this kind of research (e.g. the United Nations Intergovernmental Panel on Climate Change (IPCC)) we
The four scenarios distinguished in the UK- Foresight study in relation to axes for governance (vertical) and values (horizontal).

Predicted change in precipitation and wind speed due to a climate change scenario according to two different climate models.
understand that the atmosphere warms up, that sea levels will rise significantly, that rainfall patterns are likely to change, and that there may be more extreme weather events. But we do not know how fast and to what extent. Recognizing this the EU Directive requires member states to take into account the impact of climate change on floods in their flood risk assessments. Floodsite has established that scenarios may be a good way to do so.

A scenario, in this context, is defined as all future autonomous developments, i.e. all future developments which are not purposefully influenced by flood risk management measures and related policy instruments. This definition excludes all measures and instruments which constitute a strategic alternative for flood risk management; intentionally, as the performance of these alternatives must be assessed against the scenarios.

So scenarios are not predictions, but rather stylized constructions of possible future developments, sometimes quite deliberately in the form of stereotypes, archetypes, doomsday situations, or other extremes – but they should be conceivable. Scenarios thus serve to investigate the question ‘what might happen if…?’, not as an answer to the question ‘what will happen?’ Scenario-based methods can therefore show to policy makers what may happen if their policy remains unchanged, and also what the future may look like if they were to change their policy or policies.

What are good scenarios then, or are there no good or bad scenarios?

Obviously, scenarios should cover the variables which determine flood risk, i.e. tell us something about the development of the hazard and the development of society’s vulnerability. Also, they should span the whole field of possible futures, so that a full exploration of possible future developments is ensured. Finally, it is recommended not to define entirely new scenarios, but instead to connect to scenarios which have already been developed for other policy fields such as environment or economy, and which apply to society as a whole. This allows easier integration of flood risk management policy and other policy fields.

A first general requirement for scenarios is that they must be internally consistent. For example, each demographic development cannot necessarily be combined with each economic development, because of feedback mechanisms within the society-environment system. Consistent scenarios are scenarios in which the underlying assumptions are consistent over different sectors, problems and scales. A second general requirement is that the scenarios are clearly different. Contrasting scenarios may seem somewhat unrealistic, but they are clear, understandable, and they form an envelop around the whole range of uncertainties. Most likely, the future will in reality prove to lie somewhere between the different scenarios. A third and mainly practical requirement is that the number of scenarios is limited, so that the results can be understood, interpreted and communicated. After all, the whole research process must be feasible.

To ensure relevance for flood risk management planning, scenarios must allow the specification of the development in the key factors which determine flood risk, i.e. in those autonomous developments which cause changes in the hazard – such as climate change (precipitation, evaporation, storm frequency and force), changes in the upper catchment which increase runoff, or land subsidence – or in an area’s vulnerability – such as population growth, economic growth, and land use change.

Floodsite found that various existing scenario approaches already meet these requirements or can be easily adapted to do so. But it was established that scenarios may also be derived from ‘cultural perspectives’, where these represent a certain ‘world view’, i.e. a set of assumptions about how the world functions and how climate and socio-economy will change.
<table>
<thead>
<tr>
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<th>alternative</th>
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In order to allow the use of scenarios in subsequent modelling, the general storylines (or: narratives) – which are usually of a qualitative nature – must be downscaled to the area of interest (e.g. a river basin, a river reach, a delta, a coastal area or an estuary with its surroundings), and transformed into quantitative assumptions (or: model input parameters) as much as possible. Only then can they be used for quantitative analyses and assessments. This is an important step, which is seldom adequately described.

**But different scenarios probably mean different performance of different strategic alternatives. How to tackle that?**

That is true, and it poses primarily a practical problem. In principle, however, scenarios are the right approach to explore the future, and the different performance of alternatives shows exactly which choices and decisions are fail-safe – or robust – and which, in contrast, may potentially cause huge future regrets, if for instance the future develops otherwise than expected.

In the foregoing we have already discussed how to assess strategic alternatives and which criteria to use for such assessments. This included criteria related to flood risk, but also criteria related to the impacts of implementing the measures and instruments of a strategic alternative, in terms of social effects, economic effects and environmental effects. Some of the mentioned criteria may be assessed irrespective of how the future develops, for example the costs of implementing an alternative. But effects on flood risks obviously depend strongly on how the future develops; after all, they depend on how much the sea level rises, on how much rainfall increases, on how many people will be living in a hazardous area in the future, etc. So, changes in flood risk must definitely be quantified for each future scenario. The same applies to criteria for impacts on, for example, economic opportunities or natural development.

Thus, in practice, one may have to perform an assessment of some 4 or 5 strategic alternatives by some 5 to 10 criteria for about 4 future scenarios: a predominantly practical problem, as said, as one ends up with a huge table. In the course of the research this is inevitable. The interpretation of such a table may, however, be facilitated by using colours to indicate the ranking, or by deriving simplified tables to accompany the reporting in words. In any case, it is important to help the audience – e.g. the policy makers – to understand the outcomes of the research. This is more a question of how to communicate about the research than on how to perform the research.

**Is it still possible to draw robust conclusions for a future flood risk management strategy then?**

Yes, certainly; case studies undertaken by FLOODsite concluded that you can, provided that care is taken in the selection, definition, and scoring of qualitative criteria. Case studies in which the Delphi method – a formal way of consolidating expert judgment – was applied to score the qualitative criteria resulted in an assessment which revealed the effects of the strategic alternatives on all relevant sustainability criteria.

What such an assessment may reveal especially is that some alternatives score very well in one particular future scenario, but perform poorly when the future develops otherwise. Other strategic alternatives may, in contrast, perform adequately in all possible futures. Thus, decision makers may opt for a cautious approach, or otherwise. This is what principles and concepts such as climate adaptation, robustness, flexibility, precaution and no-regret are all about.
Conclusions on the analysis of the Westerschelde Estuary (Task 14)

- Currently, the flood risks in the Westerschelde Estuary can be expressed by the following average annual figures: 0.53 million Euro of damage per year, 19 affected persons per year and 0.15 casualties per year.
- If the current flood risk management strategy (strengthening of embankments to enable withstanding the once in 4000 year conditions) is not changed, flood risk will increase in the future due to climate change, population change and economic changes. The future Expected Annual Damage for example may increase with a factor 3 to 30 resulting in an EAD of 1.5 to 14 M €/yr.
- The current flood risk management strategy is cost effective if the World Market scenario becomes reality. In the other scenarios, however, the economic risk reduction is lower than the costs made for dike raising. These figures are indicative only and do not include intangibles such as the reduction of casualty risks.
- If from now on no strengthening of embankments or other measures would be carried out, but if only maintenance would continue, then flood risks will increase rapidly from about 0.53 M €/yr to 13 or even 2700 M €/yr (depending on the future scenario).
- The Storm Surge Barrier alternative scores best on people-related indicators. The Spatial Planning alternative scores best on environment-related indicators and on indicators which describe the system’s sensitivity to uncertainties, whereas the Risk Approach alternative scores best on the economy-related indicators.
- The scores of the strategic alternatives on the sustainability criteria differ per scenario. In the World Market scenario the current policy scores best, while in the other scenarios the Spatial Planning alternative scores highest.
- If all scenarios and criteria are considered together, then the Spatial Planning alternative scores best.
- A flood risk management strategy which combines protection standard differentiation and spatial planning thus seems most promising.
Well, I would like to hear those conclusions....

So I would imagine! However most conclusions can only be well-understood in the context of the specific case, i.e. the physical geographical context with the flood type, the socio-economic context which determines population and economic development, etc. Therefore, we necessarily refer to the FLOODsite pilot studies, for example the one on the Thames which is related to the UK’s Thames Estuary 2100 project, or that of the Westerschelde Estuary, or the one on the German Bight.

Still, some general notions may be shared. It was found that in these cases climate change and the related sea level rise do increase the danger of the flood hazard – as expected –, but the increase of the vulnerability of the flood-prone area through economic growth is at least as important if not more important a determinant for the increase of flood risk. It was also found that combining spatial planning measures (to prevent the vulnerability increasing) with flood defence measures (to counteract sea level rise) is very effective. Furthermore it was found that gigantic measures such as storm surge barriers in estuaries are not only very expensive, but also provide the largest opportunities for economic development. In a scenario of World Markets and rapid local economic development this would pay off, but in other scenarios or in more remote areas which develop less intensively it might instead lead to future regrets for the large amounts of money spent.

Again, these conclusions result from specific cases; other circumstances might lead to other conclusions. So, it is advisable to perform a ‘tailor-made’ exploratory investigation of strategic alternatives by a scenario approach dedicated to the area of concern. FLOODsite provides the relevant guidance on how to proceed with such an investigation.
Disaster management cycle (Task 17)
CHAPTER 5

On remaining risks: what if flooding does occur?

In the foregoing we have discussed how to reduce flood risks. Now, what if flooding seems unavoidable?

Although many measures may be taken to reduce flood probability, the chance of a flood will always remain. Flood risk cannot be reduced to zero and absolute safety does not exist. Therefore, we must consider what to do in the event of flooding.

If flooding is imminent or taking place, there are a number of actions which may be taken in order to reduce flood impacts. These actions are often described as ‘flood event management’ (FEM) or – in the UK – ‘flood incident management’ (FIM). Flood event management may prevent panic and chaos and hence save lives and contribute to a reduction of total damage. In addition, organising recovery after floods may be considered to be part of managing a flood event.

Flood event management involves:
- Flood forecasting and (early) warning;
- Operation of (emergency) flood control measures and flood defence structures;
- Evacuation of people (and livestock) out of the flood-prone area or into shelters;
- Rescue of people from the flooded area;
- Care for people remaining in the flooded area;
- Recovery after the flood.

The degree to which these actions may be effective depends on the situation, especially on the time remaining between a forecast and the actual flooding. The operation of (emergency) defence structures and evacuation is generally more important for coastal areas and large river basins where there is more time for action, while rescue is generally more important in smaller river basins, where lead times may only be of the order of a few hours.

So, flood forecasting and warning are the first in the action list. Could you explain a bit about these?

Indeed, it all starts with forecasting and warning. If flood events can be forecasted in a timely and accurate manner, they can be acted upon better and in a more timely way. All other flood event measures rely on these forecasts and on timely warning of the right persons.

Nowadays forecasting and warning are usually combined into “flood early warning systems (FEWS)”. All such systems include components for the forecasting and detection of dangerous hydro-meteorological conditions such as severe rainfall, high river flows, or – in case of coastal regions – high tides and/or extreme storm surges. They also contain components which help to translate rainfall intensities or water levels into information which is meaningful and understandable to the responsible authorities or inhabitants.

Getting the information to the right people is of paramount importance if FEWS are to be successful in flood emergency situations. This requires that FEWS is part of a more encompassing flood early warning and response system which includes advice about response actions, evaluation of flood early warnings, and which ensures flood preparedness.
The principal elements of a flood forecasting, warning and response system (Task 10)

- pre-flood preparations of emergency response agencies
- training for readiness
- public sensitization and education about floods and flood warnings
- post-event debriefing
- lessons learned
- enhancements implemented

- flood preparation, awareness & readiness
- flood detection
- flood forecasting
- flood warning formulation
- flood warning communication
- flood warning response
- post-flood warning evaluation

- interrogation of hydrometric networks
- transmission and recording of hydrometric data
- weather radar data
- severe weather forecasting and warning
- receiving, integrating and processing meteo & hydrometric data
- running flood forecast models
- forecasting flood levels and their timing for specific locations
- interpreting forecasts & understanding likely flood impacts
- issuing appropriate warnings
- updating warnings

- warning dissemination/media engagement
- warning confirmation

- pre-flood damage reducing actions
- emergency response agency engagement and loss mitigation
- public damage reducing actions

- pre-flood damage reducing actions
- emergency response agency engagement and loss mitigation
- public damage reducing actions

The principal elements of a flood forecasting, warning and response system (Task 10)
What information is used for flood forecasting?
Evidently this depends on the situation, which may concern on the one hand a coastal or estuarine area where a storm surge poses the flood hazard or, on the other hand, a river basin or lowland river, where the flood hazard results from rainfall events. In the latter case the size of the river basin is very important; flood levels in the downstream part of a large basin result from flood waves passing through the catchment at a limited rate. Flood forecasts can then be based on discharge or flood level measurements, whereas in small catchments the flood occurs within a few hours of the rainfall event. And these small basins are seldom gauged, either for discharge or water level, or for rainfall amount. Also, the flood generation mechanism is fundamentally different: extremely intense storm rainfall events which cause flash floods have a relatively small spatial extent and are hence difficult to forecast.

For coastal areas flood forecasts mainly rely on superimposing the water level forecasts related to storm surge predictions on predictions of the astronomical tides. Storm surges can be forecast on the basis of large-scale weather forecasts which yield information on the movement of low pressure areas, wind fields, etc. For the North Sea, for example, such forecasts are based on weather forecasts of the European Centre for Medium-Range Weather Forecasts in Reading (UK) for the northern Atlantic Ocean. In addition, water level measurements from fixed gauging stations at sea (e.g. on gas and oil platforms) are used to constantly adjust the model output to measured data; so-called data-model integration.

In small basins flood forecasts rely heavily – if not entirely – on rainfall forecasts or rainfall measurements, because time is too short to use measured water levels. Often rainfall measurements are not available, because not all small catchments can be supplied with rain gauges. Rainfall forecasts are obviously more uncertain than direct measurement of water levels.

In large basins with longer lead-times, flood forecasts do not have to rely entirely on rainfall measurements, but can also be based on measured water levels or discharges. Rainfall predictions then yield a first estimate, which is progressively improved using rainfall measurements and discharge measurements as additional input as time goes by.

How are rainfall forecasts translated to flood forecasts?
Rainfall forecasts can be translated to flood forecasts in different ways.

The simplest approach first establishes the historic relationship between rainfall quantity and flood events (including the threshold rainfall for flooding to commence), and then simply identifies the extent to which the predicted rainfall may exceed the flooding threshold.

A more sophisticated approach makes use of rainfall-runoff models, many of which exist, from the very simple to the highly complex. Rainfall-runoff models allow us to incorporate the most important hydrological processes and to take into account initial soil moisture conditions. Which of the many available models to choose primarily depends on the validity for the case in question of the various methods adopted to account for specific processes, such as snowfall and snow melt. In general, however, the accuracy of flood forecasts does not so much depend on the model, but rather on the quality of the available rainfall input data and on how the model is implemented, calibrated and updated.
Running time of a flood wave in the Rhine River basin to the border of the Netherlands
Recently a data exchange linkage has been established between quantitative precipitation forecasts generated by numerical weather models and flood warning systems. Sometimes only one weather forecast is used, but in some cases ensembles of different rainfall forecasts are used to account for uncertainty and to obtain a probability distribution of discharges or flood levels. The European Flood Forecasting System (EFFS, an EU 5th Framework project), for example, used ensembles of weather forecasts provided by the European Centre for Medium-Range Weather Forecasts in Reading (UK). This EFFS can alert on possible floods as early as 3 to 10 days in advance of an event. EFFS has been transformed into the European Flood Alert System (EFAS), which is continuously being updated and kept alive by the Joint Research Centre (JRC) of the EU.

EFFS can provide daily information for large rivers, such as the Rhine and Oder, as well as alerts for flash floods in small basins. It comprises a broad-scale model for Europe and can hence provide flood warnings for catchments in Europe that at present do not have any forecasting system in place. It is also used as an early warning system by agencies who already have a 0-3 day flood forecasting system in place, thus providing extra time for response.

In contrast to these data-intensive sophisticated approaches, many ungauged small river basins may benefit from a simpler approach, which allows rainfall forecasts to be directly translated into flood forecasts. Such a method was developed in FLOODsite based on the Flash Flood Guidance (FFG) approach of the USA. In this approach, critical rainfall thresholds are first established for each flash flood basin which are known to cause flooding. Then flood warnings are based on just comparing rainfall forecasts with these critical rainfall threshold values, including an indication of likelihood. This approach has the advantage of not requiring the ability of users to run an on-line flood forecasting system. But it can also serve as a back-up system in case of the failure of more sophisticated on-line models. A disadvantage of this approach is the relative lack of accuracy compared with rainfall-runoff models, which results in frequent false alarms, particularly when lead-times are longer.

So there is always a certain level of uncertainty in flood forecasts?
Yes, indeed. Particularly uncertain are flood forecasts which largely depend on forecasts of local rainfall, although the level of uncertainty also depends on the type of basin. Forecasts can be reasonable in the case of rainfall from large slow-moving low-pressure areas, which cause rainfall in large areas. However, in the case of thunderstorms developing on hot days, rainfall quantity forecasts are very difficult to make.

Forecasts for coastal floods and for floods in large river basins are generally more reliable than for flash-floods, although it is always difficult to predict precisely whether and when certain thresholds (for example embankment levels) will be exceeded. The main reason for a higher reliability lies in the possibility of adjusting the forecast by taking into account water level or discharge measurements from upwind or upstream.

In what respect are flood forecasts and warnings being improved currently?
Flood forecasts are being improved by making use of newer rainfall measuring techniques, by using ensemble forecasts in a more efficient way, and by extending the coverage of forecasts and warnings. Furthermore, hydrological and hydraulic river models are constantly being improved, which improves the accuracy of the water level predictions. Rainfall forecasts are obviously more uncertain than direct measurement of water levels, but these too are constantly being improved. Various new remote sensing techniques
Example of a flood depth map in a flood forecasting system for a floodplain in England.
So lead-time is the key difference between flash flood basins and large river basins …?

Yes, indeed, but the reliability of forecasts also differs greatly. In small river basins flash floods occur suddenly: a severe thunderstorm may cause a flooding in the following few hours! Since the reaction of small rivers to thunderstorms is so fast and because thunderstorms and thus flash floods occur very locally, it is impossible to make long-term forecasts and one can only warn for ‘dangerous weather conditions’. The difficulty of predicting floods far in advance implies that there is hardly any time left for emergency actions or evacuation. Alerting and rescue are very important measures in such areas.

In large river basins, however, floods only occur after a longer wet period in a large part of the basin. They can often be forecasted days ahead and the forecasted water level can be constantly adjusted on the basis of measurements more upstream. As an example, the discharge of the Rhine at Lobith on the German-Dutch border is forecast 4 days in advance, although the publicly published forecast is restricted to a lead time of 2 days ahead.

And how about estuaries and coasts?

In coastal areas and estuaries floods can generally be forecast further in advance than in small river basins, but not as long ahead as in major river basins. This does allow emergency structures to be operated and evacuation to be considered, although it may often be too late. The actual lead-time of the forecast depends on the possibility to forecast storm surges adequately.

When a dangerous flood is predicted, what then?

When dangerously high water levels are predicted, the responsible authorities need to be warned first. They will have to decide which actions to take on the basis of information about which area is threatened by flooding. So, predictions are needed of which area will be flooded, how fast it will be flooded and how deep it will get.

Flood inundation modelling can inform us about the flood extent and expected depths of flooding. The inundation process of an upcoming flooding event can nowadays be simulated quite precisely if a good forecast of the flood levels is available in time. There are many different types of inundation models available. The simplest type is a one-dimensional (1D) model which can be used for rivers and concentrates on the water level in the river itself. The water level in the river can yield a first estimate of possible flood extents by applying GIS-techniques, such as spatial extrapolation and overlay with a digital terrain model to produce water depths in the floodplains. For predicting the extent and depth of flooding such techniques are, however, less accurate than true two-dimensional (2D) hydraulic models, but they may suffice for relatively narrow river valleys without flood defences. 1D models have the advantage of being relatively fast.
Types of numerical models used for inundation modelling (Task 8)
And what about areas with flood defences? Defences may fail, don’t they?

In areas with flood defences it is necessary to use models that can simulate both the rise and fall of the river level and the inundation process of the protected areas at the same time and in interrelation. Such combined (1D2D or 2D) flood inundation models (for example Sobek1D2D or Mike21) are used to simulate the flooding process in time. This simulation shows where the water flows, how soon it will arrive at certain locations, what water depths and flow velocities may be expected, and what the maximum flood extent will be.

The exact flood inundation process depends to a large extent on the location and way of failure of a flood defence. Which embankment will fail, and where, is highly unpredictable. As this is unknown, nowadays practice is often to simulate a number of hypothetical failures at different locations and under different conditions (water level, tide, storm) in order to explore what would happen if the embankment would fail just there.

Evidently this is the best method to assess imminent flooding!?

It would be the best method, if such simulations didn’t take so much time. Simple inundation simulations may still take hours and for complicated areas several days are needed for one calculation.

Evidently, during a flood event there is no time to make such calculations. Therefore, many simulations for potential dike failure locations are made in advance for a range of different extreme events. The results are stored in databases. During a flood event the responsible authorities only need to look in the database for simulations which come nearest to the actual conditions and breach location.

So, in fact, one uses the same inundation models as are used for designing long-term strategies?

Yes, in many cases one does. However, the type and number of calculations may differ. For flood event management many calculations for different breach locations are made, but all for the current flood protection situation. For designing long-term strategies one needs not only calculations for the current situation, but also calculations to determine the effect of alternative flood risk management strategies.

If it is known which area may become flooded, what should be done next?

If the flood prediction and the interpretation of the results indicate an imminent threat of flooding, the authorities responsible for public safety must be warned. Together with the flood risk managers they will form a crisis team, which must consider all possible further actions which might limit the exposure to and the consequences of flooding. This may include the operation of emergency measures, warning or alerting the people in the flood-prone area, evacuation, but also preparation for search and rescue.

This final step of flood early warning systems, namely issuing and communicating flood warning and alerts, has traditionally received less attention than flood forecasting itself. However, for adequate response and in order to prevent panic and chaos, the communication of trustworthy information and details on what may be expected is essential.
Thames barrier

Example of sliding of inner slope

Sand bags placed to reduce the process of piping.
In what respect is flood warning being improved currently?

New communication systems permit different flood forecasting and warning approaches to be used and reduce time-lines and increase access to warnings. In England and Wales for example, a new multi-media warning dissemination system has recently been launched which enables flood warnings to be communicated by telephone, pager, fax, email and SMS text messaging.

Obviously, these new communication systems allow for more widespread dissemination of relevant information. But, unfortunately, they all rely on electricity provision and communication networks which need to function under extreme conditions. Entirely relying on those may imply a risk by itself.

Could you first explain a bit about emergency measures which may be taken in response to warning?

Indeed, if flood forecasts indicate that the situation may become dangerous, emergency measures may be taken. This may involve the operation of flood control measures or the installation of temporary flood defences, as discussed earlier (Chapter 3).

Some of those structures, such as flood barriers or inlet gates to detention areas are operated automatically on the basis of water-level or discharge forecasts or information on actual water levels. This is the case for large and sophisticated storm-surge barriers such as the ones in the Thames Estuary (UK) or those in the Netherlands. For other structures, such as de-mountable flood defences, people must be warned and put to work. If detention areas are available, they must be put into use at the right moment; not too early but neither too late.

But many emergency measures may also have to be taken within protected areas which are expected to be flooded. All openings in inner-embankments must be closed, for example sluices and locks in canals and other water courses, gates in tunnels and road crossings through embankments, etc.

In some cases temporary reinforcement or raising of embankments may be needed, for example by sealing with plastic sheets, by placing sand bags or by topping up with demountable flood walls or by other kinds of temporary reinforcement. In some cases small leaks in embankments or other defences must be repaired before they grow into breaches.

How does one know in time where embankments need care or repair?

During a flood, defences usually show early signs of forthcoming failure. Whenever a flood warning is issued, embankments and structures must be monitored constantly. This requires appropriate organisation and many vigilant people. For example in the Netherlands, when high water levels are forecast, the water boards set up so-called ‘dike-watches’.

A dike-watch consists of experienced people on the spot who inspect the embankments on any signs of weakness by each walking an assigned stretch of the dike. Dike-watches usually comprise the people who are responsible for the yearly inspection of the defences on behalf of the water board, but many more people are needed. Especially local people who know the situation from daily experience are indispensable for this. Whenever a weak spot is identified, measures will be taken immediately, for example placing sand bags.
It is important that people engaged in a dike-watch are able to recognise weak spots and early signs of possible failure. In the Netherlands a computer programme has been developed to train the dike-watch. It is a kind of computer game in which the ‘player’ must walk up and down a dike stretch and learn to recognize and interpret the early signs of leakage or cracks and how to report them.

**What do the people do when they receive a flood warning or alert?**

FLOODsite research among inhabitants in a number of river basins showed that most people living in flood-prone areas in Europe do not consider taking any action other than to try to save their own life in response to a flood warning. Many people first want confirmation of a flood warning, before they will consider taking any action. Of those who decide to take action to reduce flood damage, the most common responses appear to be (1) to try to prevent floodwater from entering their houses, and (2) to remove possessions such as cars, valued property and important items (for example medicines) and memorabilia (for example photographs). An alarming proportion of people, however, endanger their lives by the way they seek information or satisfy their curiosity.

Flood warning does, however, enable inhabitants to move possessions out of the reach of flood water, which reduces the total flood damage. This is especially the case in unprotected river valleys with relatively slow-rise floods. In flash-flood basins, however, running for your life carrying only essentials is the proper response; here flood warning should be flood alerting. And in large protected areas which may be flooded to great depth, again other responses are required. Adequate response to flood warning may, however, reduce the overall flood damage significantly.

**How much economic damage reduction can be achieved by appropriate response to flood early warning then?**

FLOODsite developed and tried two methods to assess how much damage reduction can be achieved with flood early warning: a refined version of the already existing “UK FHRC Model” and a new “Flood Warning Response and Benefits model”. These methods incorporate the latest knowledge on factors which determine an adequate response and were based on data sets from the UK, the Czech Republic, the Loire valley in France and Germany.

The models were applied to a number of situations, including the village of Grimma in the Mulde catchment (a tributary of the Elbe River in Germany). For that area, it was found that flood warnings might reduce flood damages to households by between 6 and 14%.
What can be done to improve the effectiveness of the response to flood warnings?

The effectiveness of flood event management depends to a large extent on the preparedness of the authorities, the availability of emergency plans, and the preparedness of the inhabitants to act on these plans. Preparedness is thus a key prerequisite for effective flood event management.

Before a flood occurs much can be done in preparation. The response to flood warnings and alerts is much better if the authorities and people understand the dangers correctly, know what may happen and how fast it may happen, know their responsibilities, know the possible ways they can reduce flood impacts, and have the power and means to act appropriately. They must also know where to obtain information on the actual flood event and at what moment to take which actions.

The majority of this knowledge and information must be obtained before a flood event occurs so that everybody really understands what may happen and can be sufficiently prepared for any possible flood event. Providing understandable knowledge and information is, of course, the responsibility of the flood risk managers and their supporting organisations. In this regard, flood hazard maps and flood risk maps, but also the post-processed output of flood inundation models, for example in the form of motion pictures or maps, are key educational material.

The general awareness level of inhabitants can be improved by providing geographically accurate information about flood hazards in their own environment as well as on ways to reduce their own vulnerability. This may be achieved through leaflets, via education at schools, through local newspapers, via the internet, etc. We discussed communicative instruments earlier (Chapter 3).

How can the flood awareness and preparedness of institutions be enhanced?

Flood event management must be planned before the event. Anything completely new that needs to be found out, to be arranged or to be organised during a flood event will involve far too much time. So the preparedness of local authorities and responsible organisations such as the fire brigade, the police, hospitals, etc. can only be improved by developing clear emergency plans in sufficient detail and by practising.

Emergency plans should contain information about possible flood scenarios, about measures to be taken, and about evacuation procedures. But they should also contain a clear picture of the organisation of flood event management, rules for communication, the distribution of tasks and responsibilities, and reference to sources of up-to-date information about the flood during an event.

In the Netherlands, the Task Force for Flood Event Management (TMO) organised a whole week of practising on a very large scale in November 2008. This activity was based around postulated scenarios of having to respond to very extreme (< 1 : 10.000 probability) flooding events of large areas along the coast, along the Rhine, or as a result of a huge storm causing Lake Ijssel to flood a polder.
Evacuation of some polders along the Rhine River in 1995 in the Netherlands using dedicated public transport for those who did not have their own means of transport.
You just mentioned evacuation again. This is also a very important measure for some areas, isn’t it?

Yes, it is, especially in protected areas where flooding may result from failure of defences. This may cause quite sudden flooding of large areas to great depths, as was the case in the 1953 flood disaster in both the Netherlands and East Anglia (UK) and also during Hurricane Katrina in New Orleans.

A successful evacuation can save many lives and avoids the need for large rescue operations during and after flooding. However, an unfinished evacuation may turn into a disaster if rising flood water takes people by surprise, for example while they are caught in a traffic jam. Furthermore, in most European member states, people can only be advised to evacuate; they cannot be compelled to do so nor can authorities insist on people leaving their homes at the most appropriate time. Consequently, departure times and traffic flows cannot be controlled and this endangers the potential effectiveness of evacuation.

The decision whether or not to evacuate, and which area, and whether or not by force, is therefore of paramount importance. But this is a difficult decision which requires the right information about what is about to happen as well as a thorough understanding of management options and their consequences.

What kind of information is needed for evacuation, and by whom?

There are two groups who need information before and during an evacuation. The first group is, of course, the authorities responsible for deciding on evacuation and on the evacuation procedure such as the regional and local authorities, the police, the fire brigade and other relief services. These need information on which areas are to be evacuated, in which order, along which routes, when and how fast, etc. The second group is the people—the would-be evacuees—themselves who also need information.

The authorities usually act according to the emergency plan in force, which in this case should include an evacuation plan. Once the flooding process has begun, they need up-to-date information to decide for each particular location whether to evacuate or not. The authorities and services are usually also responsible for organising the evacuation of those who cannot take care of themselves such as elderly, ill or disabled people. For those who do not have their own transport means public transport may be provided, as was the case in the Netherlands in 1995 when 250,000 people were evacuated. Sometimes the authorities also take care of cattle, although these are usually transported by cattle transport companies or by farmers helping each other.

The inhabitants need to know whether they may become flooded, when the water will arrive, what depths are expected at their location and in the surrounding, when they should leave, what time-slot they have in which to leave and when they ought to have arrived at a safe location, where the safe areas are to which they might go—or are ordered to go—and what they should do in the mean time (and take with them) and should not do (or take with them). They may also need to know roughly how long the floods are expected to last (hours, days, weeks or months). The information to be provided to the inhabitants and how they should be informed should be specified in the evacuation plan.
Evacuation modelling for Canvey Island

Canvey Island is an island in the Thames Estuary, covering an area of 18.5 km². It is formed on an extremely flat and low-lying alluvial fan that has an average height of approximately 1 m below mean high water and has a population of approximately 37,000. Canvey Island is protected against flooding by defences all around it. In 1953, the island was inundated by the ‘Great North Sea Flood’ that breached the island’s flood defences and resulted in the death of 58 people and the destruction of several hundreds of houses. Access to Canvey Island is currently only possible by two roads, which meet on one and the same roundabout. Any disruption to these routes not only severely limits access to the industrial areas on Canvey Island but would also terribly hamper evacuation from it.

Within FLOODsite (Task 17) work was undertaken to assess evacuation times for Canvey Island for a number of flood event scenarios using a prototype Life Safety Model (LSM) developed by BC Hydro in Canada. LSM is a model which allows simulation of the behaviour of individual receptors (in this case people and vehicles) in interaction to each other and in response to the flood wave. The model was validated by simulating the 1953 flood event.

The results for the present situation indicated that it would take around 12 hours to evacuate all the residents off the island, and that if a breach of the flood defences would occur during an extreme flood event there could be up to 400 fatalities.

Evacuation routes from Canvey Island in the northeastern part of the Thames Estuary
So, even before a flood event takes place, evacuation plans need to be made. What information should such plans include?
The contents of an evacuation plan will differ from one country to another and according to the type of flooding and situation. In Hungary – to give a good example – evacuation plans are developed for each town. These plans contain, among other things:

- a check-list of tasks to be carried out;
- general descriptions and major data for the town;
- a description of each flood-prone area and the number of inhabitants in each block of that area;
- options for preventing or delaying further spreading of water in the town;
- evacuation and rescue routes (roads, rail, traffic control points);
- an overview of shelters;
- a register of hospitals;
- lists of available means of transport, transport needs and transport need locations;
- an overview of actions available to prevent dispersion of pollutants;
- organisation charts with names, addresses and telephone numbers of emergency staff and crews; and
- a list of material needs (beds, blankets, tents).

In Hungary these plans are updated every year.

Who is actually responsible for evacuation planning?
Most countries distinguish between organisations responsible for water management and those responsible for emergency management, including evacuation planning. The planning and execution of evacuations is usually done by regional and local authorities.

Thus, water management organisations, which usually have better insight in the inundation processes, seldom have any responsibility for evacuation planning. This is probably why in practice evacuation plans focus predominantly on the organisational aspects rather than on the best evacuation strategies and traffic routing and why little evacuation modelling has been carried out so far.

Okay, so evacuation plans must be made in advance. But what knowledge is required to make evacuation plans effective in practice?
The most important piece of knowledge for decision-makers is to have reliable forecasts of the timing of flooding, of expected water depths and flow velocities. Based on that information they can determine how many people and which vulnerable elements of communities such as hospitals, elderly homes and schools are at risk, and where people should go to.

Decision-makers also need to know how long evacuation of certain communities is likely to take. This can be established by evacuation modelling. Based on the results of such modelling the decision makers can decide to evacuate a large area, or instead to advise people to go to nearby shelters, or just to stay at home.
Different approaches to evacuation modelling according to scale and related complexity (from FLOODsite Task 17)
To summarise, typical information needed by decision-makers includes:

- The possible size and extent of the flood event, expected depth of the inundation, pattern of flooding, timing of the flooding process, etc;
- The whereabouts of people and vulnerable groups;
- The amount of time required for evacuation;
- The capacity of the road network and the current state of the traffic.

Much of the required information for such a decision may be obtained from a dedicated decision support system (DSS), which can be called an ‘evacuation support system’.

**So how do the authorities decide whether to evacuate or whether to advise people that it is better for them to stay at home?**

The decision must be made based on the fact that people are obviously safest outside the flood-prone area, but also evidently safer in many kinds of modern buildings (even houses) of reinforced concrete than in cars during flooding. If sufficient time is available, people will be advised or forced to evacuate to safe areas outside the flood-prone area.

However, if it is likely that people will be trapped in traffic jams and may drown in their car, evacuation must be avoided. In such cases, people may better be advised to go to nearby higher buildings or higher areas or they may be told to stay at home. The advantage of shelters made available within the flooding area is that they are generally closer and can be reached walking or cycling. In the event that a flood lasts for a long time, however, it may be necessary later on to rescue the people from those shelters by boats or helicopters. This may be difficult and time-consuming and insufficient boats and helicopters may be available for the task.

The time required for evacuation of course depends on the population size and characteristics of the area: does it involve millions of inhabitants in a polder area such as the western part of the Netherlands, or part of a city on a primarily estuarine valley bottom such as parts of London, or only a small village in a natural river valley with hills nearby? Moreover, it takes more time to evacuate vulnerable people such as children, elderly persons or hospital patients, than it does to evacuate healthy young adults. The evacuation time thus depends on the type and number of inhabitants; the distance to safe areas; the capacity of the road network, bridges, tunnels, etc.; and the ability of the inhabitants to look after themselves.

When making a decision on evacuation the weather conditions must be considered as well: if it is freezing and raining or if a terrible storm is blowing traffic accidents are likely and traffic jams may be unavoidable. Under such conditions people are better advised to stay at or near their homes.

**Are there any tools available to help decision makers to plan evacuations?**

Yes, there are many different tools available which can inform decision-makers, but many of them still need further development and improvements. There are traffic models, macro- and micro-scale evacuation models and Decision Support Systems (DSSs).
Evacuation Support System, exemplified for the Schelde

FLOODsite (Task 19) developed an Evacuation Support System (ESS) to support decision makers who may need to decide on evacuation. The Schelde ESS was developed as a prototype for the regional and local authorities in the flood-prone area along the Westerschelde Estuary.

The ESS provides weather information, information on expected flooding and on vulnerable objects in the flood-prone area. It can also show the effect of various evacuation schemes. The ESS includes an on-line linkage with providers of weather forecasts, of information on the current weather situation, and of radar information on precipitation, as well as with providers of water level forecasts and current water level measurements at sea and in the estuary.

To obtain relevant information on flooding process the user should select a certain breach location. The ESS then shows the expected flood pattern in the form of maps of: maximum water depth; maximum flow velocity; moment of inundation; potential collapse of buildings; and locations where the water will rise rapidly.

In order to support evacuation decisions, the following information is also generated by the ESS: number of inhabitants that are likely to be flooded; available infrastructure and road capacities; location of shelters, hospitals and other important objects. This ‘exposure information’ is combined with the ‘hazard information’ in such a way that the decision maker can see in a glance which zones will be most endangered, how many people live in each zone, which routes leads to safe ground and where the closest hospitals or shelters are.

The ‘management response module’, finally, allows a preliminary assessment of different evacuation schemes. This requires that exit points, evacuation routes and zones to be evacuated are defined. Dynamic links between this module and transport models is expected in the near future.
Macro-scale evacuation models simulate the evacuation process by representing overall traffic flows, whereas micro-scale evacuation models simulate the movement of individual persons and cars. Most macro-scale evacuation models combine traffic models with data on the number of inhabitants of a certain area. Some enable the dynamic simulation of traffic flows along different routes in the flooding area. Macro-scale models usually yield an estimate of the duration of the evacuation of larger areas.

Micro-scale models represent separately all individual people and cars in the flooding area. They show which people are safe, which are in the flood water, where people have drowned or where they have been trapped in collapsed houses. These models require many input data and, therefore, are usually applied in small areas only (villages or smaller cities).

Although micro-scale models give more detailed results on the fate of persons and cars, the results are not necessarily more reliable than those of macro-scale models, because the quality of the input data limits the quality of the results. Because it is impossible to obtain exact data about where each person is located when a flood warning is issued, to judge precisely how he or she will respond to the flood-warning, and to predict what the weather conditions will be at the time of flooding, even micro-scale models will never be able to produce exact predictions of evacuation durations for each individual. However, these models remain very useful for obtaining a rough estimate of the average duration of evacuation and for giving directions to people.

This all sounds very uncertain again...
Well, yes. But as explained earlier, decisions about evacuation must be made despite the significant uncertainties. More research may help to reduce some of these uncertainties, but as each flooding event is different and happens under different circumstances, many uncertainties cannot be eliminated by more research. In particular, it will remain very difficult to account for human behaviour, which is a key factor for the effectiveness of evacuation.

But simulations, like most other models, do help us tremendously in better understanding what happens during evacuation. Modelling thus contributes to improving our theoretical concepts, and the formulation of additional hypotheses and other connected research questions.

You also mentioned Decision Support Systems. What about those?
Evacuation DSSs combine relevant information about possible flood events and about the flood-prone area in a way that helps decision makers to rapidly assess the situation at hand, as well as the consequences of their potential decisions on evacuation.

Such DSSs comprise modules for flood forecasting, information from inundation simulations on which areas may become flooded and which areas remain dry, and data on where people may be present in those areas. They include information on the location of hospitals, schools and other vulnerable objects. Of course, they also make reference to the organisations which must be contacted. FLOODsite developed an architecture for such DSSs, and made prototypes for the Thames and the area north of the Westerschelde Estuary.
Factors which determine the recovery capacity and recovery rate:

**Physical factors**
- How fast will the area be dry again?

**Economic factors**
- Is there sufficient money for reconstruction?
- Is help from other areas expected?

**Physical factors**
- Does social structure enhance recovery?
- Are people prepared?
- Are the inhabitants healthy and do they have skills?
What can be done when time is up and flooding happens?

When the area is actually being flooded, damage and casualties can still be reduced. But this requires people to be rescued and property saved.

In most EU member states, crisis teams consisting of the fire brigade, ambulances and other emergency services take action in such circumstances. But when a large area is flooded, the army may also be called in to assist. Many inflatable boats or helicopters are often required for rescuing people from areas which are deeply flooded, and here the army is often best equipped. But in many other cases, for example in river valleys with shallow water, tractors with carts or lorries can be used to transport the majority of the stricken people to safe ground. When floods are a frequent phenomenon, rescue and self-help activities within the local community may even have become commonplace.

It is obvious that in this matter of rescue, natural science research or engineering play a very minor role indeed. It is mainly a question of good organisation and proper preparation, which may be sustained by social science research about organisation and planning. Within FLOODsite, however, this kind of research has not been addressed.

But information about the possible access to the region must be very important for rescuing ... ?

Indeed it is, and that is exactly where research on the flooding process and on traffic management may again be of some relevance. For rescue services in flash-flood areas, information about the status of the road network is crucial: which roads are still accessible and which are already flooded; which alternative roads or other infrastructure are available, etc.

FLOODsite developed a method and tool to forecast the flooding of roads in flash-flood catchments in real time. The method and tool were applied on the Gard basin in France and calibrated and validated with data from past flood events. It was found that dangerous road sections exist where roads cross rivers, where road sections run through floodplains, and in depressions where rainwater accumulates. The tool uses a combination of rainfall-runoff models to forecast the floods and the results of an assessment of the roads’ submersion potential to achieve a real-time forecast of the likely flood status of the entire road network.

Such a tool may help prevent emergency services becoming stuck en route, because of a flooded road section. It may also be used in the context of flood warnings in order to prevent people in cars taking routes where they may become trapped in their vehicles when those roads are suddenly flooded.

And after the flood?

After a flood, it is a matter of recovery. A significant amount of research has already been done on vulnerability and recovery capacity, which shows that recovery is a complex subject. In general, however, recovery after a flood can be stated to depend primarily on the flood’s severity and duration, and on the capacity of the affected society to recover.

In the event that only a small area is affected, the damages are usually small and recovery may be fairly easy, especially if no loss of life has occurred and the psychological impacts of the flood have been limited. In the case of large disruptive floods, however, in which people lose their lives, cattle are drowned, houses collapse, and communities disintegrate, recovery is more difficult and takes much longer. The memory of the flood and its consequences may last for years, decades or generations, as is the case with the Great North Sea Flood in East
Anglia and the Netherlands. Houses – or whole villages – must be rebuilt, infrastructure repaired or replaced, networks restored, etc. This not only involves roads, but also electricity and water supply and sewer systems. The recovery of such infrastructure may take several years, but the psychological consequences of the flood may last longer than one generation.

Recovery also depends on the community which is affected by the flooding: how vulnerable it is and how capable of re-organising itself. An efficient and clear arrangement of private insurances or damage compensations is known to enhance recovery and to reduce stress and frustration. But recovery rate may also be enhanced when surrounding areas and communities come to assist. This is more often the case when those communities can imagine themselves having been affected – like communities from other polders in the Netherlands if one polder were to be flooded – than when the larger community does not consider itself responsible – as was the case in the US when recovery from Katrina was not considered to be a federal issue. Recovery thus also depends on the solidarity of the larger community – sometimes with fund raising actions – and the support of regional or national authorities.

**Does recovery ‘only’ involve return to the pre-flood situation or pre-flood development?**

No, certainly not. There is no reason to strive for restoration of the same, obviously risky, pre-flood situation. Instead, a flood, even a devastating one, very often forms a splendid opportunity for completely reconsidering the flood risk management strategy followed up until that time. As such, it offers a significant window of opportunity.

In practice, however, local, regional or national politicians often express strong opinions about such events not being acceptable ever again. For this reason, alternative flood risk management strategies must be available at the very moment of such a window of opportunity, with professionals able and willing to explain the advantages and disadvantages of these to these politicians. This brings us back to the issue we addressed in Chapters 1 to 4, namely the design of a sustainable long-term flood risk management policy.

With this answer, we have rounded off one full iteration of the continuous process of flood risk management planning.
Developing the ‘Language of Risk’

Background, methods and techniques
Even among specialists (and sometimes especially among them!) there is disagreement about what terms mean, owing to the many different disciplines that are involved with flood risk management. Different nationalities with different languages may use the same technical terms but with different meanings. For example the common English term ‘flood’ can be translated into the Dutch language by three different terms with different meanings. And both the French words ‘crue’ and ‘inondation’ may be translated into English as simply ‘flood’, which misses out the difference implied in the French language. As further illustration we might quote the word ‘dike’ or ‘dyke’. In the Oxford English Dictionary the first meaning of this word is watercourse, the second is bank or embankment. However, due to the many translations from Dutch to English, embankment is now becoming a more accepted meaning of dyke, and even the standard in many internationally authored documents. In US practice the word ‘levee’ is used (not levée) for a dike or embankment.

FLOODsite sought to clarify this situation by proposing a set of definitions for use within and outside the project. Although this effort was not without controversy, it was an important step forward.

Results
An explanatory text about the main concepts and relevant terminology as well as a flood risk management dictionary called the Language of Risk.

To take some examples, these are the majority which start with the word ‘flood’

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>Flood</td>
<td>A temporary covering of land by water outside its normal confines.</td>
</tr>
<tr>
<td>Flood control (measure)</td>
<td>A structural intervention to limit flooding and so an example of a risk management measure.</td>
</tr>
<tr>
<td>Flood damage</td>
<td>Damage to receptors (buildings, infrastructure, goods), production and intangibles (life, cultural and ecological assets) caused by a flood.</td>
</tr>
<tr>
<td>Flood forecasting system</td>
<td>A system designed to forecast flood levels before they occur:</td>
</tr>
<tr>
<td>Flood hazard map</td>
<td>Map with the predicted or documented extent of flooding, with or without an indication of the flood probability.</td>
</tr>
<tr>
<td>Flood level</td>
<td>Water level during a flood.</td>
</tr>
<tr>
<td>Flood management measures</td>
<td>Actions that are taken to reduce either the probability of flooding or the consequences of flooding or some combination of the two.</td>
</tr>
<tr>
<td>Flood peak</td>
<td>Highest water level recorded in the river during a flood.</td>
</tr>
<tr>
<td>Floodplain</td>
<td>Part of alluvial plain that would be naturally flooded in the absence of engineered interventions.</td>
</tr>
<tr>
<td>Flood prevention</td>
<td>Actions to prevent the occurrence of an extreme discharge peak.</td>
</tr>
<tr>
<td>Flood protection (measure)</td>
<td>To protect a certain area from inundation (using dikes etc).</td>
</tr>
<tr>
<td>Flood risk zoning</td>
<td>Delineation of areas with different possibilities and limitations for investments, based on flood hazard maps.</td>
</tr>
<tr>
<td>Flood risk management</td>
<td>Continuous and holistic societal analysis, assessment and mitigation of flood risk.</td>
</tr>
<tr>
<td>Flood warning system (FWS)</td>
<td>A system designed to warn members of the public of the potential of imminent flooding. Typically linked to a flood forecasting system.</td>
</tr>
</tbody>
</table>

Implications
This Dictionary has facilitated communication within the project, between different specialists and different nationalities, and hence greater consistency of understanding of flood risk and flood risk management. It may do so outside the project as well.

Reference
The analysis of flood extremes

Background, methods and techniques
The increasing development of coastal zones has enhanced the vulnerability of these areas to flooding. A sound understanding of the probability distribution of extreme conditions is essential for managing the risk in those areas. FLOODsite investigated the probability distribution functions of extreme water levels, storm surges and waves which jointly determine flood hazard, with the purpose of improving flood risk analysis and management methods.

Results
The research focused on the probabilistic assessment of flood extremes using advanced statistical methods. It established the probability distribution of flood extremes as a function of climatic change and human responses, by analysing the consequences of different conditions and scenarios. Extreme flood data were analysed from sample locations in a variety of environments (see Figure). Based on correlations – both spatial and in time – improved single and joint probability density functions could be defined.

The implications
Flood risk management is about how better to understand and manage extreme events. With the results of this statistically-based research the assessment of flood risks and strategic management responses can rely on more accurate quantitative descriptions of extremes.

Reference
FLOODsite key research advances

Understanding the failure of flood defences

Background
Many floodplains are protected by embankments and other structures, and any flooding that occurs is the result of the failure of any of those structures. Little is known about defence failure. FLOODsite has developed tools that (a) help determine which failure modes are most likely with which structures and (b) allow calculating the probability of failure. These tools are based on a synthesis of knowledge, experiences and experiments in different EU countries (Germany, UK, the Netherlands).

Methods, techniques and results
FLOODsite (Task 6) performed some large-scale experiments in the Large Wave Flume (GWK) in Hannover in 2008 preceded by small-scale experiments (see Photograph here). Waves simulated are those which are common for the German Bight. The key objectives of the experiments were to establish a more thorough understanding of breach initiation and breach development; the results provide far greater understanding of the conditions that lead to defence failure.

In collaboration with other research projects, FLOODsite (Task 4) developed and tested a simulator for wave overtopping to establish the structural stability of embankments as well as their behaviour before and during breaching. The erosion of the inner slope of an embankment under wave action is likely to differ from that under a steady flow of water, since wave overtopping results in pulses or surges of water overtopping periodically. The issue that this research especially addresses is how much protection is actually offered by grass cover on the inner slope of embankments. The wave overtopping simulator provides for the periodic and controlled release of water down the face of a real in situ embankment. The simulator produces pulses of water flushing downhill representing a wave overtopping scenario and thus allows assessment of the performance of the real grass cover under these conditions. This in turn allows us to refine the performance assessment for the embankment.

Implications
This research confirmed that prior understanding of the failure of flood defences was insufficient. The results may help reduce the uncertainty of estimates of the failure probability of flood defences, thus improving the accuracy of estimates of the risk to people and property behind such defences.

References
Micro-scale urban flood hazard mapping

Background
In urban areas, great flood water depths and high flow velocities form hazards that are small in scale but highly dangerous. When aiming to reduce flood risk to people such hazards, which can vary from street corner to street corner, should be kept in mind when designing the urban fabric. Even the entrances of buildings need to be located where safe access and egress is more likely. A case study of Nice, in France, revealed that two-dimensional modelling at the street scale can assist this urban design.

Methods, techniques and results
In France there was a need for a pragmatic approach, which can contribute to the preparation of flood event management plans in urban areas using detailed 2D hydrodynamic models for the simulation of the flooding. The objective was to support the planning of the local organization responsible for warning, informing, protecting and supporting the population in any known hazardous event. The two-dimensional model outputs give information about the flooding process and pattern in terms of important characteristics of the flood hazard such as water depth and flow velocity. The Figure shows the flood hazard map for the research site in Nice for a 5,000 m3/s flood due to an embankment breach, on a scale from low to very high.

Implications
The main conclusion from the French pilot is that it is possible, from results such as those obtained, to develop micro-scale hazard maps. Decisions can therefore be taken on, for example, moving a school entrance and preparing evacuation routes on a very detailed scale.

References
Risk perception and social resilience: cross-country comparisons

Background, methods and techniques
The awareness of flood risk is very uneven across EU countries, as is the adoption of ‘community measures’ to reduce exposure and vulnerability. Only very few earlier attempts have been made to examine this across countries; this called for additional work by FLOODsite. Three different methods – standard and non-standard, quantitative and qualitative – were applied to different audiences in three countries (Germany, Italy and the UK). The main method of data gathering – standardised questionnaire surveys – was preceded by interviewing decision-makers and focus groups as preparation, and was followed by discussing the results with the communities examined and/or authorities in charge of flood risk management.

Results
Two topics were especially investigated: (a) social vulnerability and social resilience in relation to floods, and (b) social constructions of flood risks.

In all three countries it was found that context is essential for a community’s social vulnerability and resilience, and how important it is to understand this when analysing the impacts of flood events on social groups and local communities. However, the research findings also revealed that, in general, the following groups within communities may (but not necessarily do under all conditions) need specific targeting and support:

- those with no previous flood experience;
- those who have recently moved to an area;
- those with lower social status;
- those living alone without disposing of a social network outside their home;
- households with long term ill or disabled members;
- those living in vulnerable housing;
- older, in particular very old people;
- women or those with greater domestic and caring responsibilities; and
- those renting properties (dependent upon national tenure cultures: this does not apply in Germany).

Yet it is important to stress that this is no universal catalogue – it always needs to be checked with respect to the specific local/ regional, socio-economic, demographic and cultural context.

As for social constructions of flood risk and its consequences for flood risk management it was found that the fact that people take any risk reducing measures implies that those people are both aware of the risk of being flooded and that they attribute a certain significance to the measures that they take. In other words, they regard the measure they take as meaningful, and at least hope that it will be effective. All of these perceptions and behaviours are related with the peoples’ social constructions of risk. Thus risk is neither simply attributed to a natural hazard nor an objectively given constant. Rather, perceived risk is to be understood as being socially constructed in the sense that normative views and values, as well as belief systems, influence and possibly define it.

Implications
Flood risk management will only be effective if the public is involved. Risk reduction measures therefore need to be tailored to the highly differentiated awareness levels across and within EU countries. Supporting this finding, the European Floods Directive states that “Member States shall encourage active involvement of interested parties in the production, review and updating of the flood risk management plans...” (Article 10). Stronger involvement of citizens may contribute to raising risk awareness and disaster preparedness, the local populations may provide knowledge that is fruitful for risk reduction efforts, and the involvement of the public may enhance the acceptance of risk management measures.

Reference
Empirical and mathematical models for assessing loss of life

Background, methods and techniques
Loss of life in European floods is not an easy area to model because of a lack of calibration data. FLOODsite (Task 10) gathered data on fatalities due to floods across Europe in pursuit of an empirical model to predict potential loss of life. Data were collected on 82 deaths in 25 EU locations from flood events between 1997 and 2005.

Also (Task 17) an existing mathematical model (the Life Safety Model LSM) has been tested on the well-documented 1953 flood in Canvey Island, UK, by applying it to model both evacuation and the number of fatalities. The model produces estimates for number of deaths from drowning; exhaustion; building collapse; and vehicles being swept away. It also produces estimates on evacuation times.

Results
Despite the fact that many new data were collected on floods in Europe, a sufficiently reliable empirical relationship between number of fatalities and flood hazard and vulnerability characteristics could not be derived from the data within the Task 10 research. Therefore, a semi-quantitative but more sophisticated model was developed in the form of a look-up table which allows the users to assess where the risk to life of floods is greatest. The model determines low, medium, high or extreme risk to life and also includes mitigating factors such as receipt of flood warnings and evacuation. The model also allows simple mapping of the risk to life using GIS.

The LSM modelling, in addition, yielded results which agreed well with the available historical data on the 1953 Canvey Island flood. The model predicted approximately 100-120 fatalities, as a result of drowning (48) and exhaustion (71). The actual fatalities on Canvey Island were 58. Anecdotal evidence on the number of buildings destroyed in 1953 also seemed to match the LSM results.

Implications
With this research we can have greater confidence in forecasts of fatalities in flood events, and can better understand the implications of different evacuation strategies. This may help to reduce the number of fatalities of future flood events.

References

Exploring flood risk management under global change

Background, methods and techniques
With the prospect of climate change affecting flood hazard, one needs to look and plan a long way ahead. To do this requires the development of strategic alternatives (sets of measures and policy instruments) that will sustainably reduce risks, but as the future is uncertain they should perform adequately in different possible futures. The uncertainty of the future is accounted for by developing scenarios which are relevant and realistic. The development of guidelines on how to do this, within Floodsite (Task 14), is an important step forward for long-term flood risk management planning.

A review has been carried out of some mainstream existing methods of scenario development and use, of methods to design strategic alternatives and of criteria to assess the sustainability of such strategic alternatives. Also a procedure — or methodological framework — was developed which was subsequently put to trial by applying it in three case-studies.

Results
The successful trials in the case studies demonstrated the applicability of the methodological framework developed and showed the usefulness of scenarios in long-term flood risk management planning. The use of scenarios was especially found to be useful, because:
• It shows that the performance and sustainability of the strategic alternatives differs per future scenario;
• It thus shows that taking into account the uncertainty on the future is important, since strategic alternatives may function well in one scenario, while leading to gross regrets in others;
• There are strategic alternatives which function reasonably well in all future scenarios or which can easily be adapted to changes in demographic, economic or climatic development.

Implications
Since scenarios are still rarely used in long-term flood risk management planning now, and since the assessment of the functioning of strategic alternatives across different scenarios is a new approach, the method developed may improve policy analyses for flood risk management whereas its concrete applications are likely to be useful for policy-makers.

References
Improving flash-flood warning

Background, methods and techniques
Many flood events in Europe come with very little warning, as flash floods in urban areas or in steep catchments – often resulting from summer thunderstorms in Mediterranean climate. The only strategy that can help manage the risk of this kind of flooding is giving a timely warning, and this usually requires real-time interpretation of radar images of clouds and rainfall. Improvements to the interpretation of radar images of rainfall events that are likely to lead to flash flooding will mean that alerts can be issued earlier than before, thus saving valuable minutes or hours for evacuation and the mobilisation of rescue and recovery efforts.

Results
FLOODsite (Task 15) has improved the ways to measure rainfall quantities from weather radar images, and (Task 16) has provided guidelines on: i) the effectiveness of using either rainfall-runoff models or instead applying simple thresholds for flash flood forecasting; ii) the worthwhileness of using rainfall-runoff models to further specify the flood probability in a given catchment.
The main scientific advances (Task 16) were to provide a comprehensive overview of the state-of-the-art of flash flood forecasting and warning methods, and to improve on these methods. One of these methods is Flash Flood Guidance (FFG). FFG is the calculated threshold amount of rainfall that is likely to cause flooding at the outlet of the drainage basin being considered. The forecasted or observed rainfall (from radar), FFT, is compared with this FFG and if it is greater than the FFG then flooding is likely. The technique is rapid to apply – necessary in the case of flash flooding – and reasonably accurate.

Implications
The techniques that have been developed should allow alerts of flash floods to be given several hours earlier than has hitherto been the case. Some of the results (the FFG approach) have been implemented into the operational system for flood forecasting in the Upper Adige River basin in Italy. The concept of flash flood guidance also proved of considerable help in the communication between hydrologists, meteorologists and decision makers.

References
**Uncertainty analysis**

**Background, methods and techniques**

Flood risk management requires dealing with uncertainty. This begins with understanding the many uncertainties that are involved: about the data that are used, about the future, and about the calculations that are performed. FLOODsite (Task 20) has developed an approach to examine these uncertainties in a structured way, as well as a model (‘Reframe’) to allow the investigation of which parameters and data contribute most to the uncertainty in any flood risk management decision.

**Results**

The framework for conducting uncertainty analysis and for communicating about uncertainties with stakeholders is given in the Figure below. Whilst the methods - for example for estimation or propagation of probabilities - may differ, the logical structure is generically applicable to all strategic planning decisions, although it may need to be adapted to the characteristics of a specific situation.

**Framework for uncertainty analysis**

The approach is – as far as possible – quantitative. Uncertainties are propagated through to key outputs for decision making (for example net benefit in terms of risk reduction). Results are presented as probability distributions and maps. Sensitivity analysis is used to establish the contribution that different factors make to total uncertainty. The influence of uncertainty on decision making is analysed using robustness analysis. The conceptual framework is supported by a new software framework designed to make uncertainty analysis more routine in flood risk management decisions as well as by the software itself (Reframe).

**The implications**

The framework and software outputs may help decision makers to better understand the implications of limited data, model uncertainties, changes in the flood risk system over the long term, inadequate scales of appraisal, and potentially conflicting policy objectives for their decisions.

**Reference**

A user-friendly decision support tool for long-term planning

Background, methods and techniques
Long-term planning for flood risk management requires that decisions makers question the current practice, determine the merits of innovative ideas, and explore alternative strategies. To do so, those making decisions need tools that allow them to ask 'What if ...?'. FLOODsite (Task 18) has developed a prototype of such a decision support tool that allows key parameters to be varied, and that shows the effect of various risk reduction interventions. It relies on a conceptual framework which allows confronting flood risk management options with different future scenarios of external change (for example climate and socio-economic change). It allows the decision makers (including policy makers, their technical advisors and the general public) to easily access and integrate information on hazard, exposure, vulnerability, risk and the influence of interventions and external change on these.

Results
A prototype decision support tool has been developed (see Figure) that allows decision makers to experiment with different assumptions on future developments and different decision criteria. By moving 'slider controls' (see Figure) the effects of changing assumptions becomes immediately evident, for example in terms of higher or lower expected annual damages. Output maps will change simultaneously, to show visually the impact of the 'slider control' position changes. The tool has been developed in the widely available ArcGIS format, so that it can be made available to a wide range of stakeholders involved in flood risk management decision making.

Example initial screen for the Thames prototype tool

Implications
With such a decision support system (DSS) the transparency of decision making in flood risk management should improve. More stakeholders can be involved, and the influence of assumptions on results can be more easily explored and taken into account in the public debate before decisions are being taken.

References

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