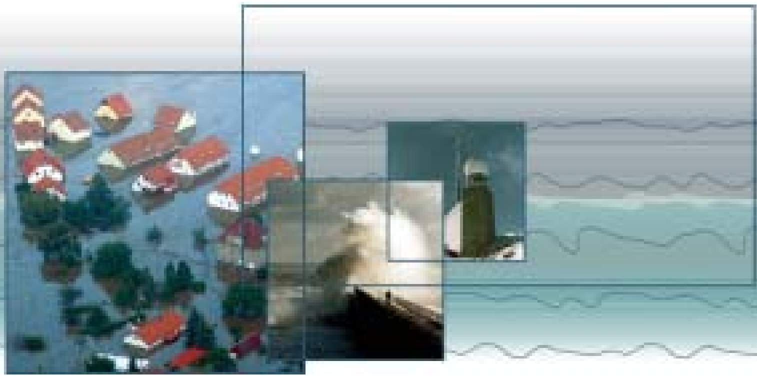
Integrated Flood Risk Analysis
and Management Methodologies



Evaluating flood damages: guidance and recommendations on principles and methods

Date January 2007

Report Number T09-06-01
Revision Number 2_2_P44

Deliverable Number: D9.1
Due date for deliverable: October 2005
Actual submission date: January 2007
Task Leader UFZ

FLOODsite is co-funded by the European Community
Sixth Framework Programme for European Research and Technological Development (2002-2006)
FLOODsite is an Integrated Project in the Global Change and Eco-systems Sub-Priority
Start date March 2004, duration 5 Years

Document Dissemination Level		
PU	**Public**	**PU**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Co-ordinator: HR Wallingford, UK
Project Contract No: GOCE-CT-2004-505420
Project website: www.floodsite.net

DOCUMENT INFORMATION

Title	**Evaluating flood damages: guidance and recommendations on principles and methods**
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Distribution	**Public**
Document Reference	**T09-06-01**

DOCUMENT HISTORY

Date	Revision	Prepared by	Organisation	Approved by	Notes
30/9/05	1_1_Pn44	Meyer	UFZ	Messner	
12/10/05	2_1_Pn44	all	Chapter 2: UFZ 3, 5 & 7: FHRC 4 & 6: UT		
14/10/05	3_0_Pn44	Messner	UFZ		
24/10/05	3_2_Pn44	Haase	UFZ	Meyer	Contribution on Inundation Modelling
15/12/05	3_3_Pn44	Meyer	UFZ	Messner	Include comments in section 2 from CG and CL
20/01/06	4_0_Pn44	Meyer, all	Chapter 1&2: UFZ/FHRC Ch. 3: UFZ Ch. 4, 6, 8: FHRC Ch. 5, 7: UT	Messner	• New: Chapter 1&2 • Revision of all other chapters
23/01/06	4_1_Pn44	Messner	UFZ and comments of FHRC on chapter 2	Task meeting	this version will be discussed in task meeting in Braunschweig
27/03/06	5_0_Pn44	All		Messner	Revision after Braunschweig meeting
26/04/06	5_1_P01	J Bushell	HRW		Formatting changes, addition of due date for deliverable, adjustment of dissemination level to PU
09/05/06	5_2_P01	J Bushell	HRW		Correction of deliverable number to D9.1, minor edits, formatting
09/05/06	1_0_P01	J Bushell	HRW		Change of name from '30_03_06_Guidelines_for_socio-economic_flood_damage_evaluation_v5_2_P01', insertion of summary text and final formatting
10/01/06	2_0_P44	Meyer	UFZ	Messner	Final Revision: Inclusion of comments received from experts
27/01/07`	2_1_P10	Penning-Rowsell, Parker, Tapsell	FHRC	Meyer	Minor edits, new edition of chapter 8
15/02/07	2_2_P44	Meyer	UFZ	Messner	Change of title, as agreed after task review
04/04/07		J Bushell	HRW		Final formatting for publication

ACKNOWLEDGEMENT

The work described in this publication was supported by the European Community's Sixth Framework Programme through the grant to the budget of the Integrated Project FLOODsite, Contract GOCE-CT-2004-505420.

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SUMMARY

Recent events like the 15 extreme floods that occurred 2002 in various parts of Europe showed that floods continue to pose serious risks in many EU countries. Indeed there is evidence that flooding is getting more serious over time, in terms of the number of floods occurring as well as the damage and the loss of life being caused.

The social purpose of flood risk management is to reduce flood damages. Since flood risk management strategies can require a significant diversion of resources from other purposes, it is desirable to determine whether the reduction in flood damages justifies the resources so expended. Equally, only if we are in a position to evaluate alternative intervention strategies in terms of their relative benefits and costs we are able to make 'better' choices and introduce more effective flood risk management strategies. As a consequence, the quantification and evaluation of flood damage is practised in a growing number of EU countries as an important factor to be considered in the decision process about particular flood risk management measures. Unfortunately, the methods used are quite diverse and they sometimes do not reflect the state-of-the-art in flood damage evaluation.

The major purpose of these guidelines is, therefore, to give guidance for practitioners of governmental authorities and executing bodies dealing with ex-ante flood damage evaluation in order to appropriately appraise public flood defence projects or strategies on different spatial scales.

With these guidelines we want to address a large community. On the one hand, we want to give guidance to countries just starting with flood damage evaluation studies. For this group we want to demonstrate how to proceed step by step in flood damage evaluations (especially chapters 3-4). Chapter 3 describes the state-of-the-art in evaluating direct, tangible flood damages. This chapter can be used by practitioners of countries with few or even no experience in flood damage evaluation in order to find an appropriate start into the endeavour of applying flood damage evaluation as a decision support tool. Chapter 4 reveals the principal rules and the procedure of building up a proper flood damage data base in order to ensure a consistent set of flood damage data, which is needed if flood damage evaluation is to be used as a long-term decision support tool.

On the other hand, we want to address flood damage evaluators in countries which already possess some experience in this field and we offer our guidelines to them as a checklist and want to inspire them to improve their evaluation methodology, e.g., by including methods for damage types which have been neglected hitherto in their work (especially chapters 5-9). Chapter 5 outlines the approaches to evaluate flood effects on industrial production. Chapter 6 indicates possible procedures to include social flood effects. Environmental flood effects and methods of their evaluation are described in chapter 7. Thereafter, chapter 8 focuses on damage reducing effects of flood warning in order to support specific decisions on flood warning systems. Chapter 9 gives an overview of flood damage categories which have not been considered in more detail in these guidelines and indicates relevant literature sources for further reading.

Last but not least we want to provide fundamental standard knowledge, specify key principles for economic evaluation of damages and reveal the sources of uncertainty that need to be considered. Hence, we want to help preventing errors in flood damage studies (chapter 2).

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1. Introduction: Purpose of these guidelines

Contributed by Frank Messner and Edmund Penning-Rowsell

1.1 Floods and the damage that they cause

Floods continue to pose serious risks in many EU countries. For example:

- In 1997 there were serious floods in the Czech Republic, Germany and Poland (Bronstert et al. 1998)
- 2000 saw widespread fluvial flooding in the UK, the worst since 1947 in terms of its extent and the number of properties affected (Penning-Rowsell *et al.* 2002)
- In August 2002 the maybe most severe flood event in Europe up to now occurred at the Rivers Elbe and Danube and some of their tributaries and caused huge damage in the Czech Republic and Germany (IKSE 2004).
- One of the most recent floods in Europe affected in summer 2005 parts of Switzerland, Austria, Southern Germany and various countries in south eastern Europe (IRV 2005)

Indeed there is evidence that flooding is getting more serious over time, in terms of the number of floods and the damage (Munich Re 2005) and the loss of life (EM-DAT) that it has caused.

But floods across Europe have very different characteristics. For example, there are the following types of flood, depending on geography, climate/weather characteristics, and the human occupance of the areas at risk:

- Major slow rising rivers, with floods generated by snowmelt or frontal rainfall systems (e.g. the Rhine, the Thames, the Po, and the Loire);
- Summer thunderstorm type events, resulting in 'flash floods' with very short warning lead time, often characteristic of Mediterranean summer days and/or mountainous regions (e.g. Ore Mountains in August 2002);
- Floods caused in urban areas through heavy pluvial events falling on inadequate sewer systems which are overloaded and may fail owing to inadequate maintenance or poor levels of investment (e.g. heavy rainfalls in July 2002 in Germany);
- Coastal floods, where embankments may be breached or storm surges overwhelm coastal defences (e.g. the North Sea floods in 1953 and 1962)
- Ice dammed rivers, generating floods through the back-up of flows spreading on to wide floodplains (e.g. the Vistula)
- Dam failure, although this is very rare but does pose a potential threat (e.g. Cyanide spill from a mine into the Tisza River 2000), although this type of flood is outside the scope of these Guidelines.

These floods all have very different characteristics and affect different populations. Damage characteristics will vary, for example in the extent of the failure of the structure of buildings. Loss of life threats will also be very different. Coastal flooding generally brings strong wave action, and urban drainage floods are likely to be heavily polluted. In turn, rural populations are likely to be better adjusted to flooding, with greater awareness and understanding of flood-inducing mechanisms. Older people are likely to suffer more in floods than young, mobile and adaptable people, and the extent of warning will bring different degrees of damage saving and loss minimisation.

All this means that developing these Guidelines for the assessment of flood damage for this range of circumstances and applicable right across the European Community is a complex task, and the results will necessarily be imperfect. This needs to be borne in mind by users when reviewing this volume.

1.2 Our target audience: stakeholders in flood damage assessment

In the wider context of integrated catchment and coastal zone management, the different stakeholders and particularly those who will bear either the flood damages or the costs of intervening to reduce the flood risks have an interest in the quantification of the damages from floods. Two obvious reasons for seeking to quantify flood damages are, first, to determine which combinations of floods and affected populations result in the greatest damages or, second, to determine the relative effectiveness of alternative intervention strategies. The social purpose of flood risk management is to reduce flood damages. Since flood risk management strategies can require a significant diversion of resources from other purposes, it is desirable to determine whether the reduction in flood damages justifies the resources so expended. Equally, only by being able to evaluate alternative intervention strategies in terms of their relative benefits and costs will we be able to make 'better' choices and introduce more effective flood risk management strategies. Consequently, the quantification and evaluation of flood damage is practised in many EU countries as one factor to be considered in deciding what to do in any particular choice. What each stakeholder wants to know about flood damages varies between stakeholders and sometimes between decisions:

- Some of these many possible choices faced by the different stakeholders are: Those who are considering implementing flood risk management measures may want to consider all benefits and costs of their policy measures in their decisions – and the most important benefit of flood risk management measures is the reduction in flood damages. Hence, they are interested in ex-ante flood damage evaluations in the context of project appraisals.
- National ministries and provincial governments responsible for flood risk management policy have a need to account for the amount of tax money they spend on flood protection. As a consequence, they want to use quantifications of ex-ante flood damage calculations to demonstrate that government spending for flood risk management schemes is beneficial to the public, contributing to the avoidance of millions of Euros of flood damage every year.
- Emergency planners will wish to identify where the critical areas of flood damage are and hence where emergency action should be concentrated, and which areas may have to be sacrificed in order to protect others.
- Governments of a nation, which were hit by a flood event, normally want to know afterwards how serious the flood was, which damages happened and how large the total amount of loss for the nation and the economy was. Such calculations might be used to just inform policy makers or they might also be used as a basis for the allocation of compensation payments to flood victims.
- Insurance companies are also highly interested in flood damage calculations. However, contrary to the government perspective, insurance companies are not interested in national loss, but only in insured financial loss referring to their clients. They need flood damage data to assess the flood risk of properties and to specify premium levels for insurances.
- Last but not least private firms and even private house owners might also be interested in the amount of damages that potential floods events might cause to their property. Based on this information they can judge whether it is worth while to take out a flood insurance policy or to bear the costs of private flood protection measures. Alternatively, they can also use the data to demand political flood protection measures.

The underlying **definition of the term "damage"** can also vary significantly depending on the interests of the stakeholders involved.

The first three bullet points refer to a national or regional policy perspective. In these cases the definition of damage usually encompasses national welfare losses, including damages to private *and* public goods and services. Hence, a broad economic perspective is appropriate in these cases.
Insurance companies and private entities, the last two bullet points, ordinarily focus on private assets and on the financial strain in terms of replacement of valuables that follows a flood event. A financial stance is usually taken in these cases.

Regarding the third bullet point a rather mixed approach can be observed with regard to ex-post flood damage evaluations in practice, depending on the skills and perspectives of the persons in charge. Although it can be argued that ex-post flood damage evaluation should take a broader economic perspective due to the public issues involved, officers in the authorities often tend to apply financial accounting practices.

1.3 The purpose of these Guidelines

The major **purpose** of these guidelines is to give guidance for practitioners of governmental authorities and executing bodies dealing with ex-ante flood damage evaluation in order to appraise public flood defence projects or strategies on different spatial scales.

Since such appraisals involve private and public goods, flood damage evaluation is mainly described from a broader economic perspective. Although the other perspectives will be mentioned and referred to time and again, these guidelines aim at becoming a practical guide for policy makers by demonstrating how to proceed appropriately in flood damage evaluation in order to use it as an important source of information for flood defence and its decision making process.

Since there is a large diversity of methods existing for all types of damages within the EU − as research of Meyer and Messner (2005) revealed for four EU countries − another purpose of the guidelines is to give some orientation, which flood damage evaluation method should be used, and which damage types should be included for which kind of policy issues under consideration of case-specific requirements regarding time horizons, spatial precision requirements and budgetary restrictions.

While it is *not* the goal to present *one* harmonised flood damage evaluation method, we aim at proposing a harmonised set of assessment principles and general procedures of flood damage evaluation studies in order to advance the quality and the comparability of such studies within Europe.

1.4 The content of these Guidelines

With these guidelines we want to address a large community. On the one hand, we want to give guidance to countries just starting with flood damage evaluation studies. For this group we want to demonstrate how to proceed step by step in flood damage evaluations (especially chapters 3-4).

On the other hand, we want to address flood damage evaluators in countries which already possess some experience in this field and we offer our guidelines to them as a checklist and want to inspire them to improve their evaluation methodology, e.g., by including methods for damage types which have been neglected hitherto in their work (especially chapters 5-9).

Last but not least we want to provide fundamental standard knowledge, specify six key principles for economic evaluation of damages and reveal the sources of uncertainty that need to be considered. In this way we want to help preventing simple errors in flood damage studies (ch. 2).

1.5 A ‘health warning’

Of course, the danger in any set of guidelines is that they institutionalise last year’s good practice, whereas their purpose should be to enable us to develop better practice.

We require innovation and learning if we are to do better, and cannot afford to institutionalise the past. The guidelines must therefore provide a basis for recognising which innovations will be an advance upon current practice. Depending upon the current state of the art, these guidelines either set out good practise or the principles of ‘good enquiry’.

Furthermore, these guidelines are to be understood as a "living" document, which will be up-dated once in a while in order to include new developments and innovations as well as to consider feedback from practitioners.

Finally, as some principles of flood damage evaluation stay true over time, we also want to refer to the substantial work done in the EUROflood project in the early nineties (Green et al. 1994; Klaus et al. 1994)

2. Fundamental issues in the economic evaluation of flood damage

Contributed by Frank Messner and Colin Green

In this chapter we want to discuss basic aspects of economic flood damage evaluation. We start with a short demarcation of the principles of good enquiry (2.1), outline fundamental aspects of validity and reliability of evaluation methods (2.2) and discuss the role of flood damage evaluation as a decision support (2.3). In 2.4 we outline the types of flood damages that need to be distinguished. In the following, we summarise the key assessment principles to be considered in studies with a broad economic perspective (2.5) and outline the uncertainty problems related to flood damage evaluation (2.6). We complete the chapter with a more detailed overview over the structure and content of the remaining chapters in this document (2.7).

2.1 Principles of good enquiry

As the famous economist Maynard Keynes pointed out, economics is not a doctrine but a system of analysis, a way of thinking. Economic techniques are thus aids to thought rather than having any merit in their own right. These guidelines are therefore supports to thought rather than being a set of rules which can be mechanically applied.

This approach requires that we start by establishing the criteria for good practice. We are seeking to measure something, a state or set of relationships, and to do so with minimal random or systematic error. What we seek to measure varies between states, static conditions, and the dynamics of relationships. We can want to measure the impact of a flood upon a particular economic unit but we also often want to be able to determine how those states vary according to the nature of the flood and the characteristics of the economic unit: to understand the dynamics of the relationships. Hence, a key criterion for a methodology is: to what extent does it provide new understanding? We want that understanding to be real and not simply an artefact of the experimental method so we also require that the methodology provides valid and reliable results.

Furthermore, theory and methodology are intertwined: the methodology is built upon an underlying theoretical model and consequently applying that methodology is a test of that model. If we want better methods, we also want better theories, ones of greater explanatory and predictive power.

The purposive sense of 'better' is to gain a greater understanding of the nature, extent and causes of impacts of the flooding in order that we can determine what are the best means of intervening to reduce those impacts. It is not curiosity that drives us but the desire to do something, and the greater understanding exists only in so far as we gain greater insight into what action to take. In particular, we want to be able to predict:

- which economic/social entities will be most vulnerable to which kinds of floods; and
- what are the most effective means of intervening to reduce that vulnerability.

2.2 Validity and reliability

A methodology needs to be both valid and reliable if it is to be of any use. In social science in particular, a methodology is always theory driven; what it is sought to measure is that which is defined by the theory. Thus, economic analyses are based upon some economic theory, and conventionally upon neo-classical economic theory. That theory, for example, is based upon the assumption that economic value of some resource is solely defined by the desire by someone for the resource in question.

Validity and reliability are to some extent the two sides of the same coin. Validity is about differentiation, the ability of the measure to measure that which it is intended to measure and nothing else, and to show differences when real differences exist but not when they are not predicted: what is a real difference is one that is strongly predicted by theory and experience. Thus, validity is the ability to pick systemic differences. Conversely, reliability is the extent to which the measurement technique is insensitive to factors that can generate random error. In short, validity is the extent to which a measure yields differences that are theoretically predicted; reliability is the extent to which it does not show differences when these would not be theoretically predicted. Consequence, any test of the validity of a measure is simultaneously a test of the theory or hypothesis upon which it is based. What is a systemic difference and what would be random error are defined by the underlying theory. If a measure produces a difference when none is predicted then either the measure is invalid or there is a problem with the underlying theory: the problem is then to determine whether it is the theory or the measurement technique which is at fault.

Since the nature of the differences and similarities predicted by the theory vary from theory to theory, there are potentially many different forms of validity (Carmines and Zeller 1979). These include:

- *construct validity* – this is the extent to which the measurement instrument is clearly a reflection of the underlying theory or theoretical construct and nothing else.
- *discriminant validity* – the extent to which the measurement instrument picks up differences when theory predicts those differences to exist.
- *convergent validity* – the degree to which two instruments measuring the same theoretical construct agree.
- *predictive validity* – the success of the measurement instrument in predicting those conditions which would theoretically be expected to follow from the state measured by the instrument.

Equally, there are many different forms and tests of reliability, depending upon what differences are not predicted by theory.

The presumptions of conventional economic theory are therefore defined in Section 2.5.

2.3 Flood damage evaluation as a decision support

The consideration of flood damage in the context of the decision making process of flood risk management policy is still a relatively new concept. There is even less experience in integrating such a consideration into the forms of analysis and practice as are now necessary under the EU Water Framework Directive (and will be required in the context of an EU Flood Directive in coming years as a first proposal of January 18, 2006 called "Directive on the assessment and management of floods" indicates). Historically, it is government and government agencies that have used economic appraisals to support their decision making whereas the new emphasis on governance shifts that responsibility to the stakeholders. That change simultaneously changes the roles of experts from determining the 'optimum' intervention strategy to one of informing the stakeholders of what the stakeholders want to know but also what they need to know. The different countries of the European Union have decided upon different institutions to be the designated 'competent authority' under the Water Framework Directive. Some countries, such as Spain, have come closer than others to meeting the emphasis in the Directive on engaging with the many different stakeholders who will either have to act if the objectives of the Directive are to be met, or who will be significantly affected by actions taken. Two obvious stakeholders are those who will benefit by any reduction in the risks of flooding and those who will bear the costs of any such intervention for that purpose. Whilst this shift to decision making through stakeholder engagement has significant implications for the form of the information which the stakeholder decision makers will require, there is no real experience in providing such decision support.

Traditionally, a design standard philosophy dominated the sphere of flood risk management policy. Decision makers decided upon the "appropriate" protection level to be achieved based on the knowledge about the technical flood protection possibilities. For example, national law in the Netherlands still prescribes today that the coastal regions must have a protection level that ensures security even against extreme flood events with a frequency of occurrence being up to once in ten

thousand years (Baan/Klijn 2004). This means, the protection objective is given by politicians and scientific aspects are considered later when the means to achieve it come into play.
In recent years a new philosophy of flood protection evolved, which aims at the management of flood risk, and which considers floods just as one of several sources of risk in human society (Sayers et al. 2002). In this context flood risk is defined as expected flood damage for a given time period. Here, the flood risk management strategy obviously has the effect of producing some notional design standard of protection but that strategy is determined by wider considerations than some target level of risk. Considering flood risk management as part of the wider issue of Integrated Water Resource Management implies the immediate question, whether it is justified to spend a huge amount of tax money for flood risk reduction, while other areas of risk in society might receive much less financial support to reduce it. This kind of thinking leads to the necessity to consider all benefits and costs of flood risk management policy (or specific protection measures) in order to,

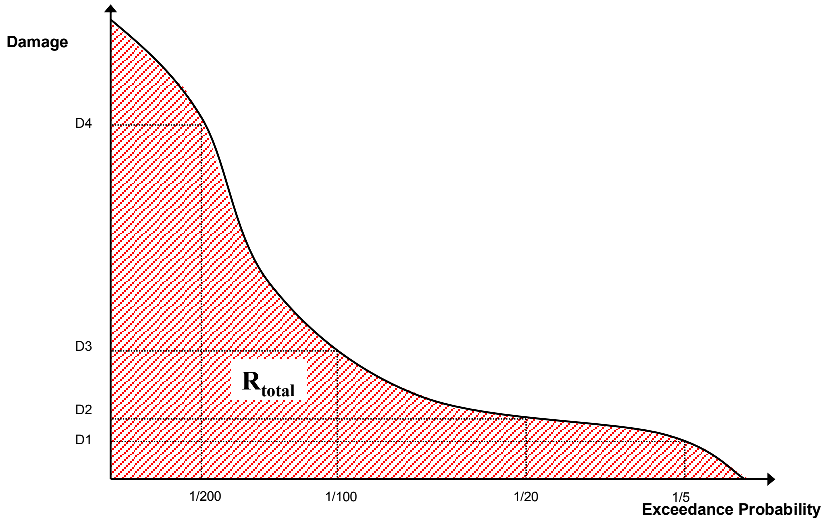
(1) specify the risk situation (how large is the current risk in terms of damage per year?),
(2) determine the potentials of risk reduction and their respective costs (by how much is it possible to reduce risk and how costly is it?),
(3) compare the benefits and costs of risk reduction in terms of the benefit-cost ratio and/or the net benefit (are the benefits larger than the costs?) and,
(4) compare the benefit-cost ratios of several policy fields dealing with risk reduction in order to decide where the tax money should be spent first.

Hence, there is an increasing significance of flood damage evaluation methods for decision support in flood risk management policy (Penning-Rowsell et al. 2003).

Flood risk analysis is a holistic approach, which considers the risk of all kind of flood types and flood events for the study region. Flood risk analysis does not only encompass the risk that *one specific or one extreme flood event* may occur (as it is sometimes misunderstood in practice). It rather combines the hydrological knowledge about the frequency of different types of flood events, the hydraulic modelling information about inundation behaviour of flood water in flood plains and economic flood damage evaluation knowledge in order to provide so-called damage-probability curves for individual floodplains or also for nations as a whole (see fig 2.1, see also Annex 2.1). Such a figure shows the amount of total damage which is to be expected if a flood with a specific frequency of occurrence happens. For example, in figure 2.1 the expected damage of a flood with a frequency of occurrence of once in hundred years (1/100) amounts to a damage of D3. The total area under the curve represents the average total expected flood damage *per year* for all kinds of floods.[1] Hence, the damage-probability curve contains important risk-related information for decision making on flood risk management policy.

[1] Please notice that for the calculation of these annual expected damages the run of the curve at both ends and especially for low probabilities is important.

Figure 2.1 Damage-probability Curve



Three significant spheres of applying flood risk analysis information in public policy must be distinguished:

1. Supporting decisions on financial allocation of tax money. Considering the area under the damage-probability curve and comparing the flood risk in terms of yearly expected amount of flood damage with other societal risks like expected damage due to transport, illness or earthquakes provides enlightenment about the significance and severity of different risk factors in society. Such information can provide decision support for decisions about the allocation of tax money to various policy fields aiming at reducing societal risk.

2. Project appraisal. Information on yearly expected flood damage is also an important input for decisions on flood risk management measures and investments. The risk-reducing effects of different flood risk management measures can be estimated by means of flood risk analysis as shown in figure 2.2 (see also Annex 2.1 for a more detailed description).

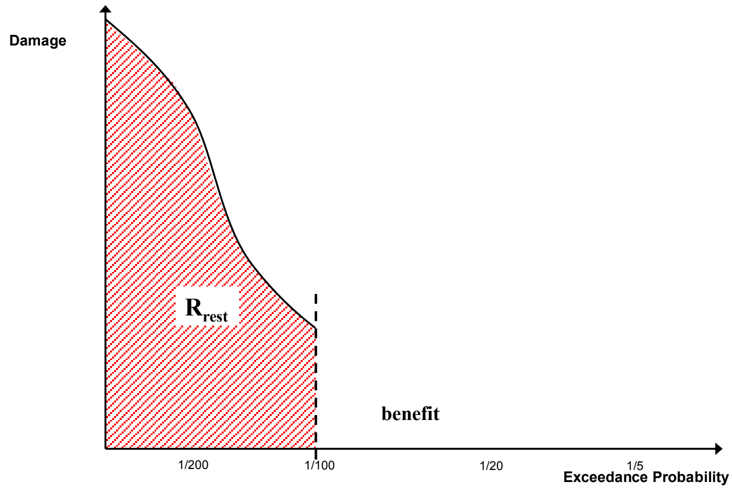
In this example a flood defence structure is able to ensure protection against floods with a frequency of once in hundred years. The yearly benefit of a scheme is given by the difference in the areas under the curves for the 'with scheme' and 'without scheme' situations. In this particular case the area under the curve at the right side of the dotted line represents the yearly risk-reducing effect of the measure in question.[2] Other kind of measures will have other impacts on the shape of the damage-probability curve. For example, a reduction of settlements in the floodplain would probably lead to a left-shift of the whole curve. It is therefore necessary to calculate the impacts of a measure across the entire range of probabilities.

Comparing this figure with the costs of the measure in an appropriate time frame (yearly costs or costs over the expected life time of a flood risk management structure) delivers information about the efficiency of the measure, i.e. whether benefits to society are larger than costs. If the benefit-cost ratio of a flood protection measure is robustly larger than one, this measure can be considered to deliver efficiency gains to society. Otherwise, if this ratio is significantly smaller than one or afflicted with

[2] For simplicity reasons it is assumed in this example that this measure will not have any influence on damages of events above the design standard. In reality such effects will occur, i.e. the loss-probability curve "with scheme" will differ from the "without-scheme" curve also on the left side from the 100 year event (see DEFRA 1999). Reason for this might be, e.g., that the construction of a dike leads to increased settlement development in its Hinterland: If the new dike fails damages would be higher than before its construction.

high degrees of uncertainty one should rather abandon the measure. This kind of information out of a cost-benefit analysis (CBA) framework is an important input for decision making to decide over measures or to set up a priority list of measures.

Figure 2.2: Benefit of flood protection against flood events with a yearly frequency of occurrence of once to one hundred



3. Accountability. Flood risk analysis results are an important means to justify public investments and to demonstrate the appropriateness of public spending. They are helpful to explain why certain flood protection measures are more efficient in one river basin and less in another, and they can be used to justify the overall spending for flood risk management measures by demonstrating that the risk figures and the efficiency of risk-reducing investments are high in this policy field.

Eventually, it should be mentioned that flood risk analysis – and flood damage evaluation as an essential part of it – need not necessarily be based on monetary damage figures alone. Some damage categories are very difficult to assess in monetary terms or they are just not accepted by policy makers in this way. For example, loss of time due to disruption of traffic can be measured in time units or in average figures of opportunity costs of persons affected. In the U.S., were there is a significant tendency to apply monetary units to almost all kinds of effects, politicians banned the use of monetary units to support decisions on transport policy because they found that a time unit would express the effect more clearly. Similarly, effects on the environment, on cultural values, on human health or the loss of human life are very difficult to assess in monetary terms. Therefore, they are called intangibles. Methodological problems are involved in these damage categories and also ethical objections are expressed by different stakeholder groups. Since flood risk analysis is prevailingly considered to be a holistic approach, the inclusion of intangibles is desirable. Achieving this requires either to monetise all intangible damage effects or to integrate them into a multi-criteria framework of analysis. Since at least loss of life is not treated in monetary units in any EU country, flood risk management policy must be considered a policy field which has to deal with a bundle of decision criteria in practice. Therefore, although there is a clear focus on monetary evaluation of flood damage in these guidelines, multi-criteria aspects and evaluation approaches are also mentioned in some chapters of this document.

2.4 Types of flood damages

It is, of course, essential to consider all known flood damage categories in flood risk analysis and flood damage evaluation. It is therefore necessary to specify the different flood damage categories which need to be involved in the analysis. The term “flood damage” refers to all varieties of harm caused by flooding. It encompasses a wide range of harmful effects on humans, their health and their

belongings, on public infrastructure, cultural heritage, ecological systems, industrial production and the competitive strength of the affected economy.
Although the terminology differs occasionally, flood damages are mostly categorised firstly in direct and indirect damages and secondly in tangible and intangible damages (Smith & Ward 1998; Parker et al. 1987; Penning-Rowsell et al. 2003; Messner & Meyer 2005).

- **direct/indirect damages**: direct flood damage covers all varieties of harm which relate to the immediate physical contact of flood water to humans, property and the environment. This includes, for example, damage to buildings, economic assets, loss of standing crops and livestock in agriculture, loss of human life, immediate health impacts, and loss of ecological goods. Direct damages are usually measured as damage to stock values.
  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 of their suppliers and customers, the costs of traffic disruption or the costs of emergency services. Indirect damages are often measured as loss of flow values.
- **tangible/intangible damages**: damages, which can be easily specified in monetary terms, such as damages on assets, loss of production etc. are called tangible damages. Casualties, health effects or damages to ecological goods 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 indicated as “intangibles”.[3]

Table 2.1 combines the two differentiation criteria and gives some examples for each category.

Table 2.1: Typology of flood damages with examples

		Measurement	
		Tangible	**Intangible**
Form of damage	**Direct**	Physical damage to assets: - buildings - contents - infrastructure	- Loss of life - health effects - Loss of ecological goods
	Indirect	- Loss of industrial production - Traffic disruption - emergency costs	- Inconvenience of post-flood recovery - Increased vulnerability of survivors

Adapted from: Penning-Rowsell et al. 2003; Smith & Ward 1998

Furthermore, Smith & Ward (1998) distinguish between primary damages, which result from the event itself, and secondary damages, which are at least one causal step removed from the flood. For example, the loss of production of a firm which is flooded and therefore is unable to carry on with their production would refer to as primary indirect loss. The induced losses of production of customers or suppliers in- and outside the affected area due to backward and forward linkages would be indicated as secondary indirect damages. [4]

[3] Nevertheless, there exists a range of methods by which such “intangibles” can be evaluated in monetary terms (see e.g. chapters 6 & 7).
[4] This terminology differs from that used in economics. Here, the primary indirect damages would be referred to as “direct cost” while only secondary indirect damages would be called an “indirect cost”. Note that e.g. in the US FEMA reports (www.fema.gov/hazus/) loss of industrial production is handled as a direct loss; in the official Dutch Government reports this approach is also applied.

2.5 Six key principles of economic evaluation

As has been indicated above there exist different rationales of economic evaluation. Financial evaluations look at damage from a perspective of a single person or firm, neglecting public affairs and focussing on the actual financial burden. Economic evaluations have a broader perspective and want to assess the impact on national or regional welfare, including impacts on intangible goods and services. This broader economic perspective is the appropriate one to apply if calculations of flood damage are to be designed for supporting public policy decisions. Several principles of economic evaluation need to be considered in order to conduct a comprehensive flood damage evaluation study in a consistent way. The most important principles as regards the economic evaluation of flood damage are specified in the following.

1. Define appropriate time and spatial boundaries of the study!
In order to include all important impacts of a flood in one study, it is important to choose a suitable length of time and the geographic extent over which the flood effects are felt. Regarding the spatial boundaries the inundated area might not be sufficient, because indirect effects like disruptions of transportation and production are sometimes felt outside the inundated region. In transboundary studies problems like different currencies and purchasing power have to be considered. Similarly, in the choice of the time horizon of a damage study it should be preconceived that some flood damage categories like health or environmental effects might require the consideration of time spans which are longer than those normally applied for typical material damage categories (e.g., Young 2005: 31).

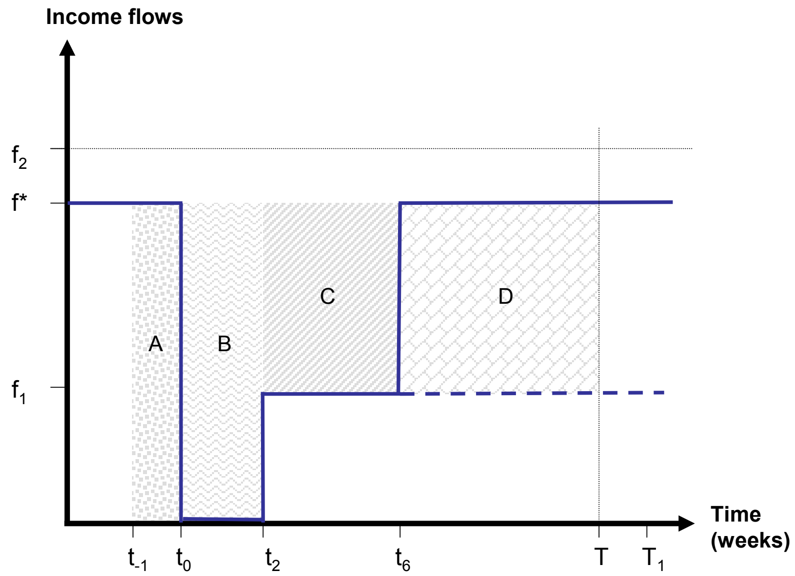
2. Apply scarcity prices for the evaluation of market goods!
The economic evaluation of goods and services which are traded in the market is a task that is relatively easy to accomplish. However, according to economic theory several rules need to be considered to identify the "correct" value. As stated in most economic textbooks, the value of a market good corresponds to its scarcity price. And a scarcity price emerges in the context of an ideal competitive market with many competing actors involved and without government intervention. Since these ideal conditions are never fulfilled in a real-world market, adjustments are necessary in order to calculate the ideal "shadow price" of the good under examination. This means, real world market prices must be translated into shadow prices by excluding all kind of transfer payments like taxes and subsidies and by converting monopolistic market prices into competitive market prices (e.g., Hanley/Spash 1993: 13 ff, Schönbäck et al. 1997: 11 ff).

3. Only consider real effects, this means: neglect pecuniary effects!
Economic evaluation does only consider real effects on the utility of societal market actors, while pure pecuniary effects due to inflationary pressures (rising oil prices, wage increases etc.) are explicitly removed. This means, all monetary benefit and cost figures need to be deflated in order to reflect inflation-adjusted prices which all refer to one basic year (e.g., Hanley/Spash 1993: 11).

4. Consider the fact that stock and flow values are two sides of one (economic value) coin!
From an economic point of view the value of a (market) good can be represented in two ways. On the one hand, its value is represented by its scarcity price. On the other hand, the good can be considered as a capital good, which can be used to generate a flow of income to the owner. The sum of this capitalised income over the life span of the market good represents its value, too. If the market is not distorted, and is at equilibrium, then the scarcity price of a good − its stock value − is equal to the sum of its income flow values over the rest of the good´s life span (Georgescu-Roegen 1981: 220 ff.). Therefore, summing up both in a flood damage evaluation study would be inappropriate due to double counting. As a consequence, a fundamental principal of economic evaluation reads: never sum up stock and flow values for one element at risk.

However, although this rule sounds logic and easy to apply, there are some complications with regard to its use in practical flood damage evaluation. Consider a small firm located in a flood-prone area, which is inundated at the time t_0 by a flood for two weeks with the consequences that the stock of inventory representing the production of one week is destroyed and production is ground to a halt. After the flood water disappeared, production can be started at time t_2 with the portion of the productive capital which is not damaged, while it takes four additional weeks of reconstruction (until t_6) before production performs at its pre-flood level. For simplicity reasons it is assumed that sub-contractors are not indirectly affected. Figure 2.3 shows the impact on the income flow (solid blue line) of the affected firm (neglecting economic effects in the overall economy). Before the flood the firm realises an income flow of f*. Regarding the damage impacts, four different types of damage must be distinguished in this case. First, the loss of the inventory represents a loss of an income flow which pertains to the production of the week before the flood, and therefore, can be illustrated as area A. Second, area B reflects the loss of income flow of the firm due to disruption of production during the time of inundation (t_0 to t_2). If another national firm takes over the production and generates a larger income flow, the national loss equals the income loss of the inundated firm (B) minus the income gains from the other firm. If a firm outside the country takes over the production, the income loss B of the inundated firm represents a national loss (if there are no further national firms inundated). Third, area C corresponds to the loss of income due to reduced output after the disappearance of the flood water such that the income flow of the firm is reduce to level f_1. Again, the increased output and sales of other firms must be considered as well, if a broad economic perspective for a whole nation is taken. Finally, fourth, area D represents the loss of income over the remaining life time of the productive capital stock (t_6-T), which would have been materialised if reconstruction activities had not been carried out such that the income flow would have remained at level f_1 after t_6 and the sales would have been lost to competitors. Again, this is only the damage of one firm. For a broader economic analysis the effects on other national and international firms need to be included.

Figure 2.3: Example of an income flow of a firm damaged by a flood



Applying the above stated rule (never sum up stock and flow values for one element at risk) would mean: either subtracting the scarcity value of the flood-affected firm after the flood from its scarcity value before the flood (value in terms of stock) adjusting with scarcity values of firms which realised gains *or* calculating the all income flow losses minus all income flow gains (value in terms of flows). The first approach is almost impossible for most firms, because their scarcity value is usually not known. The second approach would be easier, but often data on income flows is not available either. It might be most appropriate to approximate all flow values of the damage by means of regional economic models – if available (see chapter 5). However, a compromise approach would be to combine stock and flow evaluation for the individual value components A, B, C and D, i.e. to choose the stock or flow approach for each damage component according to data availability. Area A could be quantified by the loss of income due to not selling the products which were already produced. In this respect the market value of the inventory free of tax could be used (stock value) or, alternatively, the income flow which is usually generated by this amount of products (average flow value). Area B can be monetised for the whole economy by the total loss of income flow of the inundated firms during the time of the flood (two weeks of production in the example) adjusted by gains of income of competitors. Area C can be represented by the loss of income flow which would be realised if output is reduced, also adjusted by income gains elsewhere. Finally, area D can be monetised in two ways: either by calculating the loss of income flow for the rest of the life span of the capital stock (t_6-T) that would have been realised if reconstruction would not have taken place (flow value of D) − adjusted by income gains elsewhere in the economy. Alternatively, the reconstruction costs can be estimated which enables the firm to reach its old level of production − and competitiveness − for the time period t_6-T (stock value of D). An example for the compromise approach to evaluate flood effects with stock and flow values would be to monetize areas A and D through stock values (scarcity value of inventory and reconstruction costs) and B and C by means of lost/gained income flows. Although stock and flow values are used in this latter case this is still correct, because *each* of the damage components A, B, C, and D is quantified by means of stock *or* flow value. No double counting is involved. Just calculating the costs of reconstruction(as is often done in damage studies) would be inappropriate in this case, because this would only reflect damage D and neglect A, B, and C, hence an underestimation of damage would result.

After having considered this example the evaluation rule can be specified: *Each individual component of a damage of any category should be monetised either by stock values or by flow values; including both for one component would be double counting.*

5. Apply depreciated values and not full replacement costs!
In an economic damage study depreciated values should be applied in order to reflect the value of a good at the time when it is damaged by a flood. Using replacement costs is an overestimation of damage from a broader economic perspective, because replacement usually involves improvements: old goods which are damaged during a flood are usually substituted by new, more productive and better performing goods (Penning-Rowsell et al. 2003: ch. 4.4.2). With regard to figure 2.3 and damage component D, the use of replacement cost would mean to overstate this damage component, because the life span of the firm´s capital is prolonged by reconstruction and the firm´s productivity will probably improve such that the level of the income flow might increase to f_2 after reconstruction. One possibility to consider this aspect is to survey the average age of relevant consumer goods and to estimate their value through secondary market values or through application of depreciation rules. In the UK surveys have been undertaken to identify the average age of relevant retail goods in order to calculate so-called “average remaining values” (see chapter 4).

6. Use the net present value of benefits and costs in the context of cost-benefit analyses!
Benefits as well as costs may occur in different points in time in the future. All these future values have to be discounted by a yearly discount rate to their net present value in order to make them comparable. There are mainly two reasons for this reduction of future values (e.g., Green 2003: 78 ff; Hanley/Spash 1993: 16 ff.).

1. The opportunity cost argument says that a project should bring at least an average return to investment compared to other promising investment projects in society.
2. Many people believe that future generations will be better off due to increasing national welfare, higher income levels and improved technology. Therefore, future values need to be reduced.

It should be mentioned, too, that there are critical voices, arguing that discounting the value of environmental goods and services discriminates against future generations. In face of shrinking natural areas and growing loss of biodiversity the welfare of future generations might well be lower than today. Therefore, some economists argue that discounting should not be used for environmental values. An appropriate way to deal with the problem of discounting is to apply several discount rates in the analysis in order to consider their impact on the results and to include this knowledge in the final decision (Hampicke 1992).

* * *

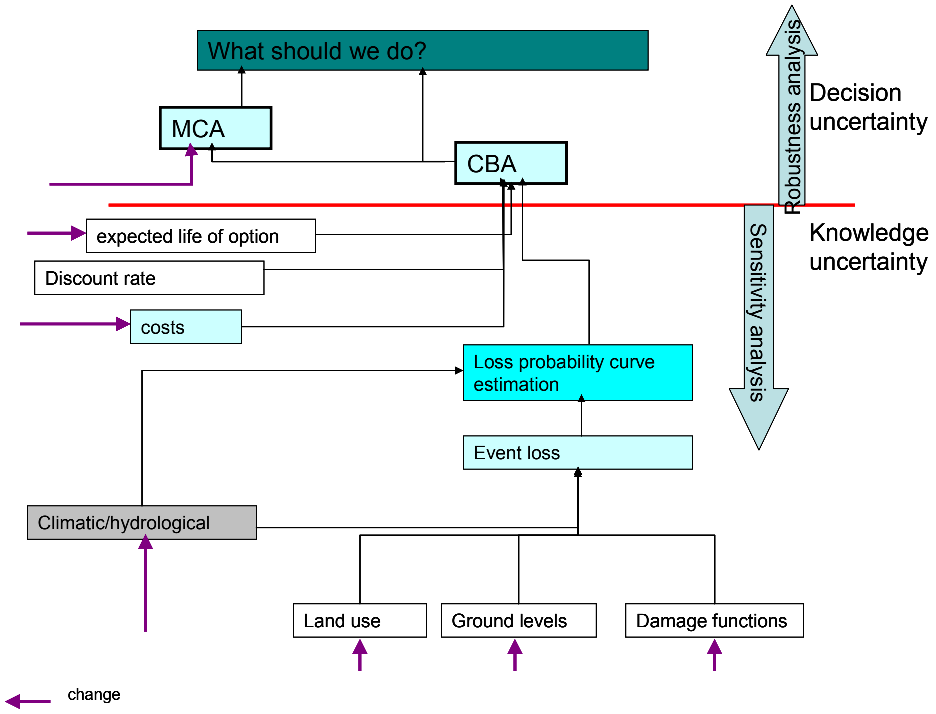
The application of the above described economic principles of economic evaluation is crucial for an appropriate ex-ante examination of flood damage, and the use of their results in flood risk analysis. It is essential to follow these principles as closely as practicable. But, in practice, no economic analysis can ever, nor should it aim to, cover every single benefit and cost very accurately and precisely. It should instead seek to include the most important benefits and costs so that a decision can be confidently taken as to which option to adopt. In this regard, the benefit-cost ratio is not a 'pass-fail' test but a measure of the confidence as to the desirability of adopting an intervention strategy. Thus, a benefit-cost ratio of one is the point of maximum doubt as to whether an intervention strategy should be preferred over the current situation. Consequently, once it is possible to have confidence that one intervention strategy or the current situation should be preferred over all other courses of action, then there is no purpose in further refining the cost-benefit analysis. For example, if the benefit-cost ratio for the intervention strategy is robustly at least three, there is little point in further refining the cost-benefit analysis.

It also follows that the cost-benefit analysis should be progressively refined; if at the pre-feasibility stage, a very approximate cost-benefit analysis indicates that it is very unlikely that any feasible option would achieve a benefit-cost ratio as high as one, then it would be a waste of money to undertake detailed hydrological and engineering studies of those options. In that iterative process of refinement, concern should be concentrated upon those costs and benefits which have the greatest effect upon the benefit-cost ratio. In effect, cost-benefit analysis should be applied to the cost-benefit analysis of the intervention strategies; it is not worth spending money to refine the estimate of one or another benefit or cost if that refined estimate would make no difference to the decision. A second and important purpose of CBA is to aid in the invention of new and better options.

2.6 Dealing with uncertainty

The assessment of flood damages imports uncertainties from the climatic/hydrological/hydraulic domain, adds some of its own uncertainties, and exports the resulting composite uncertainties into the decision domain. In some countries, that decision domain has itself been encompassed within cost-benefit analysis but the intention in Floodsite is to adopt Multi-Criteria Analysis to determine which flood risk management strategy should be adopted. The approach to the uncertainty adopted within Floodsite must therefore recognise the multiple sources of uncertainty and take these through to the decision as to what action to take. The Foresight study on flood risk management sought to define the sources of uncertainty, and also the relative magnitude of the uncertainties surrounding each. Figure 2.4 summarises the broad sources of uncertainty, and highlights the importance of change over time as a source of uncertainty.

Fig 2.4: Source of uncertainties in flood risk management



Since economics is concerned with choice, economics is centred upon predictions or expectations of the future. Two different philosophies as to the nature and extent of uncertainty have developed. The first philosophy is that associated with Knight (1921) and later Keynes (1937); they argued that uncertainty and probability are two entire different concepts. Keynes in particular defined very narrowly the domain of predictions about which probabilistic statements could be made, asserting in 1937 that the price of copper in twenty years time was a parameter about which no meaningful probabilistic claim could be made. Since twenty years is relatively short term and the price of copper appears to be a relatively simple parameter, this was to draw the boundary about meaningful probabilistic statements extremely narrowly. Unfortunately, examination of the price of copper twenty years later suggests that Keynes was right to the extent that no useful probabilistic statement could have been made. The problem with the Knight-Keynes approach is that it appears to provide only limited guidance as to how to take uncertainty into account in making choices. Consequently, the alternative philosophy developed in which uncertainty could be expressed in the form of Kolmogorov probabilistic claims (1950)[5]. Von Neumann and Morgenstern's (1947) seminal book introduced expected utility theory, an approach which was further developed by Savage (1954). This approach has the great advantage of appearing to offer a means of incorporating uncertainty into decision making through sensitivity analysis, carried out at the completion of the analysis, coupled to Monte Carlo modelling (e.g. ADB 2002). This latter approach has consequently been both widely recommended and adopted, but often greatly underestimates the uncertainties and tells us little more than we knew already. For example, one recommendation that has been made is to test the effect of decreasing the benefits or increasing the costs by 20%. However, the uncertainties surrounding both will typically be considerably greater than 20% and the effect of either change is already known from the benefit-cost ratio. The definition of uncertainty in terms of Kolmogorov probabilities led on to the examination of the extent to which a decision maker should be risk averse or risk neutral (Arrow and Lind 1970).

[5] That is, a probability statement that conforms to Kolmogorov's mathematical axiomisation of probability. Other axiomisations have been developed.

There are therefore two important questions:

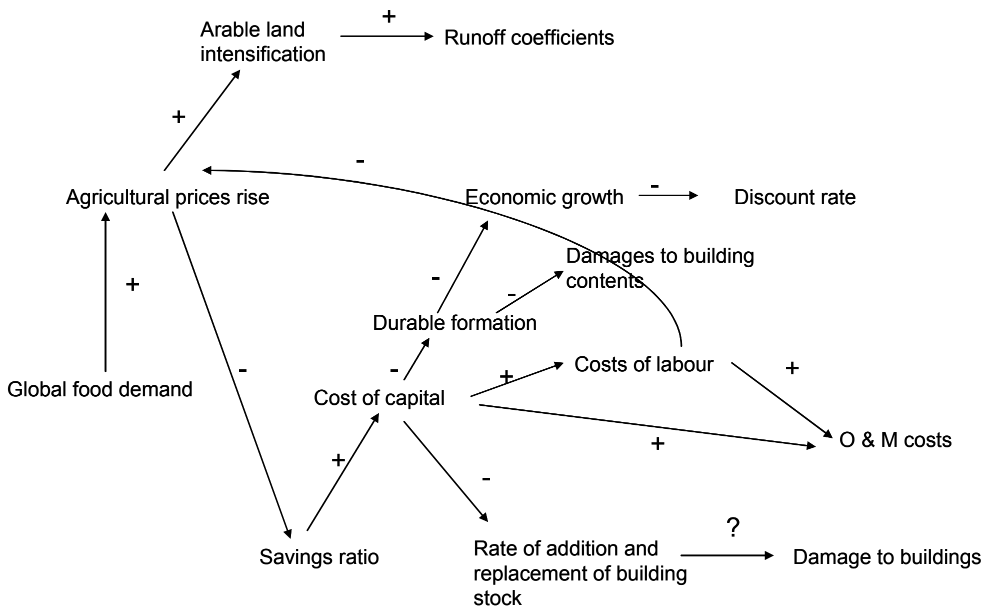
1. When we say that we are uncertain or that event is uncertain, is this the same as saying that an event has a probability? For example, can we make any meaningful claim that an unknown coin is a fair coin? Equally, can we make meaningful statements in probabilistic terms about 'statements': is it not a category mistake to treat a claim about the truth of a statement as being equivalent to a claim about the likelihood of an event?
2. Does the Kolmogorov mathematical axiomisation of probability have those properties which truly represent the nature of the statement which we wish to make in the particular circumstances in question? Kolmogorov's 2nd axiom, that probabilities sum to one, in particular has been challenged (e.g. Green 2004).

In addition, any assertion of a probability is itself an epistemological claim: a claim as to what we can know and how or why we can know it. The basis of this claim frequently varies between claims although each claim is expressed in terms of a probability. That a probability statement is based upon an epistemological claim means that all probability statements are conditional probabilities so that a claim based upon an examination of the length of record that the probability of a flood of given magnitude is 0.01 is conditional upon at least the following three statements being true:

a) the record is a random and unbiased sample of flood flows in that river.
b) there is no systematic change over time either in the past or in the future.
c) that statistical distribution which best describes the data has been fitted to the record.

Pending the detailed analysis of the incorporation of uncertainty into flood risk management that will be undertaken in Floodsite, it would be inappropriate to provide detailed guidance on the handling of uncertainty at this stage. What can be observed is that these uncertainties are substantial and arise in multiple ways (Figure 2.5). For example, since direct damages are largely estimated through depth-damage curves, and depth is estimated as the difference between flood level and floor level, errors in either will result in errors in the estimation of flood damages. The effect of these errors are greatest for shallow depths of flooding because flood damages at 0.1 metres of flooding for the UK average house is estimated to be 23% higher than those for 0.05 metres (and considerably higher for 0.05 as opposed to 0 metres). Again, in the UK it is known that estimates of the construction costs of schemes are significantly uncertain and estimates are biased so that preliminary cost estimates are, on average, 60% below final construction costs (Defra 2003). Worldwide, Operation and Maintenance costs are not estimated with anything like the same attention as capital costs. However, if bank protection works are a major cost and there is uncertainty as the frequency with which such works must be repaired or replaced, this is likely to be a critical parameter (Green 2003). Similarly, Defra (1999) provides guidance as to the maximum error to be expected in calculating the damage-probability curve and the most efficient means of reducing that uncertainty. It has thus been suggested that if the robustness analysis conducted at the end of the analysis does not vary the benefit-cost ratio by a factor of three, the analyst is not really trying and is making quite spurious claims as to the degree of certainty that can be claimed about the performance of a flood risk management strategy over a life of perhaps 100 years (Green 2003).

Figure 2.5: Impacts of uncertainties in agricultural prices on other economic variables



A particular problem in economic analysis is that we are dealing with a system; in consequence, a change, and hence uncertainty, can be propagated through the system if there is a change in one variable. Figure 2.5, which it is not claimed to be more than indicative, illustrates how a long run change in world agricultural prices (the effect of a change in energy prices would be similar but more complex in that there is scope for substitution in the case of energy) might be propagated through the economic system via positive and negative linkages. In one case, the effect of changes in rate of the replacement and addition to building stock upon direct damages to buildings, the direction of the change is indeterminant. Thus, the uncertainties about individual parameter values are correlated and this must be taken into account in any Monte Carlo simulation. There are additional uncertainties as to the form of the functional relationships between the parameters, and here the discovery of chaos theory creates a problem in that quite simple functional forms can yield chaotic results. For example, the output from the equation $x = r.x.(1-x)$ is stable for a value of r of 2.7, oscillates for an r value of 3.0, and is chaotic for a r value of 4.0 (Gleick 1987). Equally, in a simple study examining the effects of varying the distribution of benefits over time, it was found that the present value of those benefits was dependent both upon the functional form of the probability distribution adopted and the kurtosis of the distribution function. Hence, a Monte Carlo analysis should include varying the probability distributions that are assumed and the variance for each of those distributions, rather simply assuming some probability distribution about some estimate of the mean value.

That the potential errors and uncertainties are so large suggests that one possible way out of this problem is to distinguish between ‘decision uncertainty’, doubt about what to do, an inability to discriminate between the options, from ‘knowledge uncertainty’: uncertainty about the state of the world now and particularly in the future (Green 2003). One reason why the decision maker may be unable to decide is that the balance of advantages and disadvantages of each option are equal; the second reason why the decision maker should be uncertain is the lack of knowledge makes it impossible to discriminate between the options. In this latter case (Figure 2.4), the decision maker should undertake a sensitivity analysis at the beginning of the analysis in order to determine which are the parameters upon whose values the choice between the options critically depends. It is these parameters upon which attention should be focused. It is only by assessing the implications for the decision that both the absolute and relative importance of uncertainties in individual parameters can be determined. If the benefit-cost ratio is very large then there can be major uncertainties in several parameters without those uncertainties affecting the decision. In more marginal cases, it is on the critical parameters upon which attention should be focused in seeking to improve the estimates of the parameters. It is also on these parameters upon which risk management should be focused. In general, it is those benefits and costs which occur early in the life of the intervention strategy and/or occur frequently which are likely to be critical. These include:

- Capital costs
- Operation and Maintenance costs
- Flood levels as estimated from ground levels and water levels
- Damages from frequent floods
- Land uses at low levels including below ground land uses

The following means by which to incorporate uncertainty into flood risk management have been suggested:

- Seeking to learn throughout the design cycle of individual projects, over the life of projects and across projects, and the general importance of institutional learning.
- The application of risk management principles in design, construction and operation.
- The adoption of the principle of seeking to manage all floods and not just some: the avoidance of adopting some design standard of protection and instead considering how the intervention strategy will affect the risk from the entire spectrum of floods.
- The adoption of the related principle of designing for failure: designing so that failure occurs in a manageable way.
- Seeking to allow adaptability to future change.
- Since many flood risk management strategies have spatial requirements, it is likely to be desirable to leave space for possible future interventions.
- The principles of managing all floods and designing for failure suggest that multi-layered strategies are likely to be appropriate.

2.7 Outlook on the structure and content of the remaining guideline chapters

The following chapters of these guidelines are mainly organised according to the various flood damage categories described in chapter 2.4. The following chapter 3 describes the state-of-the art in evaluating direct, tangible flood damages. Based upon a guiding flowchart the selection of case-specific flood damage evaluation approaches is supported. This chapter can be used by practitioners of countries with few or even no experience in flood damage evaluation in order to find an appropriate start into the endeavour of applying flood damage evaluation as a decision support tool. It might also be used by experienced flood damage evaluators as a checklist for their proceeding or by practitioners of various riparian countries to find a common flood damage evaluation methodology. Chapter 4 reveals the principal rules and the procedure of building up a proper flood damage data base in order to ensure a consistent set of flood damage data, which is needed if flood damage evaluation is to be used as a long-term decision support tool.

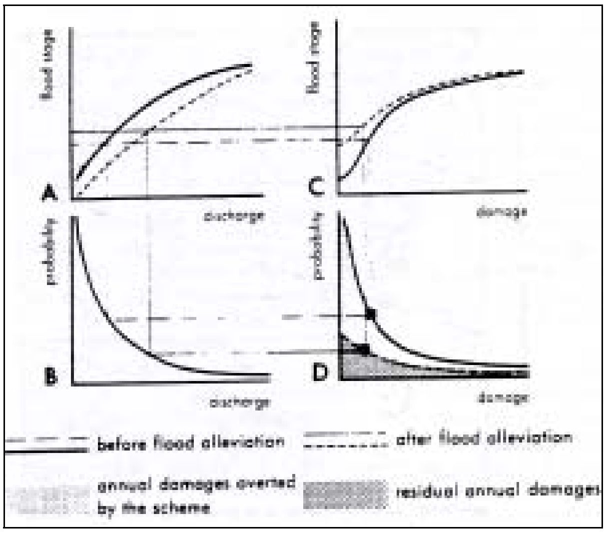
The subsequent chapters focus on specific damage categories, which are up to now rarely included in flood damage evaluation studies. The methods presented are not standardised yet for flood damage evaluation, but they are intensively discussed in the economic literature. Chapter 5 outlines the approaches to evaluate flood effects on industrial production. Chapter 6 indicates possible procedures to include social flood effects. Environmental flood effects and methods of their evaluation are described in chapter 7. Thereafter, chapter 8 focuses on damage reducing effects of flood warning in order to support specific decisions on flood warning systems. Chapter 9 gives an overview of flood damage categories which have not been considered in more detail in these guidelines and indicates relevant literature sources for further reading. The guidelines are completed by a glossary which defines important notions of flood damage evaluation and a comprehensive bibliography.

Annex 2.1: Calculating annual average damages by combining data on flood depth, extent, probability and damage caused

The methodology for assessing the benefits of flood alleviation is well-known and relatively uncontroversial (Penning-Rowsell and Green, 2000a and b). In essence, it combines a risk assessment, in terms of the probability of future flood events to be averted, and a vulnerability assessment in terms of the damage that would be caused by those floods and therefore the economic saving to be gained by their reduction.

Figure A2.1 provides the classic four-part diagram summarising the inter-relation of hydrology, hydraulics and economics as the basis of calculating the benefits of flood alleviation. Those benefits must always be calculated with the "with and without" criterion in mind: benefit-cost analysis looks at the difference in a nation's resources with and without the investment that is being appraised.

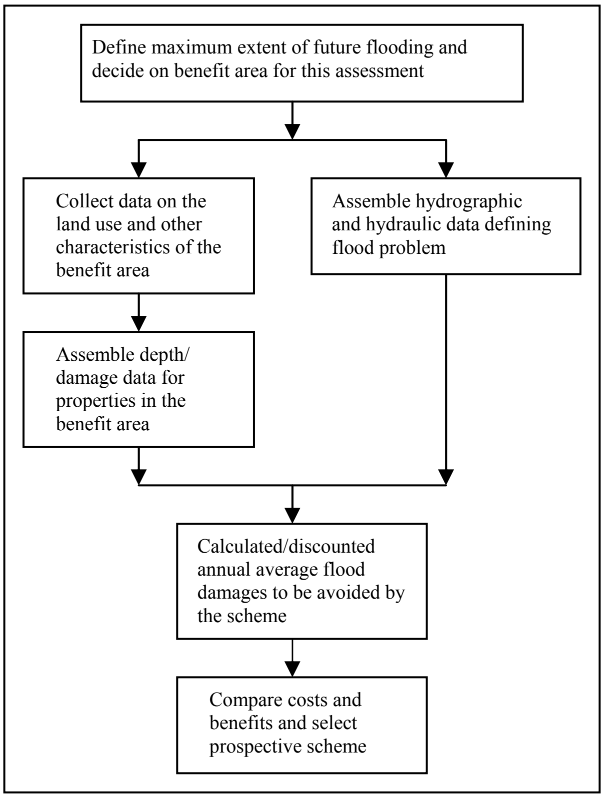
Figure A2.1 The classic 4-part diagram summarising the calculation of annual average flood losses



Thus in Figure A2.1 (bottom right-hand diagram) it is the difference between the relationship between probability and damage with and without the flood alleviation scheme that comprise the benefits of that scheme. Thus if a scheme does not prevent all the flooding that might occur in the future, but residual overtopping of fluvial or coastal defences is likely or a failure of the scheme is possible, then the damage from such continuing or possible additional future flooding in these situations should be appraised. The current relationship between flooding and damage is the "do nothing" situation, and the reduction in flood damages at a range of flood probabilities represent the result of the necessary investment in reducing the frequency of flooding or the impact of that flooding on the land use affected.

In terms of calculating the benefits of flood alleviation, therefore, assessing the relationship between probability and damage (the damage-probability relationship) is crucial. Figure A2.2 gives a simplified flow chart of the stages that need to be followed in order to calculate the benefits of flood alleviation (or, put another way, the stages for calculating the capitalised value of flood damages that will occur in the future if a "do nothing" option is adopted). Figure A2.3 gives a more detailed flow chart, identifying the various stages that have to be completed before the benefits can be compared with the costs and the option selected that best passes this test of economic efficiency.

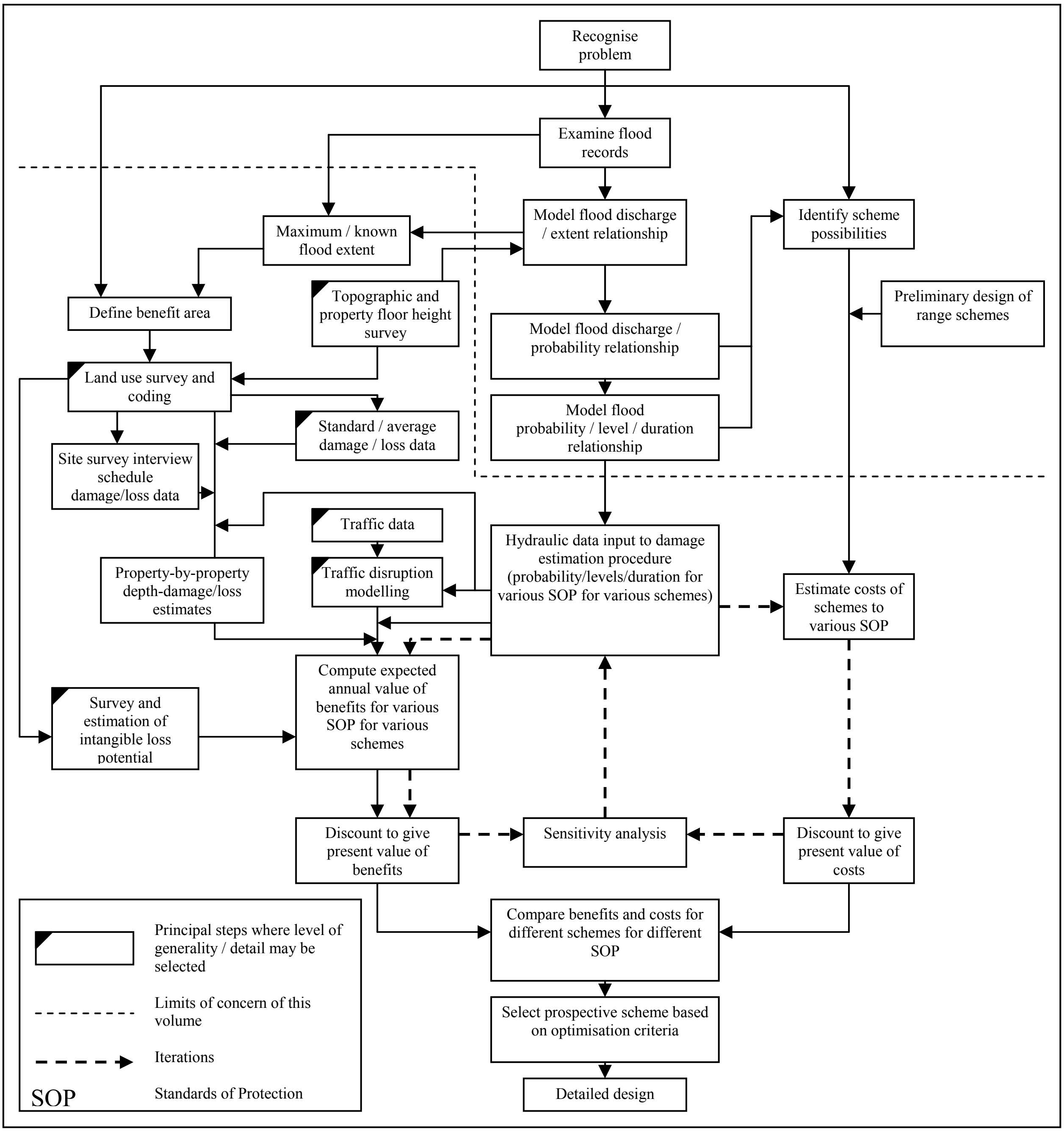
Figure A2.2 A simplified flow chart of the stages that need to be followed in order to calculate the benefits of flood alleviation



The annual average flood damage is the area under the graph of flood damages plotted against exceedance probability (the reciprocal of the return period in years). This is the area under the curve in Figure A2.1 (bottom right-hand diagram), and this curve should be derived from an analysis of several future floods with a range of severities, or the results will be unreliable (at least 3 and preferably 6 flood events should be used).

It is important, in particular, to determine the annual probability of that flood at which damage begins, assuming that some floods cause no measurable damage. It will also be important in the coastal situation to gauge accurately the timing and annual probability of the failure of existing defences, if that is the mechanism of flooding to be alleviated. Indeed, assessing the probability of failure of existing defences remains one of the most difficult fields in the area of project appraisal for flood defence expenditure, since there is a very sparse research record on which to base the assessment of such probabilities.

Figure A2.3: A more detailed flow chart of the various stages that have to be completed so that flood alleviation benefits can be compared with the costs



3. Guidelines for direct, tangible flood damage evaluation

Contributed by Volker Meyer and Frank Messner

The objective of this chapter is to give guidance for the ex-ante estimation of direct, tangible damages of potential flood events. At least in industrialized countries such damages like, e.g., damages on buildings and their contents often dominate the total amount of damages (Smith & Ward 1998).

These guidelines are very much based on recent research into existing methods of flood damage evaluation in different European countries (Meyer & Messner 2005). It was found out that a great variety of methods exists all over Europe. This variety arises on the one hand from national or regional differences − for example, in data availability. On the other hand it can be caused by variations in the objective and spatial scale of country or regional studies.

Due to the variety of factors which determine the selection of a proper flood damage evaluation method, it is not possible to recommend one single method of flood damage evaluation. Rather, our guidelines aim at revealing the basic steps of the flood damage evaluation process, emphasising and explaining important economic evaluation principles and supporting the selection of appropriate flood damage methods for specific applications.

3.1 Overview: Basic steps of flood damage evaluation

There are four basic steps, which must be executed in every flood damage evaluation study. They are shown in figure 3.1. In this chapter 3 we explain each of these steps in detail (chapter 3.2-3.5) and at the end we recommend and specify individual flood damage methods for specific purposes in chapter 3.6. However, before we start with the detailed descriptions, we will give a rough overview of the process of flood damage evaluation by outlining the content of the four steps in order to give the reader a first rough impression of what flood damage evaluation is about.

Step 1 (see chapter 3.2) serves to find an appropriate approach for a certain damage evaluation study. The choice depends very much on a) the scale, b) the study objective, c) the availability of resources, and d) the availability of pre-existing data.

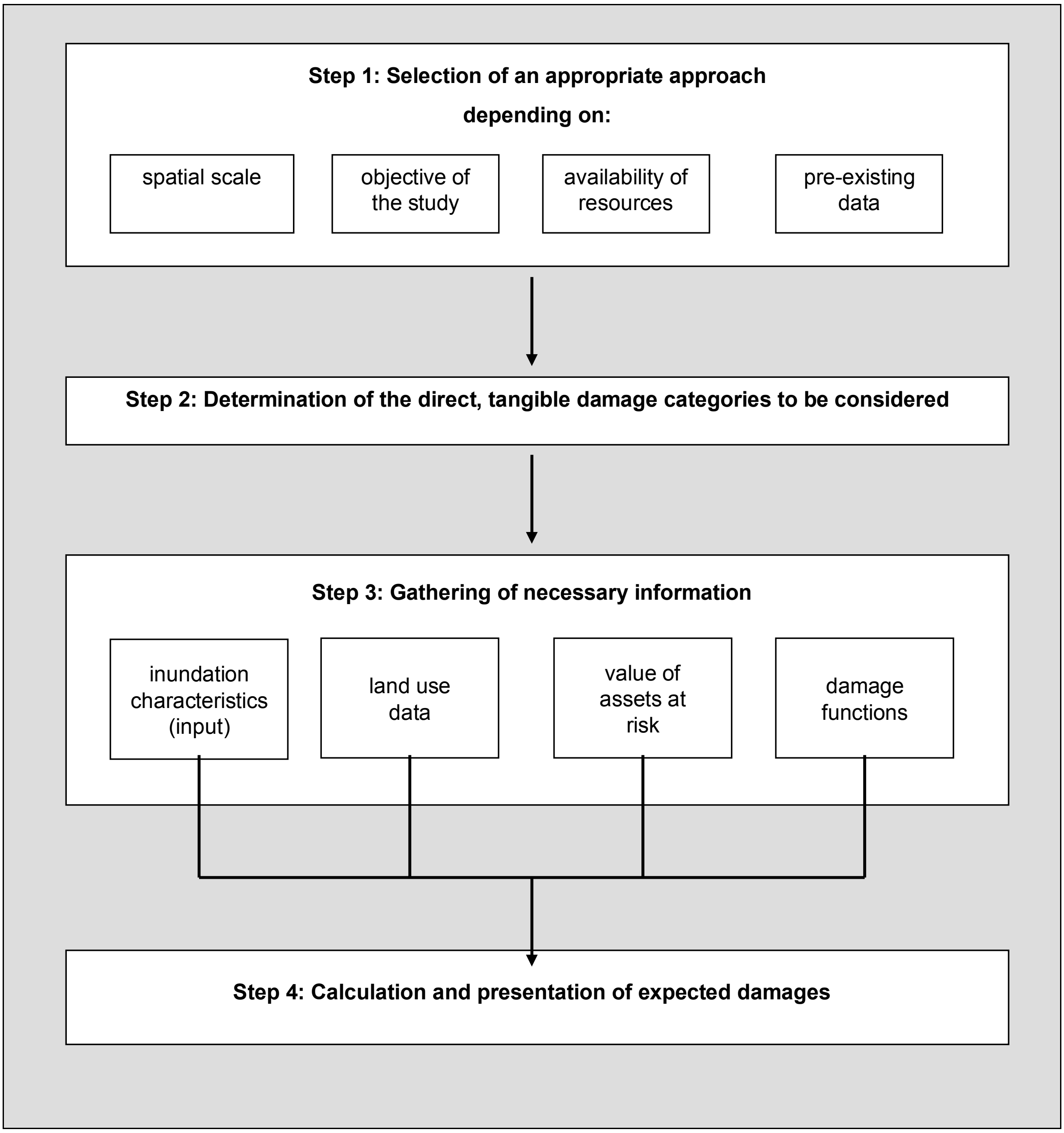
a) At the beginning the **size of the area under investigation** – the spatial level – is important. This size can vary from areas of national or even international scale to areas of local scale. Due to the fact that very precise methods require more effort (i.e. time and money) than less detailed approaches and that the resources are usually limited, the most precise methods are often restricted to small areas under investigation, while studies with a research area of regional or even national size mostly have to rely on less detailed methods.

b) Most important is that the method to be chosen and the precision of the results of a specific study must match with the **objective of the study.** If the goal of the study is to give only a quick and approximate overview of the amount of damages, a less precise (and consequently less costly and time-consuming) method might be sufficient and appropriate. If on the other hand single flood protection measures have to be assessed, for example for a prioritisation of investment, it is necessary to employ a more precise method. Nevertheless, it should always be checked if it is worth being more precise, i.e. if it has any effects on the results.

c) This leads to the **availability of resources**. Although it would be fine and desirable for every study to come to results with the highest level of precision, this is often not possible due to budget or time restrictions. If only a small budget and/or little time is available for a study, quick, easy and approximate methods have to be chosen in order to finish the study under these restrictions.

d) Indeed, the effort or costs to carry out a certain method of damage evaluation can be significantly reduced if necessary data already exists. Consequently, the **availability of pre-existing data** has an essential influence on the choice of an appropriate method. If, for example, adequate land-use data or a thoroughly developed set of damage functions already exists, this may facilitate the application of detailed approaches on a regional or even national scale. Furthermore, not only the question *whether* data are pre-existing, but also *which* data are pre-existing in a certain country or region can have a large impact on the choice of a method .
In chapter 3.2 it will be revealed, which specific method of flood damage evaluation is recommended for a specific study, if a practitioner has a clear idea about the four factors described in a-d.

Figure 3.1: Basic steps of direct, tangible damage evaluation



Step 2 (see chapter 3.3) is to determine which damage categories should be taken into account. Generally, attention should be focussed on the parameters which have the greatest impact upon the total damage. Usually, direct, tangible damage which is discussed in this chapter contributes a

significant proportion of the total damage. Nevertheless, indirect and intangible damage categories should be taken into account, too (see chapter 2).
Direct tangible damage can further be divided into several categories (buildings, inventories, infrastructure, cars, etc.). However, some damage categories − especially buildings and inventories − usually dominate the total amount of damage. Therefore, it can be reasonable to include only the most important damage categories to reduce the effort of the study. Damage categories which have only a small influence on the total damage amount can nevertheless be included in a more approximate way, e.g. by a typical share of the total damage.

Step 3 deals with the major tasks of flood damage evaluation: the estimation and calculation of economic values of potentially damaged tangible goods and the gathering of sound information for this task (see chapter 3.4).

Generally speaking, four main factors are important in this respect:

a) the intensity of inundation,
b) the number, type and elevation of properties affected (assets at risk),
c) their value,
d) and their susceptibility against inundation.

a) Data on the intensity of a studied flood scenario, i.e. **inundation characteristics,** have to be estimated (chapter 3.4.1). The area and depth of inundation are the most important information to be sampled here, but also the duration, time of occurrence, velocity or the toxicological load of flooding water could have a significant influence on damage.
As these guidelines focus on the socio-economic component of damage evaluation, inundation characteristics are regarded here as an input for damage evaluation. That means, in chapter 3.4.1 only a short overview on quantitative models for the calculation of inundation characteristics will be given..

b) Information on the location, number and type as well as the elevation of properties which could be affected by a certain flood event (the elements at risk) needs to be gathered. Such information is normally given by **land use data** (chapter 3.4.2). This can be either primary data from field surveys or secondary data, i.e. data from already existing sources. Furthermore, the spatial resolution and level of categorisation can be highly diverse. It ranges from broadly aggregated land use information (e.g. "industrial area", "residential area") to detailed information on the type of every single building or property.

c) In order to measure damage in monetary terms, information on the **value of assets at risk** needs to be quantified (chapter 3.4.3). This information can be integrated in the process of damage evaluation in two different ways (see also step 4):

- First, the **total value** of all assets at risk in a study area is estimated. The damaged share of this total value is then calculated by relative damage functions (see below in d).
- Second, the value of elements at risk (or at least parts of them) is **integrated in absolute damage functions**, showing the absolute damage depending on magnitude of inundation characteristics.

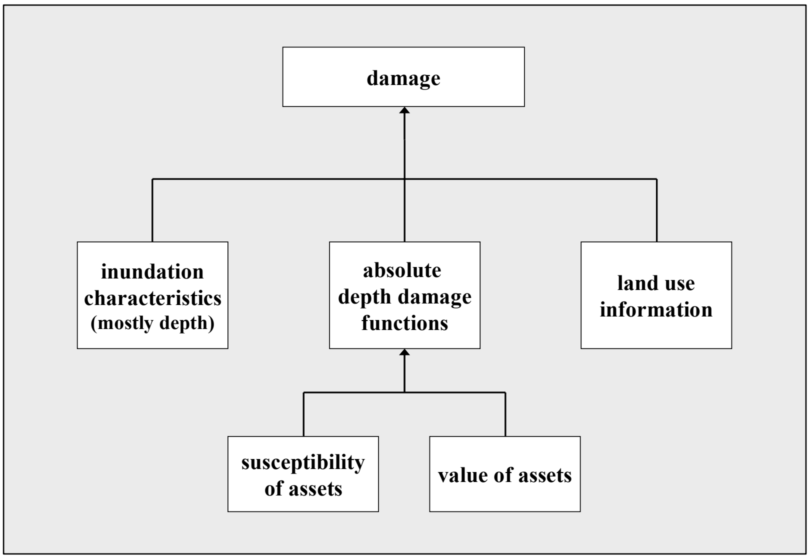
d) Finally, **damage functions** are needed to provide information on the susceptibility of elements at risk against inundation characteristics (chapter 3.4.4). They show either the damaged share (therefore it is here referred to as relative damage functions) or the absolute monetary amount of damages per property or square metre (therefore it is here referred to as absolute damage functions) of a certain group of elements at risk as a function of the magnitude of certain inundation characteristics. In the current state-of-the-art the main inundation parameter considered in these damage functions is inundation depth (depth-damage functions). Others, like velocity, duration and time of occurrence are rarely taken into account. As the susceptibility of elements at risk depends on their type and attributes (e.g. mode of construction), properties of similar type are grouped and expressed by one approximate damage function. The extent of this aggregation and categorisation varies among the different approaches.

It needs to be mentioned that further factors like risk perception of the people in flood prone areas and their preparedness to be flooded can also influence the susceptibility of elements at risks and, hence, the potential flood damage amount. Up to now such factors have not been included in damage functions − at least not explicitly.

Step 4 serves to bring all information gathered in step 3 together and to **calculate the damages to be expected** from a certain event (chapter 3.5). Two basic approaches of damage evaluation can be distinguished here, considering the way the monetary value is integrated in the calculation:

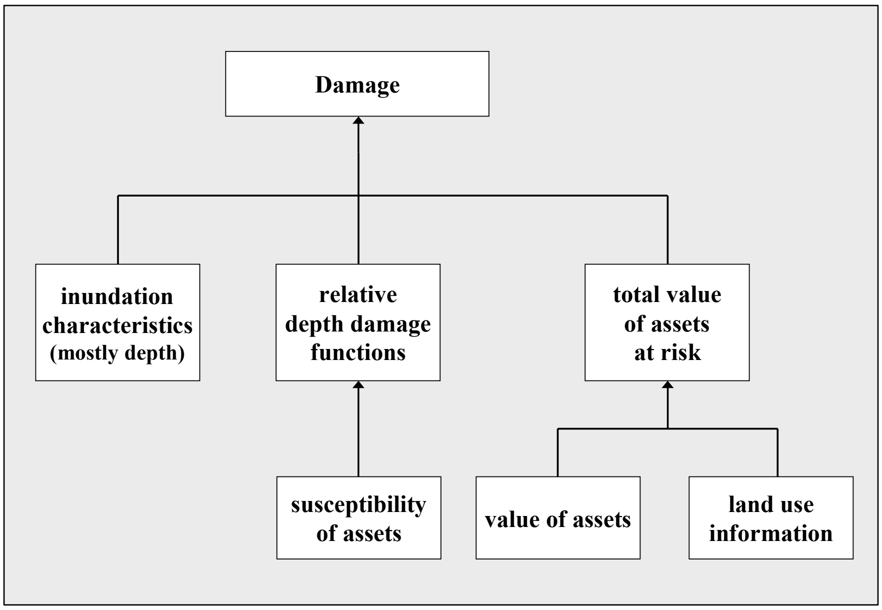
a) The **absolute or direct damage estimation approach** (Figure 3.2): Here, the total value of assets at risk is not calculated at any time. Instead, information on the value of assets and on their susceptibility against certain inundation depths is used to develop absolute damage functions. Combined with data on inundation depth and land use information, these absolute damage functions enable a direct estimation of the absolute damage amount for each property or unit of property.

Figure 3.2: The absolute/direct damage estimation approach



b) The **percentage of property value approach** (relative damage function approach; Figure 3.3): By bringing together land use information and asset values the total value of assets at risk is calculated. This maximum damage potential is then overlaid with data on the specific flooding scenario, especially inundation depth. The resulting damage for each asset or unit of assets is then calculated by means of relative damage functions, showing the damaged share of the total value as a function of inundation depth (or other inundation characteristics).

Figure 3.3: The percentage of property value approach



Which of both approaches is chosen depends again very much on the kind of available data. I.e. if detailed data on the value of assets is at hand the percentage of property approach may be convenient. If on the other hand a comprehensive set of absolute damage functions already exists the absolute damage estimation approach could be more appropriate. However, relative damage functions can be better (but nevertheless carefully) transferred to other regions.

The formula for the calculation of the total damage amount for a certain event depends on the type of approach chosen and the type of data used. In a general and simple form this can be described by:

$$Damage_{total} = \sum_{i=1}^{n} \sum_{j=1}^{m} (value_{i,j} \times susceptibility_{i,j})$$

with:

$$susceptibility_{i,j} = f(characteristics\ entity_{i,j},\ inundation\ characteristics_k,\ socioeconomic\ characteristics_l)$$

i = category of tangible elements at risk (n categories possible)
j = entity in a elements-at-risk category (m entities possible)
k = flood type/specific flood scenario
l = type of socio-economic system
susceptibility: measured in percent

Such a calculation leads to a single direct, tangible damage amount in monetary units for each flooding scenario considered. This damage value can be used for the calculation of flood risk (the annual average damage) and for the calculation of net benefits or cost-benefit ratios in the context of economic assessments of flood protection measures by means of CBA (see chapter 1).

However, since flooding events and their damages are usually highly spatially diverse, it is advisable not only to present the results in terms of one monetary number, but also to prepare maps to show the spatial distribution of damages. This is possible by means of geographical information systems (GIS). Several **software tools** have been developed to support the process of damage evaluation as well as

the risk and cost-benefit calculation (see chapter 3.5.3). Some of them are based on GIS, others do not explicitly consider the spatial dimension in the results.
Finally, it must be emphasised that all approaches of flood damage analysis − even the most detailed − contain **uncertainties** in their results. These arise, among others, from inaccuracies and generalisation in the data used. Therefore, the dimension of these uncertainties should be reflected in the presentation of the results, e.g by specifying a range or other statistical spread parameters.

In the following chapters the four steps introduced above will be described in more detail.

3.2 Step1: Selection of an appropriate approach

3.2.1 Summary & Recommendations

For the choice of an appropriate method of damage evaluation four aspects are crucial: the spatial scale of the study, its objective, the availability of resources to carry out the study and the availability of pre-existing data. To find an appropriate approach, answering the following questions is essential:

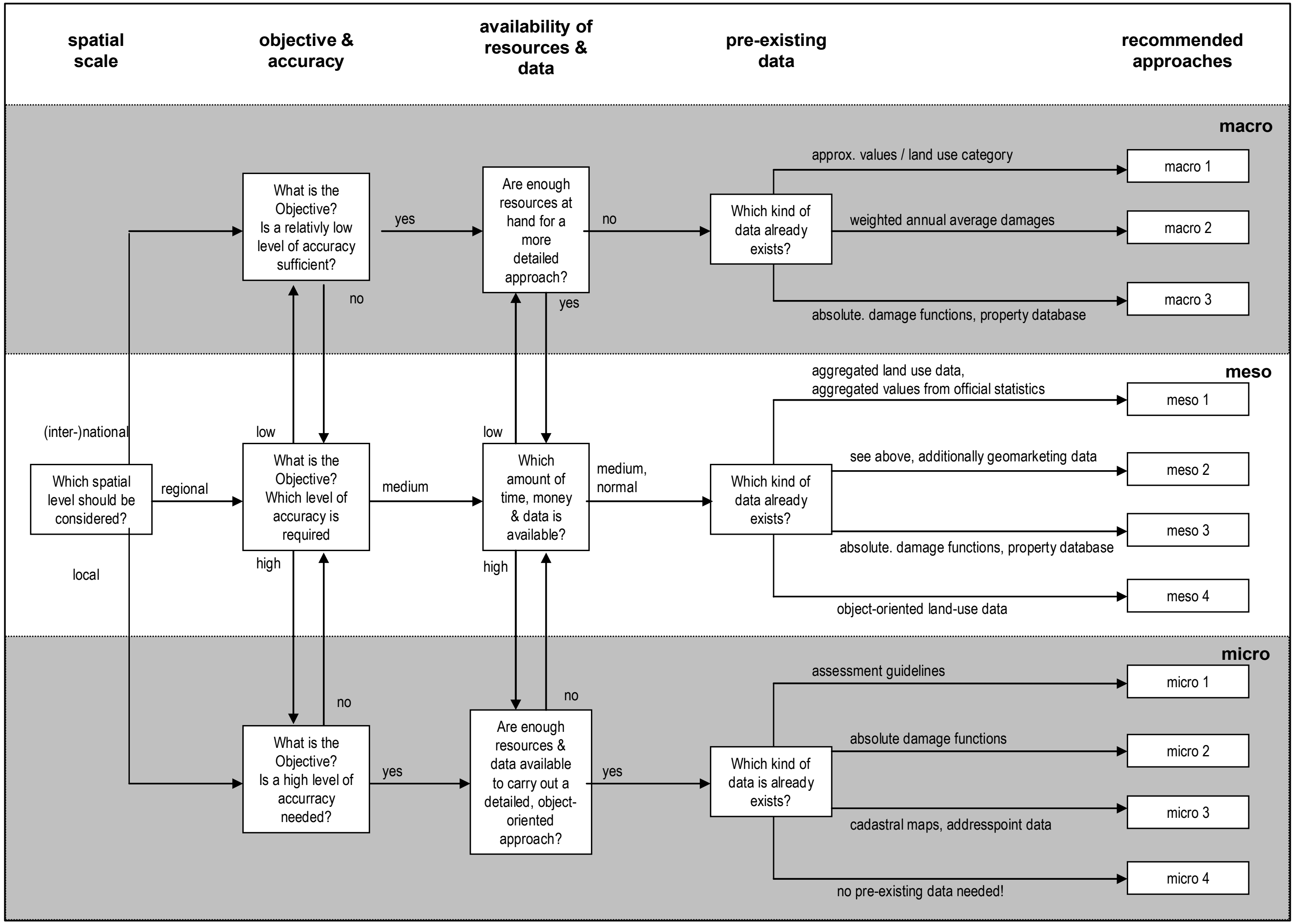
1. *Spatial scale*: Which spatial level is planned to be considered? Is it of local, regional, national or even international scale?
2. *Objective*: What is the objective of the study? Are detailed results required or are approximate results sufficient to achieve this objective?
3. *Availability of resources*: How much time and money is at hand to carry out the study? Is there a considerably high, average or low amount of resources?
4. *Pre-existing data*: Is there already data at hand which is necessary for damage evaluation? Of which type is that data?

Figure 3.4 gives guidance on how to come to an appropriate method of damage evaluation by answering these questions. The typical, recommended approaches mentioned on the right side of this figure will be further specified in chapter 3.6.

Figure 3.4 gives guidance for the selection of a specific flood damage evaluation method. Each practitioner wishing to estimate flood damage for a given objective has to answer four questions. These questions and their meaning and relevance are discussed in the following chapters.

Please notice when working with figure 3.4 that some constraints should be considered. If, for example, a study requires a high level of accuracy and there is not enough money at hand to carry out an appropriate approach we would rather recommend to get more funds than to carry out an approach which results cannot fulfil the purpose of the study.

Figure 3.4: How to find an appropriate approach?

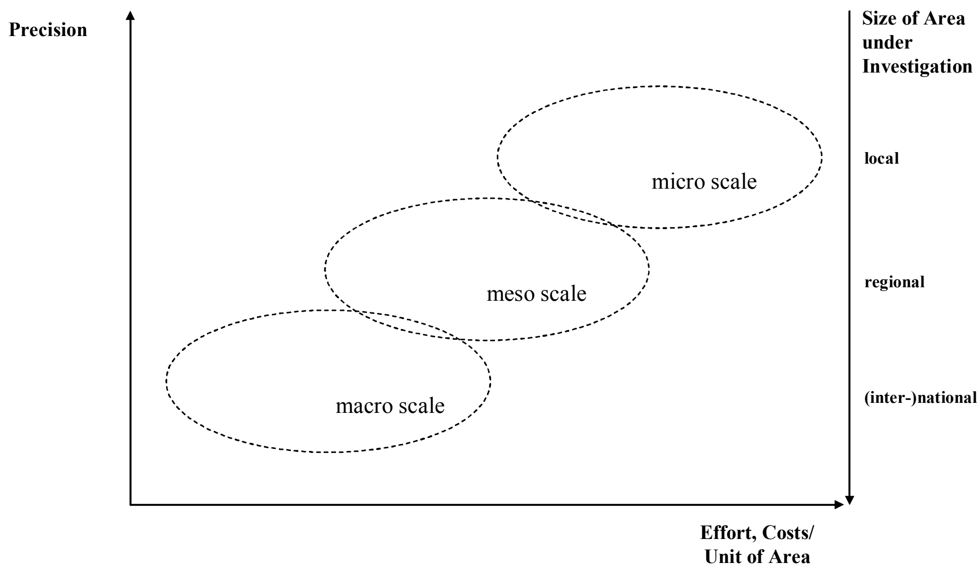


3.2.2 Question 1: Which spatial level is planned to be considered?

The choice of an appropriate method of damage evaluation depends very much – although not exclusively – on the size of the area under investigation. Any practitioner who wants to execute a flood damage evaluation study needs to take a decision about the size of his or her study. Three study types are usually distinguished. Firstly, national or even international studies may, e.g., refer to a national coastline or a river basin of a transboundary river. Secondly, regional study areas are of medium size and relate, for instance, to a part of a big river or the catchment of a smaller river. Thirdly, local-sized study areas aim at examinations of municipalities, single floodplains or even single properties.

The more detailed a method of damage evaluation is in terms of its spatial resolution and its differentiation of elements at risk, the more effort per unit of area is required to carry it out. Therefore, the most detailed methods are often restricted to areas of local size, while studies for areas of regional or even national size have to rely on approaches which require less effort per unit of area and, consequently, do not provide such a high level of precision (see figure 3.5). For this reason we recommend in figure 3.2 that national and international studies should apply macro-oriented methods, regional studies should use meso-oriented methods of flood damage evaluation, and local studies should employ micro-approaches.

Figure 3.5: Scale levels of damage evaluation methods



Source: Meyer 2001, p. 30; Reese 2003, p. 54

Especially in Germany, there had been a clear methodological differentiation of micro-, meso- and macro-scale approaches (Schmidtke 1995, Hamann & Reese 2000, Meyer 2005, Messner & Meyer 2005), mostly concerning the spatial resolution of the analysis:

- Micro-scale methods apply an object-oriented approach, i.e. damages are calculated for single properties, e.g. buildings.
- Meso-scale methods consider aggregated land use units, e.g. residential areas and industrial areas.
- Macro-scale methods consider whole administrative units, e.g. municipalities.

However, our research on the current state-of-the-art of damage evaluation in several European countries (Meyer & Messner 2005) showed that this simple micro-meso-macro differentiation no longer holds true in this strict way. Due to technical improvements and special damage databases, damage evaluation has become more elaborate and spatially precise, even on the national and regional level. For example, object-oriented assessments of flood damages are already applied on the regional and even national level (see for example Hall et al. 2003). Therefore, we do not just recommend one single macro, meso or micro approach depending on the size of the study area. We rather include other factors to support the selection of a method for a specific study. The terms "macro", "meso" and "micro" are, hence, not meant to specify one particular method of damage evaluation, but are used to indicate groups of evaluation approaches which are appropriate for a certain spatial level − under consideration of other study characteristics.

3.2.3 Question 2: What is the objective of the study? And: Are precise results required for this objective or are approximate results sufficient?

The scale or spatial level of damage evaluation studies is often strongly correlated with the management level and its specific objectives, for which a study is meant to provide decision support (Gewalt et al. 1996, see also Sayers et al. 2002). Frequently, macro-scale analyses aim at providing decision support for national flood mitigation policies, meso-scale analyses are to support decisions on large-scale flood mitigation strategies and the objective of micro-scale analyses is time and again the assessment of single flood protection measures (see table 3.1).

Table 3.1: Characteristics of macro, meso and micro approaches of flood damage evaluation

Scale	Size of research area	Management level	Demands on precision	Amount of resources required per unit of area	Amount of input data required
macro	(inter-)national	comprehensive flood mitigation policies	low	low	low
meso	regional	large-scale flood mitigation strategies	medium	medium	medium
micro	local	single protection measures	high	high	high

See also Gewalt et al. 1996, Messner & Meyer 2005

But what are the concrete objectives of flood damage evaluation on each management level and especially what level of precision is required to meet these objectives?
In chapter 1 the main objectives and purposes of flood damage evaluation are mentioned: In the public policy sphere ex-ante flood damage evaluation is used for supporting decisions on the financial allocation of tax money, for the appraisal of investments on flood protection and the justification of these investments (accountability). Furthermore the results of flood damage evaluation are used in the insurance industry e.g. for the calculation of their probable maximum loss (PML) or insurance rate settings. Last but not least damage evaluation is also used for the information of firms or households about their individual risk of flooding.

- If flood damage evaluation is used on the national or regional level to justify the **allocation** of public funding, an approximate estimation of the total amount of damages is sufficient, i.e. the demands on precision are relatively low.
- Regarding the **appraisal** and comparison of alternative policy measures by means of economic assessment methods the demand on precision is usually higher. Such appraisals are mostly restricted to the regional and especially to the local level and can consider structural measures like dikes as well as non-structural measures such as land use planning, evacuation

planning, warning sytems etc. However, the demand on accuracy can differ with regard to specific circumstances:

- o Sometimes, flood protection measures and their design (e.g. the safety level of dikes) are given and an appraisal is simply needed to decide whether a measure is efficient or not. Since only an approximate estimation of the benefits resulting from the specific measure is needed, demands on precision might be rather low.
- o Prioritisation of measures based on cost-benefit calculations aims at a ranking of measures. Since the assessment usually occurs by comparing cost-benefit ratios, a medium level of precision might be sufficient in this case − especially if the ranking is only meant to rule out certain types of flood control measures.
- o At least in theory, appraisals can support the selection of optimal, i.e. most efficient flood protection measures. This would of course require a very high level of precision in damage evaluation which currently cannot be provided.
- o If flood damage evaluation methods are used to determine the proportion of flood protection measures financing by riparian administrations or regions based on the proportion of avoided damages in the affected areas, demands on precision are high, too.

Furthermore, the appraisal process should be seen as **iterative and hierarchical** (see DEFRA 1999). Starting on the strategic level with rather approximate damage evaluation approaches a first pre-feasibility appraisal can be carried out to verify where it is worth being more precise. I.e. only if a project seems to be efficient at all (e.g. has a benefit-cost ratio greater than one) is it worth considering this alternative in greater detail; otherwise it can be ruled out. In this way, the most accurate damage evaluation approaches can be restricted to the measures which seem to be in some way efficient. In any case, it should always be tested if it is worth being more precise when comparing different flood protection measures: if a more precise damage evaluation will not lead to a change in the result it would be a waste of money to conduct it.

- If damage evaluation is carried out to inform **individual firms or households** about their risk of flooding, the demands on precision are quite high. Wrong results can lead to negative consequences, e.g. if people feel safe due to a wrong estimation they will not carry out any preventive action against flooding and will be hit harder by a flood than if they had known about their real risk.
- As mentioned in chapter 1 these guidelines do not focus on damage evaluation studies for the **insurance industry**. Nevertheless it should be mentioned that also in this context the demands on precision can differ a lot. Especially re-insurance companies are mostly interested in the calculation of their *probable maximum loss* (PML) in case of the occurrence of extreme events. As re-insurance companies are operating mostly internationally such studies consider primarily very large areas and hence require only an approximate estimation. On the other hand damage evaluation is used by retail insurance companies for the calculation of appropriate insurance rates for individual customers. In this case the demands on precision are consequently higher.

These descriptions of study objectives and their respective precision requirements should have clarified the importance of this second question. Regarding figure 3.4, an answer to this question which tends to high precision demands leads to recommendations in the direction of micro approaches, for medium precision demands meso approaches are recommended, and low precision demands are guided to macro approaches. However, the final selection of a method is still dependent on two other questions.

3.2.4 Question 3: How much time and money is at hand to carry out the study?

Of course, it might be argued that it is desirable for every study to get results from damage evaluation as precisely and in as much detail as possible. So why not carry out the most detailed method for every study and every objective? The reason is that more detailed methods are usually more time-consuming and more costly. As the availability of budget and time is limited, it is necessary to choose an appropriate method to meet the study's objectives within these restrictions. One example might be the case of the federal state of Saxony in Germany. After the 2002 floods, the flood protection system was planned to be re-established under consideration of cost-benefit aspects. Since the appraisals for many hundreds of measures in the whole state were required to be executed within a short period of time, an approximate method of damage evaluation was chosen in order to complete the flood damage evaluation work in time.

It is not possible here to give a general valid estimate, which method of flood damage evaluation requires which amount of costs and/or time per unit of area, but some examples can be given to illustrate this issue. If for example site surveys have to be carried out to obtain detailed local land use information, this is time consuming and costly. Penning-Rowsell et al. (2003) estimate that such a survey embracing about 2000 properties will need 3-6 person months (see also DEFRA 1999). Time could be saved if secondary land use data is used, which mostly provides less detailed information than primary data (see chapter 3.4.2). However, the costs of secondary land use data vary depending on its level of detail. This can be illustrated by the example of land use data sources available in Germany. While CORINE Land Cover data, a rather approximate and generalised land use data source, is freely available, the much more differentiated data from ATKIS costs 7.50 EUR per square kilometre. ALK-data, which provides even more detailed, object-oriented land use information, costs as much as 200-750 EUR per square kilometre. However, CORINE provides a rather poor level of spatial resolution especially for urban areas.

With regard to figure 3.4, the answer to the question of availability of funds guides towards micro approaches, if a lot of time and budget is available and towards macro approaches if budgets are low and time scarce. However, the concrete position depends mainly on the first two questions. If a lot of funds are available for a national level and precision requirements are rather high, a micro approach is probably appropriate. On the contrary, a regional study with medium to high demands on precision but with high time pressure leads to macro- or meso-approaches. However, there is still one question to be answered.

3.2.5 Question 4: Is there already data at hand to carry out the study?

Time and money can be saved and more detailed approaches can be carried out, if some of the necessary data already exists (information on inundation characteristics, land use data, information on values of assets at risk and/or damage functions; see chapter 3.4). For example, in England a *National Property Dataset* (chapter 3.4.4.2) was built up, containing information on location and type of every single property within floodplains. Furthermore, a standardised and extensive set of damage functions (see chapter 3.4.4.2) has been developed for many damage categories in the past. As a matter of course, the availability of such data facilitates the application of rather precise, object-oriented damage evaluation methods − even on the national level.

Furthermore, not only the question *whether* data already pre-exists, but also *which kind* of data pre-exists is important. Green et al. (1994, p 39) state that “probably the main determinant of the approach adopted is the prior availability of data on the values of buildings and contents at risk between countries”. That means, if good data, e.g., on values of assets or on land use already exists in a country, it would not make sense to neglect these sources. Rather, such data enables the realisation of higher levels of precision for all spatial scales of flood damage studies.

Eventually, after having answered this fourth question, the kind of flood damage evaluation approach, which we recommend for a specific study, can be identified. If for example, the objective of the study requires a medium level of precision (e.g. for a project appraisal) and enough time and money is available as well as a good pre-existing data base, micro-scale approaches can be carried out even on the national level. On the other side, it can be appropriate to carry out a rough macro-approach on the regional or even local level, if the demands on precision are low and time and money is scarce.

The eleven approaches shown on the right side of figure 3.4 are described in greater detail in chapter 3.6. They represent typical best practice approaches in Europe. The decision, as to which approach should be chosen on each level, mainly depends on pre-existing data. If, for example a macro-scale approach seems to be advisable and there is a property database (see chapter 3.4.2.3) and a set of absolute damage functions (see chapter 3.4.4) at hand, we recommend following an approach like *macro 3* (see chapter 3.6). Of course, it can also be possible that none of the required data is pre-existing. In that case it has to be decided individually, which approach seems to be most appropriate. However, we also recommend answering the four questions seriously and to consider the degree of precision (and uncertainty) of results when applying them for specific policy support. For example, we would never recommend the choice of macro approaches, if precision demands are very high. On the other hand, using micro approaches for rough damage estimations could just be a waste of time, money and resources. Finally, it needs to be mentioned that the recommended approaches of figure 3.4 and chapter 3.6 can only show the typical ways of performing them. Their application needs to be customised for each country, depending, among others, on existing data and regional circumstances.

3.3 Step 2: Determination of direct, tangible damage categories to be considered

3.3.1 Summary & Recommendations

Direct, tangible damages can be furthermore distinguished in different categories (see table 3.2). Although it is desirable to include all categories in damage evaluation to estimate the full impacts of flooding it has to be considered in each study if it would be more pragmatic to focus on the most important categories to reduce effort.

We recommend for studies at all levels at least to include damage to residential and non-residential buildings and their inventories. Damages to streets and railways might be negligible in plain flood areas but should be included in flash flood areas, as this kind of damage is mainly caused by high velocities. Furthermore, meso- and micro-scale studies should consider including damages to cars. A detailed estimation of damages to agricultural products seems to be necessary only for micro scale approaches or when areas with a strong agricultural imprinting are considered. Otherwise they can be included by a typical damage share, which should be derived as far as possible from ex-post analysis from the same or a comparable region.

However, if not all types of damages (and this also holds true for indirect and intangible damage) are taken into account in a certain damage evaluation study due to pragmatic reasons, this should be explicitly mentioned, when presenting the results.

3.3.2 Direct, tangible damage categories

A crucial question in damage evaluation is which categories of direct, tangible damages should be included. On the one hand it would be of course desirable to take all types of property damages into account to consider the total impact of flooding to the economy. However, this may lead to extensive and costly studies. On the other hand it might be more pragmatic to focus on the most important damage categories to keep the effort of the analysis reasonable (see chapter 3.1). Less important categories can also be included in a more simple way, e.g. by applying a typical damage share. Table 3.2 shows a listing of different categories.

Furthermore, table 3.2 gives an example for damage shares of some of these categories as recorded after the 2002 floods in the federal state of Saxony, Germany. Of course the distribution over the categories depends much on the respective event, its characteristics and which kinds of areas are affected. Nevertheless, the 2002 flood in Saxony might be a good example, as it affected big cities like Dresden as well as rural areas and had characteristics of plain flood at the river Elbe as well as of flash floods at the Elbe tributaries.

The most important categories are buildings and their inventories. In damage evaluation studies these are often separated in residential properties, i.e. residential buildings and household inventories, and non-residential properties, i.e. buildings used for industry, commerce or public issues and their fixed and movable equipment as well as inventories. These categories are nearly always considered in damage evaluation. In Saxony 2002 damage on buildings and their inventories made up altogether more than 60 % of the total direct, tangible damages.

Table 3.2: Categories of direct, tangible damages

Categories	Subcategories	Saxony 2002: Share of total direct, tangible damage[6]
Residential properties:		**33.1**
	buildings	25.2
	household goods	7.8
Non-residential properties:		**29.5**
	buildings	.
	machinery and equipment	.
	inventories (stocks)	.
Technical infrastructure:		**36.3**
	streets	8.5
	railways	13.0
	flood defence & watercourses	10.9
	further	3.8
Vehicles & cars		.
Agricultural products		**1.3**[7]
	livestock	.
	crops	.

Figures for Saxony: Calculations based on Freistaat Sachsen 2003

The question whether damage on streets and railways is worth being included in damage evaluation depends very much on the type of flooding. Streets and railways are not very susceptible to inundation depth and duration. On the other hand they can be destroyed if high velocities occur. Consequently, this kind of damage is more or less negligible in plain flood areas where their share of total direct, tangible damage hardly exceeds 1 %.[8] On the other hand damage on streets and railways can be very severe in flash flood areas. For example in Saxony, about 8.5 % of the total direct, tangible damage was on streets and bridges and about 13 % on railways (Freistaat Sachsen 2003). Furthermore, as the figures from Saxony show, damages on flood defence infrastructure like dikes etc. can be quite high, too. At least if there is a great stock of defence infrastructure in the area under consideration, this damage category should be included in the analysis, too.

Also an important category might be damages to cars or other vehicles. They often make up a significant part of the total value of assets at risk, but dependent on warning lead time a lot of them can be evacuated, so that damages to cars might be comparably low.

Damages to agricultural products, such as livestock and crops generally make up a rather low share of total damages[9]. Furthermore damages to crops depend strongly on the time of year and damage to livestock again depends on evacuation time, so both are not easy to calculate. Data on the proportional damage for different crops in different months are given in Green (2003). For agricultural damages, economic losses are considerably lower than the financial losses because the subsidy element must be

[6] The calculations are based on data published in Freistaat Sachsen (2003). Indirect categories, like emergency costs are removed here while damages to the railway infrastructure are added. The total direct, tangible damage of about 6.7 Mio EUR does not show the depreciated value as it is recommended in these guidelines but the full replacement costs which might overestimate the true damage to the economy. But this should have no major impact upon the proportion of damage shown in tab. 2.2.
[7] Damages on agri- and silvicultural sites.
[8] Here, damage is mainly centred on bridges, due to undercapacity, blockage, or scour of foundation.
[9] In Saxony 2002, only 1.3% of direct, tangible damages were on agri- and silvicultural sites (IKSE 2004). In the autumn 2000 floods in England and Wales damages to agriculture make up 5% of all economic costs (Penning-Rowsell et al. 2002).

removed in calculating the economic damages. We therefore recommend only including these categories in detailed damage calculation if it can be expected that they make up an important part of the total damages, e.g. if very rural floodplains are considered. Otherwise agricultural damages can be included in a simple, approximate way, i.e. by applying a typical damage share.

3.4 Step 3: Calculation and gathering of the necessary information

As stated in chapter 3.1 mainly four types of information are necessary for the evaluation and calculation of flood damages: Inundation characteristics, land use data, information on the value of assets at risk and finally damage functions. In the following, each of these components will be specified in greater detail and the most important methods will be described to derive them.

3.4.1 Inundation characteristics

3.4.1.1 Summary & Recommendations

For damage evaluation it is necessary to determine the most important parameters of the potential flooding events under consideration. Table 3.3 shows different inundation characteristics which may have an influence on the amount of damages.

In the current state-of-the-art mainly inundation depth is used for damage evaluation (see Meyer & Messner 2005). Only in a few approaches up to now are other inundation characteristics also considered. We therefore recommend at least gathering data on inundation area and depth. For very precise approaches additional parameters should also be considered. For example for flash flood areas it would make sense to calculate velocities and if agricultural damages should be considered in detail it would be helpful to evaluate at what time of year flooding will most likely occur. However, it would only be sensible to collect additional flood characteristics if their effect on damages can be quantified by damage functions (see chapter 3.4.4).

To calculate flood risk, i.e. the annual average damages (see chapter 1), inundation characteristics should be estimated for at least three events with different return periods (e.g. a 5, 20 and 100 year event).

For the estimation of inundation characteristics for extreme discharges different quantitative model approaches are available: Storage cell models, 1D-models and 2D-models. Each of these is briefly described at the end of this chapter.

3.4.1.2 Inundation characteristics and their impact on damage

As stated above, there are several different parameters of a flooding event which can have an important impact on the total amount of damages. Table 3.3 shows a listing of these characteristics. In the following the relevance of each of these characteristics will be briefly described.

Table 3.3: Damage influencing inundation characteristics

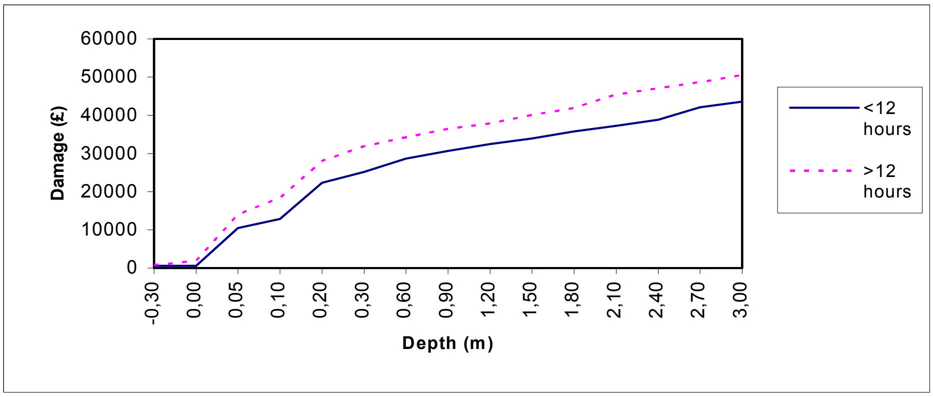
Inundation characteristics	Relevance
Area	Determines which elements at risk will be affected
Depth	Has perhaps the strongest influence on the amount of damage
Duration	Special influence on damages to building fabric
Velocity	Only high velocities will lead to increased damages; therefore mainly relevant in flash flood areas or areas near dike breaches
Rise rate	Influence on damage reducing effects of warnings and evacuation
Time of occurrence	Especially important for agricultural products
Contaminations	Contaminations and loads may increase damages significantly
Salt-/freshwater	Saltwater may increase damages; relevant in coastal areas

The most simple but nevertheless important information is first of all the **area of inundation**. In combination with land use data, it reveals which elements at risk would be affected in case of a certain flood event. In very basic approaches damages or elements at risk are simply estimated by means of the share of the total area of a city or municipality affected by inundation (e.g. Behnen 2000; Ebenhöh et al. 1997). Others simply take the floodplain area and then estimate the average flood depth by means of empirical data on flood depths (Hall et al. 2003; DEFRA 2001; see approach macro 2).

Inundation depth is generally the most important or at least most frequently used inundation parameter in damage evaluation. Based on the assumption that inundation depth has the strongest influence on damage magnitude, nearly all damage functions are solely depth-damage functions (see chapter 3.4.4). Nevertheless it should be noticed that analyses of empirical damage data showed that the variability of damages can only be explained to a rather small extent by the depth of flooding experienced (see Merz et al. 2004). But often other flood characteristics than depth are not recorded, so that it is difficult to quantify their influence.

The **duration** of flooding is important for instance when calculating production losses but could also influence direct damages. USACE (1996, p 6-6) argue that duration "may be the most significant factor in the destruction of building fabric." Penning-Rowsell et al. (2003) assume increased damages from longer duration of flooding e.g. for mortar, drains, timbers, plasterwork and tiles. They therefore distinguish between short (< 12 hours) and long duration of flooding (> 12 hours) in the damage functions of their manual for damage evaluation in the UK (see figure 3.6).

Figure 3.6 Example from the UK for Depth-Damage-Duration Data for Residential Properties (Sector Mean)



Source: Penning-Rowsell et al. 2003

The **velocity** of inundation can also have a significant influence on damages, especially considering flash flood areas or areas close to potential dike breaches. Nevertheless velocity has up to now rarely been taken into account in damage evaluation. One example for the inclusion is the *Standard Method* in the Netherlands where it is used for the estimation of casualties and building damages (Kok et al. 2004, see chapter 3.6, meso 2; see also DeLotto & Testa 2002; Kelman 2002)

In this *Standard Method* the **rise rate** of flooding is also considered; whereas it is here only used for the estimation of casualties, it may also have an influence on property damages: A high rise rate will reduce the time for warning and evacuation and therefore could increase damages on moveable assets.

The **time of occurrence** of flooding is especially important when calculating damages to agriculture: While damages would be quite high if flooding occurs just before the harvest of the respective crop, they will be relatively low in wintertime. In the Czech Republic damages on agricultural products are calculated under consideration of the month of occurrence of the flood (Satrapa et al. 2005; Čihák et al. 2005).

Furthermore the **contents and loads of flooding water** can influence damages. Especially contamination by oil etc. can increase damages significantly, but also sediment load and saltwater may lead to additional damages (see Reese 2003; Penning-Rowsell et al. 1992, p 98; Smith & Ward 1998)

For a risk analysis (see chapter 2), i.e. the quantification of annual average damages, it is furthermore not sufficient to evaluate the selected characteristics for just one particular flood event. To construct a damage-probability curve, at least three events with different return periods (e.g. a 10-, 100- and 200-year event) should be considered.

To calculate flood exposure, flood extent and inundation areas for extreme discharges different **quantitative and spatially explicit model approaches** are available. Besides estimated inundation extents derived by simple GIS-functionality (water level in the river determines the possibly flooded area, static approach) physical based flood(plain) models are applied for the calculation of the flood extent and inundation area. The variety of models can be divided into the following main categories:

- Storage cell models,
- 1D-models and,
- 2D-models (Paperberger, 2005).

Within these categories the models differ considerably according to how the channels are routed, the discretisation/incorporation of the topography data and reproduction of the surface roughness. The last issue is most important when discussing urban areas with a heterogeneous built-up surface.

According to Paperberger (2005), **storage cell models** are often considered as the least complex approaches. The models split the valley or the floodplain into single cells (Cunge et al. 1976) or the more complex representations such as polygonal shaped cells (Estrela, 1994) or Triangular Irregular Networks (TINs). The size of the model and the amount of detail depend on the grain of the Digital Topography Model (DTM) and the software resources that are available. Generally, the following aspects have to be considered concerning the use of storage cell models:

- They are flexible in precision of the modelled area.
- They permit a spatial comparison with existing inundation maps (derived from e.g. Remote Sensing), photographic material (Aronica et al., 2002, Haase et al., 2003) and ground truth data (e.g. field measurements).
- The utilisation of storage cell models needs certain hard- and software facilities,
- the availability of a DTM (with information on grain and origin of the topography data) and
- the parameterisation of every cell (surface roughness, Paperberger, 2005).
- Examples for developed models are: FLOODSIM (Bechteler et al., 1994), Lisflood (Bates & De Roo, 2000).

Further, there is a great variety of **1D-models** for flood and inundation modelling: the most famous examples according to a summary by Paperberger (2005) are ISIS, Mike11 or Mike Flood from the SHI-family or HEC-RAS (Bonner et al., 1999, Brunner, 2001, Van Looveren et al., 2000). Some of the 1D-models may be downloaded from the Internet and have to be implemented in connection with a GIS-system such as ArcView or ArcGIS (Bechteler et al., 1994, Bonner et al., 1999; see the following URL: http://www.bossintl.com/products/download/item/HEC-RAS.html).

1D-models calculate one dimensional flows between different cross sections of a floodplain by solving the full St. Vernant equation. These cross sections have to be available in form of digital or graphic data sets (maps, sketches, 2D-schemes) for larger parts of the floodplain. The areas between the sections are not explicitly represented and are rooted according to the values of the sections. 1D-models

- are relatively simple and not extremely data-intensive (need pf data on cross-sections rather than a full DTM, upstream and downstream boundaries, surface roughness data for both channel and floodplain),
- relatively fast (compared to storage cell and 2D-models),
- relatively easy to implement due to the GIS-coupling,
- optimal concerning the 2D-visualisation of the calculated inundation extents,
- widely and often utilised which enables a comparison of results for different floodplains and river basins,
- well documented through large peer groups.
- contain a certain degree of uncertainty due to the method of combination of the cross-sections and their allocation within the floodplain or basin (Samuels, 1990),
- different methods of spatial interpolation between the cross-sections deliver different spatial results (Werner, 2001; summarised in Paperberger, 2005).

Finally, **2D-models** have to be discussed briefly: they represent the most complicated approach of flood or inundation modelling. Examples are Telemac2, Mike 21, RisoSurf (Neunzert et al., 2003) or TrimR2D which all solve the 2D St. Venant equation including turbulence processes (Anderson and Bates, 1994, Feldhaus et al., 1992). 2D-models

- permit a complex and highly detailed description of flow process,
- but therefore need a relatively long time for the model run and
- in most cases they need a considerable number of input parameters concerning the event, the water flow and the surface of the area where the flood occurs.

Important results of the different inundation models which will be used for the preparation of risk maps or assessment schemes are water level height a.s.l., flow velocity and flood extent (2D in the spatial realisation).

3.4.2 Land use data

3.4.2.1 Summary & Recommendations

Land use data is needed to gather information about the exposed properties, i.e. the number, location and type of elements at risk.

This information can be gathered by field survey (primary data) or from pre-existing data sources (secondary data). The spatial resolution of land use data may vary considerably: sometimes single properties are considered (object-oriented data), sometimes objects are aggregated to areas of relatively homogeneous land use (aggregated data). Furthermore the categorisation of land use types varies between two and more than a hundred. Here, it is important to match this with the categorisation used for asset values (chapter 3.4.3) and damage functions (chapter 3.4.4).

Some examples for the use of object-oriented as well as aggregated land use data for damage evaluation are given in this chapter.

To receive detailed results of damage evaluation, detailed land use information is necessary, especially on buildings, the most import direct, tangible damage category. For a damage evaluation with a high demand on precision we would therefore recommend gathering object-oriented land use information on buildings. For micro-scale studies, this information is mostly derived from field surveys. For an application of object-oriented data on the meso or even macro level, secondary sources have to be used. The development of object-oriented databases like the British *National Property Dataset* would be advisable for such a purpose.

If such a database is not at hand, aggregated land use data sources also seem to be a good solution to obtain good results with an appropriate effort. Here, it should be checked, which data sources are available in each country and whether they can be mixed or supplemented with additional sources such as geomarketing data. For very basic and large scale – especially transboundary - approaches the *Corine Land Cover* data (CLC) can be used, as it is cheap and ubiquitous in Europe.

3.4.2.2 Types of land use data

After defining the hazard by flood characteristics it is necessary to find out who or what is exposed to this hazard. I.e. the elements at risk have to be identified. More precisely, information is needed about the number, location and type of elements at risk as well as their value and their susceptibility against flooding. While chapter 3.4.3 deals with the quantification of values and chapter 3.4.4 shows how data on the susceptibility can be evaluated, this chapter deals with land use data, which provides information on the number, location and type of elements at risk.

From the perspective of damage evaluation the ideal land use dataset will provide (1) the minimum of variance within a category and (2) the maximum of variance between categories and moreover, it has to match with the classification systems of the damage functions used.

As mentioned above there are two principal ways to get the required land use information: by carrying out an individual field survey (primary data) or to rely on pre-existing data sources (secondary data).
The advantage of **primary data** is that all required land use information can be collected at that level of detail as it is needed for damage evaluation. This means for example that a more detailed classification of land use types can be used than is usually available from secondary data. The disadvantage is that field surveys are time-consuming and costly so that they are usually restricted to small-scale studies (see chapter 3.2).

However, **secondary data** can be costly too, especially if very detailed information is needed. But in general it will require significantly less effort and costs to apply already existing data in damage evaluation. The disadvantage of secondary data is that it is almost never solely produced for the purpose of damage evaluation and, therefore, will probably not contain all necessary information at the required level of detail.

The **level of detail** of land use data is determined by two aspects: The spatial resolution of the data and the level of differentiation of different land use types.
Especially regarding urban areas the **spatial resolution** of land use information varies considerably.[10] Detailed data contains information about single properties or buildings. I.e. the location and type of every building are documented. This kind of data is called in the following **object-oriented data** (Messner & Meyer 2005). Damage evaluation methods based on this data can be called "property-by-property approach" (Penning-Rowsell et al. 2003).

In other data sources properties or buildings are aggregated to areas of more or less homogeneous land use. In the following this type of data will be called **aggregated land use data**.
The spatial information is nowadays mostly stored and presented in digital maps, either in the form of address points, discrete areas or lines (vector data) or in grid format.

The other criteria, the level of **differentiation of land use types** correlates more or less strongly with the spatial resolution: Data with a high spatial resolution often also has a high differentiation of land use categories.
The differentiation of land use types in damage evaluation approaches varies between 5-6 aggregated land use categories (e.g. IKSR 2001) up to more than hundred just for buildings (e.g. Penning-Rowsell et al. 2003). But also object-oriented land use data sometimes only provide a differentiation in two types (e.g. residential and non-residential; DEFRA 2001).

However, it is important that the categorisation of land use matches with the categorisation used for the quantification of values (chapter 3.4.3) and for the damage functions (chapter 3.4.4). I.e. it would not make any sense to differentiate buildings in more than a hundred types when later only one approximate value and one approximate damage function are used. Ideally, the same classification is used for land use data, value assessment and damage functions. This is indeed not always possible, especially when secondary data is used. Otherwise it must at least be possible to relate the different categorisations to each other.

It is of course not possible in these guidelines to describe or to list every possible land use data source in Europe. In the following at least a few examples of typical land use data used within different damage evaluation approaches will be given.

3.2.4.3 Object-oriented land use data

A) Primary data
One example of the collection of land use data by field survey would be the method recommended in the so called "Multi Coloured Manual" (Penning-Rowsell et al. 2003) for detailed project appraisals in England. A property-by-property approach is followed here, i.e. for each property in the defined floodplain the following information is collected:

- The **location** is documented by a grid reference code and address which could be related to respective plans or maps.
- The **categorisation** of property types first of all distinguishes between residential and non-residential properties. Residential properties are firstly separated by five building types, secondly by six age categories and thirdly by four social classes. Non-residential properties are divided by ten business sectors and its subcategories (admittedly not matching with the standard EU business classification NACE). This classification matches mostly with the standard depth-

[10] This differentiation is not so high when agricultural areas are considered. Here it is usually not differentiated between single properties, i.e. fields. Usually only arable and grassland is differentiated.

damage data provided in the manual. Indeed it is only recommended to use the full detail of this classification for very detailed surveys, otherwise type and age of residential buildings might be sufficient (Penning-Rowsell et al. 2003).

- For non-residential properties also the ground floor area of each property is surveyed, as it is needed for damage calculation. Residential houses are simply considered as one unit regardless of their size.
- Furthermore the altitude of the threshold of flooding for each property is documented. Especially for micro-scale approaches it is important to document how high this threshold of a building is above ground altitude in order to determine the actual depth of flooding within each individual property.

Another example would be the land use survey carried out by Reese et al. (2003; see also Sterr et al. 2005) for the MERK study in Schleswig-Holstein, Germany. The classification of house types is aligned with the official building valuation guidelines ("standard construction costs"; BMVBW 2001; see chapter 3.4.3.3 D). Besides the address of each building, its type and age, also the number of storeys and their use is documented as well as information on the existence of cellar or attic floors. The ground floor area is taken from detailed maps (DGK 5).

B) Secondary data

Object-oriented land use data is often also available from secondary sources. If and what kind of data exists, varies from country to country. Two different kinds of data can be mentioned here: Address-point data, where each property is represented by a point in a map, and cadastral maps, which also give information on ground floor area of properties in buildings. An example of each is given in the following. Both cadastral maps and address-point data are also used for damage evaluation methods in the Czech Republic (Satrapa et al. 2005; Čihák et al. 2005).

Address-point data: National Property Dataset (England & Wales)

An example for a secondary object-oriented data source is the *National Property Dataset* which was especially developed for the MDSF software tool which supports damage evaluation on the catchment level in England and Wales (DEFRA et al. 2004; see also chapter 3.6). It provides location and type of every single property in the country derived from address-point data. As the primary land use classification used in England (see above) it matches the standard damage data, whereas the classification is not as detailed: While non-residential properties are classified likewise, residential properties are not differentiated at all. Furthermore an average floor area is assumed. Nevertheless this data provides very precise information in spatial terms and makes object-oriented damage evaluation possible on the regional and even national scale with an appropriate amount of effort (Sayers et al. 2002).

Cadastral Maps: ALK (Germany)

An alternative solution for an object-oriented damage evaluation would be the usage of cadastral maps. In contrast to the address-point data described above cadastral maps locate each property not only by a point but in form of discrete ground floor area of building and property. An example of cadastral maps would be the German ALK (*Automatisierte Liegenschaftskarte*) which was used e.g. in the MERK project (Reese et al. 2003; see chapter 3.6) in the German state of Schleswig-Holstein for damage evaluation. Besides ground floor areas of properties and buildings it provides at least a differentiation of residential and non-residential use of buildings, in some areas also a more detailed classification, i.e. of house types and economic sectors.[11] However, Reese et al. (2003) state that the ALK data does not provide as much and as detailed information as collected by field surveys (see above). For example it does not provide information on the number of storeys or the exact business sector of non-residential properties.

[11] The classification so far varies among the federal states.

Furthermore, it has to be mentioned that especially address-point data, but sometimes also cadastral maps to a certain extent, focus on information on buildings. For the assessment of other areas, like agricultural or traffic areas it might be necessary to use additional (maybe more general) land use data.

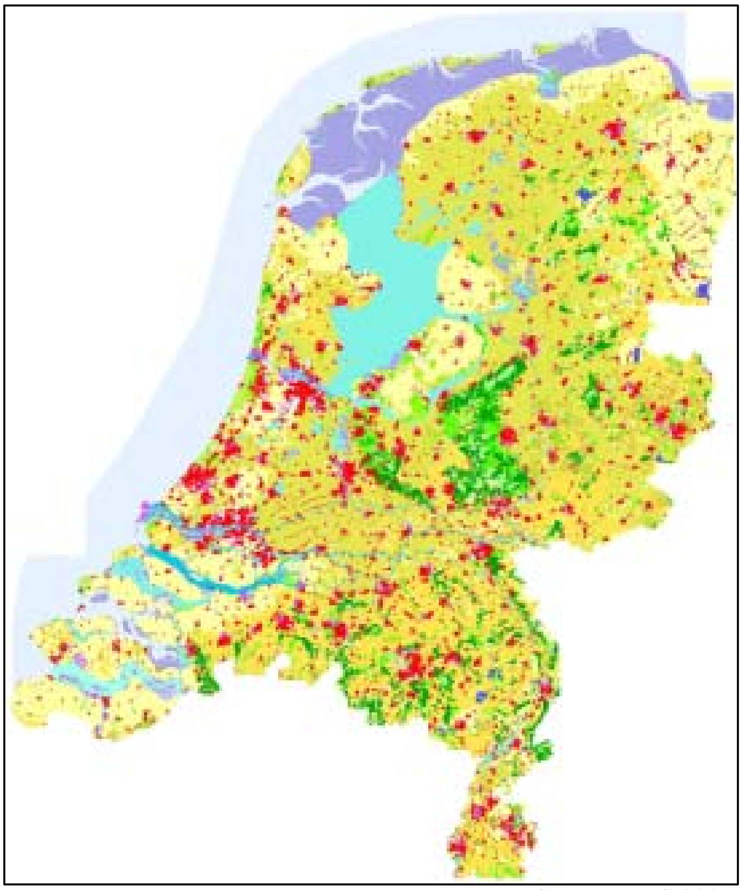
3.4.2.4 Aggregated land use data

In contrast to object-oriented data, other secondary land use data sources aggregate several properties or areas to areas of more or less homogeneous use. However, the spatial extent of these areas is seldom the same as that of the inundated area. That means intersections between land use data and inundation area have to be made in order to estimate which part of the aggregated land use units is affected. Consequently, the application of aggregated land use data can lead to some inaccuracies, as an equal distribution of buildings etc. is assumed within each aggregated land use unit.
Hereby, the level of spatial resolution and generalisation as well as the level of differentiation of land use types differs considerably between different sources. Two examples are given in the following: *Corine Land Cover* data (CLC) as a very approximate data source and the German ATKIS-DLM as an example for more detailed data.

A) Corine Land Cover
The *Corine Land Cover* (CLC) project provides land use information for all EU member states derived from satellite information (ETC 2005: http://terrestrial.eionet.eu.int/CLC2000). After a first dataset with land use information from 1990, a newer dataset (CLC 2000) has recently been released. CLC data provides quite generalized information in spatial terms: Only areas larger than 25 ha and line objects like streets or rivers wider than 100 m are considered (DLR 2005). Altogether 44 land use categories in three hierarchy levels are differentiated (see ETC 2005). Especially in urban areas this differentiation is quite low, however (see e.g. figure 3.5).
CLC data was used e.g. for flood damage evaluation in a study for the whole River Rhine (IKSR 2001). Here only six categories aggregated from CLC land use classes are used: “Settlement”, “industry”, “traffic”, “agricultural areas”, “forest” and “other”. Each category is then related to an approximate asset value (see chapter 3.4.3). The great advantage of CLC data is its availability all over Europe[12] which allows an application in transboundary projects like the Rhine study mentioned above. On the other hand it is not very detailed regarding its spatial resolution and its differentiation and can be therefore only be recommended for large scale studies with limited demands on precision.

[12] CLC data is e.g. available at: http://terrestrial.eionet.eu.int/CLC2000 or http://image2000.jrc.it/

Figure 3.7: CLC data for the Netherlands



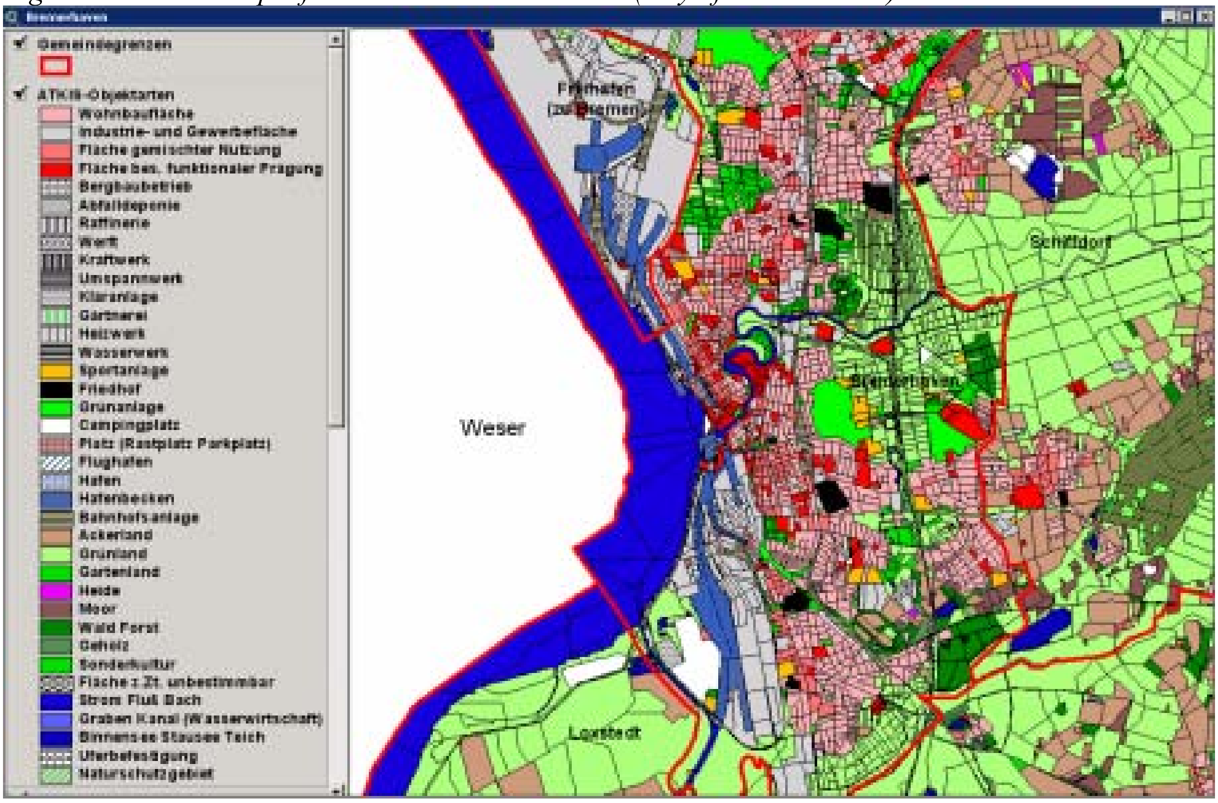
Source: ETC 2005

B) More detailed aggregated land use data: ATKIS-DLM (Germany)

Most countries however also provide more detailed aggregated land use data. An example from Germany is the *Digital Landscape Model* (DLM) from the ATKIS (Official Topographic-Cartographic Information System). The ATKIS-DLM has a considerably higher resolution than the CLC data, e.g. single blocks within settlements are differentiated (see figure 3.8). Also the differentiation of land use types is much more detailed (AdV 2003): Altogether more than 100 object categories in three hierarchy levels are provided, sometimes supplemented with additional attributes.

ATKIS-DLM data have been used in several damage evaluation studies especially on the meso-scale in Germany up to now: For example for the coast of Schleswig-Holstein (Colijn et al. 2000), for the River Rhine in North Rhine-Westfalia (MURL 2000) and for the Jade-Weser-Estuary (Meyer 2005). Usually the values of assets are taken from official statistics and then assigned to associated ATKIS categories (e.g. residential capital to "residential areas" etc.; see chapter 3.4.3.2).

Figure 3.8: Example for ATKIS-Basis-DLM data (City of Bremerhaven)



Source: Meyer 2005

Other countries provide similar data like the German ATKIS-DLM. E.g. in the Netherlands CBS land use data is used among other data sources for their standard method of damage evaluation (Kok et al. 2004) and also in the Czech Republic UPD land use data is applied for a meso-scale damage evaluation approach (Satrapa et al. 2005). If such data sources do not exist, digitized topographic maps can also be a helpful source, but they often do not contain explicit information on types of land use.

3.4.2.5 Other data

In some studies **geomarketing data** is used to integrate additional socio-economic information. Geomarketing data is not an official data source but mostly stems from commercial providers. It provides information on a small spatial scale, e.g. for postcode districts, election districts, street sections or single address-points. For each of these units further information is provided, e.g. on number of inhabitants, buildings, flats, structure of building fabric, age, social status and purchasing power of inhabitants, number and branch of firms, number of employees etc. While the main purpose of this data is to facilitate commercial marketing, it can also be valuable for damage evaluation as a supplementary to land use data described above.

In the Netherlands, for example, such data is used in the standard damage evaluation approach (Kok et al. 2004). In this way information on the number of inhabitants, number and type of flats as well as number and branch of employees per geographical unit is added to get more precise information on these elements at risk than is provided by official land use data. Comparable data is used in Germany by MURL (2000) and Meyer (2005). By using data at the level of election districts (approximately 500 households) on inhabitants, buildings, purchasing power and firms, the estimation of the spatial distribution of assets at risk can be improved. Satrapa et al. (2005) use information on inhabitants and flats per address-point for damage evaluation in the Czech Republic. In some cases such information is also provided by official statistics: Penning-Rowsell et al. (2003) are using data from the British census to find out the distribution of social classes in each enumeration district.
Table 3.4 gives a short overview of the types and examples of land use data described in this chapter.

Table 3.4: Overview of different land use data types

Source	Types & examples	Spatial resolution	Differentiation (used for damage evaluation)[13]
Primary	Field surveys	Object oriented: Single properties	> 100 different building types
Secondary	Address-point data *E.g. UK, National Property Dataset*	Object oriented: Address-points	> 20 different building types
	Cadastral maps *Germany, ALK*	Object oriented: Ground floor areas	> 2 different building types
	Detailed aggregated data *E.g. Germany, ATKIS Czech Republic, UPD NL, CBS*	Aggregated: Blocks of similar use	> 10 different land use types
	Low detailed aggregated data *E.g. CORINE Land Cover*	Aggregated: Areas > 25 ha	Ca. 6 different land use types
	Geomarketing data *E.g. NL, Bridgis Germany, Infas-Geodaten*	Postcode areas, Election districts etc.	- (Additional socio-economic information)

In many damage evaluation studies not only one source of land use data is used. The reason for this can be, for example, that one data source does not cover all types of land use, e.g. only buildings are documented and infrastructure, agriculture areas etc. have to be collected from other sources. In other cases the mix of different data sources might lead to a more precise description of land use, for example when a residential area is further specified by geomarketing data with attributes like purchasing power, fabric structure etc.

The standard method of damage evaluation in the Netherlands (Kok et al. 2004) for example uses official CBS land use data as a basis, which is supplemented by geomarketing data on inhabitants, dwellings and employees and official spatial data on streets, railways and other infrastructure. All this information is gathered and transformed into a unified 100 m grid dataset.

[13] Some of the data sources mentioned contain more categories, but not all of them are useful for the purpose of damage evaluation.

3.4.3 Determination of the value of assets at risk

3.4.3.1 Summary & Recommendations

The assessment of the total value of elements at risk is only needed if relative and not absolute damage functions are used. The latter show absolute damage amounts and therefore already include asset values.

When evaluating asset values to determine damages to the economy it is necessary to use depreciated values and not full replacement values (see also chapter 2).

Several basic assessment approaches are described in this chapter. For macro-scale studies e.g. a transfer of approximate values of land use unit from other studies is advisable (chapter 3.4.3.3 C). On the meso-scale the spatial modelling of aggregated data from official statistics can be recommended (chapter 3.4.3.3 A&B). Micro-scale studies should use at least for buildings an object-oriented assessment (chapter 3.4.3.3 D). For the derivation of absolute damage functions an assessment of property components is often carried out (chapter 3.4.3.3 E).

It is often not possible to derive the value of all asset categories from just one source. To include all desired damage categories (chapter 3.3) it is therefore sometimes necessary to mix different assessment approaches and data sources.

3.4.3.2 Value, assessment approaches & concepts

After documenting the location, number and type of elements at risk it is necessary to quantify their value in order to calculate damages in monetary terms. This information can be integrated in the process of damage evaluation in two different ways:

a) The **total value** of elements at risk in the study area is evaluated. The damaged share of this total value is then calculated by relative damage functions.
b) The value of elements at risk (or at least parts of them) is **integrated in absolute damage functions** for each category, showing the absolute damage depending on magnitude of inundation characteristics (see chapter 3.4.4).

This chapter will mainly focus on methods for the assessment of the total value (a). But as it is sometimes also necessary for the derivation of absolute damage functions to carry out an assessment, an example for this is also documented.

The methods of assessment of values vary considerably regarding the **spatial level** on which the assessment is taking place: While some methods collect aggregated values e.g. on municipality level, which are then broken down to corresponding land use categories (top-down approach) others assess the value of each building or even of its components (bottom-up approach).

Regarding the assessment of damages or values of elements at risk two different **assessment concepts** can be distinguished:

- Under the assumption that in case of flooding a damaged element has to be replaced by a similar object, the current price for a new similar object can be taken. This would be the **full replacement value**. As some insurance contracts follow this new-for-old payments, this might be the right assessment concept for a study carried out for the insurance industry. However, the damage to the economy is overestimated by taking full replacement values because the depreciation of assets over time is neglected, i.e. full replacement values also include early investments in new assets.

- For an economic evaluation of damages the assessment of assets with their **depreciated value** is advisable. I.e., the pre-flood value of assets has to be assessed which means the depreciation on the new value has to be taken into account. As it is of course not pragmatic to survey the age and the related depreciation of every single element at risk, average remaining values are assumed (see e.g. Penning-Rowsell et al. 2003). If, for example, a linear depreciation is assumed the average remaining values would be 50 % of the new value. In official statistics, e.g. in Germany, data on the value of capital assets is given for both assessment concepts, the value as new (gross value) and the depreciated value (net value).[14]

The results of damage evaluation, therefore, differ substantially depending on which assessment concept is chosen. Nevertheless both concepts are used and sometimes mixed in flood damage evaluation studies. **To evaluate the impacts of flooding to the economy we strongly recommend applying the depreciated value for the assessment of assets rather than the full replacement value and furthermore not to mix both concepts**.

3.4.3.3 Examples for typical approaches

In the following, some principal approaches for the assessment of values of assets at risk will be introduced and examples for their application will be given.

A) Aggregated data from official statistics
In many countries official statistics provide information on the value of assets in an aggregated form, i.e. for the nation as a whole or also for smaller administrative units like federal states, districts or even municipalities.

The national accounts at least provide data on gross and net value of **fixed assets**, based on market prices. Fixed assets include residential and non-residential buildings as well as machinery and equipment (Eurostat 2005) and therefore cover a lot of the total value of all assets. Nevertheless, for example industrial inventories (stocks) as well as household goods are not included and have to be taken from other sources (see chapter 3.4.3.4)

From the Eurostat-homepage data on the fixed assets differentiated in 17 economic branches can be downloaded for each EU member state.[15] Often the national or regional statistical offices also provide data on lower spatial levels. If not directly available on municipal level, it is also possible to break the data down to this level by indicators like the number of employees or inhabitants. Therefore the value of fixed assets on a state or country level is disaggregated by the share of employees in each branch and municipality compared to the total number of employees in this branch.[16]

This total value of fixed assets on a municipal level is for example used in the macro-scale study for the German coast (Ebenhöh et al. 1997) to give an approximate estimation of the maximum damage potential in the coastal area.

B) Disaggregation to land use units: spatial modelling
For more detailed studies the estimation of the value on municipality level is of course not precise enough in spatial terms, because an equal distribution of assets over the area of each municipality would be assumed. Meso-scale approaches therefore often carry out a kind of **spatial modelling**:

[14] For example in the year 2000 the net value of all capital assets of Germany is about 63% of the gross value (Frenkel & John 2002).
[15] Therefore, on the eurostat-homepage (epp.eurostat.cec.eu.int) go on “economy and finance” and there on the data section. Here, follow this tree: National Accounts ⇒ Annual National Accounts ⇒ Breakdowns ⇒ Breakdown of fixed assets. Choose “Current replacement costs” as it reflects best the current value of assets. In the following menu you can choose e.g. the region and the economic sectors to be included. To derive the depreciated value of assets it is important to choose “net values”.
[16] Regarding residential capital the number of inhabitants seems to be the better indicator for disaggregation.

Here, the value of each category of assets or economic branch in a municipality or other administrative unit is assigned to corresponding land use categories.

For example, in Germany several studies carried out such a spatial modelling where asset value data from official statistics is assigned to ATKIS-DLM land use data (Klaus et al. 1994, MURL 2000, Colijn et al. 2000; Meyer 2005; Elsner et al. 2003). This of course requires matching the categorisation of economic branches to the categorisation of land use. E.g. the value category "residential capital" is assigned to the ATKIS land use categories "residential areas" and "areas of mixed use" or the fixed assets of the manufacturing branch are assigned to "industrial and commercial areas".

In a GIS the corresponding ATKIS land use categories can be selected, merged and related to the recorded values. Thus, each value category is stored in the GIS as a single layer including information on location and concentration shown in EUR/m^2. By merging these different layers to a single layer a map showing the distribution of all monetary assets in the research area can be created by simple addition.

MURL (2000) and Meyer (2005) furthermore integrate geomarketing data (see chapter 3.4.2.5) to improve the spatial modelling: E.g., by information on number of inhabitants and their purchasing power the spatial distribution of residential capital over the areas mentioned above can be improved.

Spatial modelling can of course also be done on the basis of other land use data. E.g. Halcrow Water et al. (1999) apply a similar approach for a study in Hungary with CORINE Land Cover data (see chapter 3.4.2.4). But theoretically also more detailed data, like object-oriented cadastral maps could be used. However, it should be stated that this disaggregation of aggregated values could lead to some inaccuracies in the results. So if values derived from highly aggregated statistics are broken down to the level of single buildings a level of precision would be inferred which would not exist.

C) Approximate values per land use unit from other studies

The results of such a spatial modelling described above are differentiated asset values per square metre. From these results it is possible to derive approximate asset values per square metre for each land use category used. Especially for macro-scale studies such approximate values can be adapted and transferred. Care has to be taken that all important asset / damage categories are included in these approximate values.

Such an approach is followed e.g. in the Rhine Atlas (IKSR 2001), where damage evaluation is carried out for the whole transboundary River Rhine. Here, approximate values for different land use categories are taken from different small scale flood damage evaluation studies in Germany. These values are firstly converted to 2001 prices and than assigned to land uses categories derived from CLC (see chapter 3.4.2.3). For each of the four German federal states concerned, these values were adjusted due to differences in land use distribution. In table 3.5 these specific asset values for the state of North Rhine-Westphalia are shown. For Switzerland, France, and the Netherlands, the German values were adjusted by data on purchasing power and GDP indices.[17]

The application of these approximate values may lead to even more inaccuracies in the results than the disaggregation of values from official statistics. Such an approach should only be used for large scale studies with relatively low requirements for precision.

[17]The same approach has also been used in damage evaluation studies in the federal state of Saxony, Germany (LTV 2003). In contrast to the Rhine Atlas biotope-type data and not CLC is used as land use data.

Table 3.5: Specific asset values for North Rhine-Westphalia used in the Rhine-Atlas

Land-use category	Value of fixed assets EUR/m²	Value of mobile assets EUR/m²	Total EUR/m²
Settlement	231	59	289
Industry	231	80	311
Traffic	263	2	265
Agricultural areas	No differentiation	No differentiation	9
Forest	No differentiation	No differentiation	1
Other	No differentiation	No differentiation	0

Source: IKSR 2001

D) Object-oriented assessment of building values

For more detailed studies the determination of object-oriented asset values seems to be sensible.
For residential buildings often typical market prices are published. For example in the Netherlands the approximate market price of different flat types can be taken from official statistics. Briene et al. (2002) are using such information for the estimation of the maximum damage potential of residential capital for the *Standard Method* for damage evaluation in the Netherlands. In Germany such values based on actual sales are published yearly by so called *appraising boards of real estate values* (Gutachterausschüsse für Grundstückswerte) for each city or municipality.

In Germany also exists an official *guideline for the assessment of buildings* (WertR). Here, the value of different types of buildings is assessed by means of *standard construction costs* (Normalherstellungskosten; NHK) which are published periodically by the responsible ministry (e.g. BMVBW 2001: NHK 2000). These assessment guidelines are used for example for flood damage evaluation in the MERK study (Reese et al. 2003; see chapter 3.6, micro 1). For the application of this approach it is necessary to carry out field surveys to collect detailed information on each building, such as ground floor area, type of construction and use, number of storeys and age.

As this approach only deals with building values, other important asset values have to be evaluated seperately. E.g. the value of building equipment, inventories, household goods, cars, streets etc. have to be taken from other sources (see chapter 3.4.3.4)

E) Object-oriented assessment of property components

An even more detailed and bottom-up approach is followed in the Multi Coloured Manual (MCM) for damage evaluation in the UK (Penning-Rowsell et al. 2003; see also Penning-Rowsell & Chatterton 1977). For residential properties a classification by type, age and social status is carried out (see chapter 3.3.2). For each of these altogether 100 residential property types a typical inventory is compiled by means of expert judgement and different statistics and publications. Each of the building fabric and household inventory components is then assessed with its depreciated (average remaining) value. Here again different statistics and publications on market prices of the different building components and household goods are used. A similar approach is carried out for non-residential properties: Here, the approximate value per square metre of building fabric, fixture and fittings, moveable equipment and inventories for each economic branch is derived from surveys. It has to be stated that this approach is not used to evaluate the *total value* of property assets but instead for the development of a standard depth-damage dataset in terms of absolute damage functions (see chapter 3.4.4). I.e., only the value of the components which are likely to be damaged at a certain depth (and duration) are assessed and integrated in the damage functions.

A very similar approach has been developed by Satrapa et al. (2005; see also Čihák et al. 2005) for flood damage evaluation in the Czech Republic. Here also an inventory of the building fabric components of about 200 residential and non-residential building types is carried out. Data on the construction cost per cubic metre of each component is available in the Czech Republic from official statistics. Multiplied by the height of each building floor the value per square metre of each building floor affected can be estimated. In the more approximate damage evaluation methods used for large scale damage evaluation, only a differentiation of five different building types is applied. Here, a lower and upper limit of the value per cubic metre is used to reflect the diversity of different building types within each category. The value of residential and non-residential inventories is not available from official statistics and has to be derived from statistics.

Again, both approaches described above only consider building values and their inventories (at least in the British case). If other categories like traffic infrastructure, cars or agricultural products should be included, they have to be estimated by other approaches, which will be described in the following.

3.4.3.4 Assessment of further asset categories

The examples described above show basic approaches for the determination of asset values but they mostly do not cover all categories of assets which should be included in damage evaluation (see chapter 3.2). E.g. data on fixed assets from official statistics (see a.) generally does not include household goods as well as commercial and industrial inventories or the value of privately used cars. The object-oriented methods described above mostly concentrate on the evaluation of the value of buildings. So in the following some further examples for the assessment of other asset categories will be given.

Household goods
As the value of household goods is often not available from official statistics other sources have to be used. Some studies therefore apply aggregated values from insurance companies. For example, Briene et al. (2002) in the Netherlands use an approximate value of 70000 EUR per flat (year 2000) derived from insurance companies. German studies (e.g. Reese et al. 2003; Meyer 2005) often apply an average value per square metre of living area of 700 EUR (full replacement value) or 350 EUR (depreciated value[18]) which also stems from an insurance company. This value can then be multiplied by either the ground floor area of residential buildings derived from maps or by the total living area of a municipality derived from official statistics.

It has to be kept in mind that the application of such insurance values can lead to a biased estimate as insurance is a luxury good. An alternative would be to estimate the value of household inventories by data on household expenditure on such goods. However, such data is not always published in official statistics.

As described above, more detailed approaches derive the value of household goods from surveys or special statistics and publications (Satrapa et al. 2005; Penning-Rowsell et al. 2003).

Inventories (Stocks)
In contrast to data on fixed assets the value of private company inventories[19] are at least currently not published in statistics on National Accounts. Detailed methods (Satrapa et al. 2005; Penning-Rowsell et al. 2003) therefore carry out surveys to determine approximate values of inventories for different branches. Another approach would be to use a fixed relation of inventories to fixed assets to estimate the value of inventories. For instance Klaus & Schmidtke (1990) apply a relation of 8 % (inventories/gross fixed assets) derived from official statistics. Indeed, this relation varies strongly depending on the economic branch. E.g. while it is very high in manufacturing and trade, it is very low in agriculture, construction and service activities other than trade. Therefore other studies apply a relation inventories/fixed assets differentiated by economic branches (e.g. MURL 2000; Reese et al. 2003; Meyer 2005). It has to be checked for each country if data on inventories is published in official statistics and how it can be used for damage evaluation.

[18] assuming a linear depreciation of household goods

[19] According to Eurostat (2005) "inventories consist of stocks of outputs that are still held by the units that produced them prior to their being further processed, sold, delivered to other units or used in other ways, and stocks of products acquired from other units that are intended to be used for intermediate consumption or for resale without further processing."

Cars
While commercial vehicles are included for example in the fixed assets, private cars have to be evaluated separately. Often approximate market values of cars are used for this. Briene et al. (2002) take the approximate value of new cars and assume a linear depreciation to come to the approximate value of a car of 9700 EUR (year 2000). German studies (MURL 2000; Berger 2001) apply the approximate market price of used cars, derived from specialised consultancies like *Eurotax Schwacke* and *DAT*. However, it has to be considered that second hand prices of cars are distorted away from perfect market prices. Such an approach will consequently lead to a very approximate estimate of the real value of cars.

Streets and Railways
To determine the value of technical infrastructure, construction costs per metre or square metre are often applied. E.g. for streets construction costs per metre are used for damage evaluation in the Netherlands (Briene et al. 2002), in the Czech Republic (Satrapa et al. 2005) and in Germany (e.g. Reese et al. 2003; Meyer 2005). These values can be either derived from official statistics, special publications or directly from the responsible offices. Likewise the value of railways per metre can be evaluated.

Agricultural products
In some damage evaluation studies the value of agricultural products and livestock is also calculated separately. Although this value is generally fairly low compared with other assets it might be included in detailed studies or for areas where agriculture is the dominant activity.

For calculating the value of livestock mostly the market price of different types of cattle is taken from statistics. This value can then be multiplied by the total number of cattle in the region which is mostly also published in statistics on agriculture (Meyer 2005).

To calculate the value of different crops on farmland, depending on the time of the year, Satrapa et al. (2005) add up investments for the production of these crops. Corresponding methods are described in DEFRA (1999, Annex B) as well in the *Multi-Coloured Manual* (Penning-Rowsell et al. 2003).

In the case of livestock and also for crops, it is necessary to remove the subsidy element from agricultural prices to obtain an estimate of the economic damage. This includes subsidies on inputs as well as on outputs. E.g. for crops, the reduction in yield as a result of flooding depends upon the time of year (Green 2003; DEFRA 1999). What is lost is the real economic value of the crops minus the variable costs avoided because the crop has been destroyed e.g. harvesting, drying the crop (see also chapter 9.2)

3.4.4 Damage Functions

3.4.4.1 Summary & Recommendations

Damage functions show the susceptibility of assets at risk to certain inundation characteristics, currently mostly against inundation depth.

Damage functions can be differentiated in relative damage function, showing the damaged share of the total value, and absolute damage functions, indicating absolute damage amounts as a function of inundation depth. Damage functions can be either derived from real flood damage data (survey data) or synthetically, i.e. by expert estimation for either standardised property types or for the specific properties located in the study area.

Two prominent examples for damage databases are described in this chapter: The damage data from FHRC (UK) and the German HOWAS-database.

For the derivation of a detailed set of damage functions the development of such a damage database - if not already existing - is recommended. Chapter 3 will give further guidance on this topic.

Both absolute and relative damage functions can be used on all scale levels. Nevertheless, if a well developed set of absolute damage functions is at hand for the study area, this should be used, as it reduces the effort of damage evaluation.

On the macro level it might be sufficient to use only few (up to five) damage functions for different land use types. Meso-scale studies should use a higher differentiation (about 10 categories). On the micro level, especially when absolute damage functions are used, at least 20 different functions are recommended. Again, it is important to match this categorisation with the differentiation of land use types.

3.4.4.2 Types and derivation of damage functions

By overlaying maps of inundation and land use it is possible to evaluate which elements or assets would be affected by a certain flooding scenario and how much they are affected in terms of inundation depth or other flooding characteristics. What is now needed to estimate the damage is information about the susceptibility of these elements at risk to flooding. For this purpose damage functions are used. They show the damaged share (relative damage functions) or the absolute amount of damages (absolute damage functions) of a certain group of elements at risk as a function of the magnitude of certain inundation characteristics.

Inundation characteristics considered
As stated in chapter 3.3.1 many different **inundation characteristics**, like depth, duration, velocity, rise rate, time of occurrence and contents and loads may influence the amount and degree of damage. In the current state-of-the-art of flood damage evaluation mainly inundation depth is incorporated in damage functions, as it seems to have the most significant influence. I.e. in most methods depth-damage functions are used. Only some approaches also consider other characteristics such as e.g. in the UK, where depth-damage functions are differentiated in short and long duration of flooding (Penning-Rowsell et al. 2003) or in the Netherlands, where also the velocity is incorporated in damage functions for residential properties (Kok et al. 2004).

Absolute and relative damage functions
As mentioned above (see chapter 2 and 3.3.3) there are two basic ways of calculating damages which require two different types of damage functions:

- In some approaches first the total value of elements at risk is evaluated. The actual damage is then calculated by means of **relative damage-functions**, showing the damaged share of this total value to inundation depth ("percentage of property value approach", see also chapter 3). Such an approach is followed e.g. in the standard method in the Netherlands (Kok et al. 2004), in a damage evaluation in Hungary (Halcrow Water et al. 1999) or in several mainly macro- or meso-scale approaches in Germany (e.g. Klaus & Schmidtke 1990, IKSR 2001, MURL 2000, Reese et al. 2003).
- Other approaches do not determine the total value of elements at risk at any time. Instead, the calculation of damages is carried out directly by means of **absolute damage functions**, which show the absolute amount of damage depending on inundation depth. Such absolute damage functions are for example provided by the *Multi Coloured Manual* in the UK (Penning-Rowsell et al. 2003) or in Germany in the HOWAS-database (IWK 1999).

An advantage of the use of absolute damage functions is, of course, that it is no longer necessary to determine the value of elements at risk for each study. This reduces the effort of a study considerably as only land use information has to be gathered. On the other hand this means that a well developed, differentiated and frequently updated depth-damage database must be available (see chapter 3) or damage functions have to be created especially for the study area. Furthermore, absolute damage functions are even more dependent on the type of building or asset considered than relative damage functions, which are at least independent from the value of assets. That means that absolute damage functions have to be more differentiated in asset categories than relative damage functions. For the same reason relative damage functions are easier to transfer to other regions than absolute damage functions.

Derivation of depth-damage functions
If not transferred from another study damage functions can be derived either by survey data or by synthetic data (Green et al. 1994).

- "**Real flood damage data**" or "Survey data" (see also chapter 4.3.1) means that after a flood event data on the affected properties is gathered. At least, information on the type of each property, how deep it was inundated and what damages occurred has to be ascertained. This data can be stored in a database. By means of regression analysis, typical depth damage functions for different property types can be derived. Such an approach requires a large sample size as the whole variety of different types of construction and use has to be represented. Furthermore, it has to be ensured that all ex-post damages are evaluated with the same assessment concept. I.e. that for example depreciated values are ascertained and not full replacement values, as it is often done by insurance damage adjusters (see chapter 3.4.3).
- "**Synthetic data**" (see also chapter 4.3.2) means that damages are estimated not for actual properties but for standardised, typical property types (see e.g. Penning-Rowsell et al. 2003, 2005). I.e. firstly standard buildings types are defined by their typical size, construction and inventory components. Secondly the value of these components is assessed (see chapter 3.3.3) and thirdly the susceptibility of each of these items, i.e. the proportional damage depending on inundation depth, is estimated by expert assessors. Summing up these damage estimates of all items, a damage function for each building type can be derived. Green et al. (1994) state that the main difficulty in this approach is ensuring that the synthetically constructed standard property types truly represent actual properties with all their components. Another variant is the estimation of depth-damage functions by expert assessors directly for properties in the study area, an approach currently recommended in particular for micro-studies in Germany (Buck 2004, DWA 2007, see also 3.4.4.3 B)

Nevertheless, "synthetic" does not mean artificial. I.e. for this derivation approach a synthesis of all available data sources, including real flood damage data, is used. On the other hand, also damage functions based on survey data are often adjusted by expert estimates.

3.4.4.3 Examples of damage databases

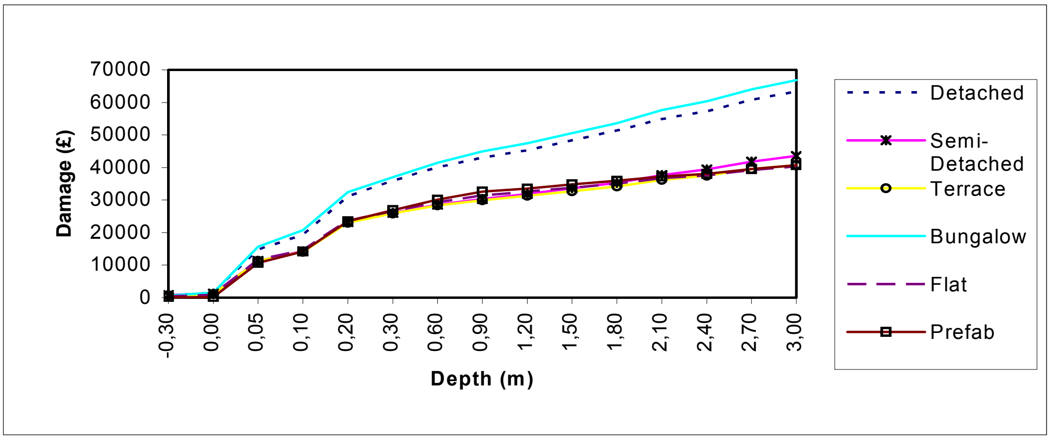
In the following two examples for damage databases and sets of damage functions are given: The synthetic damage data from the Flood Hazard Research Centre (FHRC) in the UK and the German HOWAS-database, which is a collection of actual flood damage data. Depth-damage curves for a number of other countries are given in Green (2003).

A) UK: Damage data from FHRC

Probably the best known example for a synthetically generated database of absolute damage functions is the *Multi Coloured Manual* (Penning-Rowsell et al. 2003) in England provided by the *Flood Hazard Research Centre* (FHRC) from Middlesex University, as well as its predecessors (Penning-Rowsell & Chatterton 1977; Parker et al. 1987; Penning-Rowsell et al. 1992; see also chapter 3)

It provides depth-damage functions for 100 residential and more than ten non-residential property types. As described above (chapter 3.4.3) this data is derived synthetically. I.e. for residential flats first a definition and inventory of these standard property types is done. Secondly, for each of its typical building fabric and inventory components the monetary value is determined. Thirdly, expert assessors estimate the susceptibility of each item to inundation depth. So finally depth-damage functions can be constructed for each residential property type (see for example figure 3.9).

Figure 3.9: Depth-damage functions from the Multi-Coloured Manual for different residential house types (sector mean)

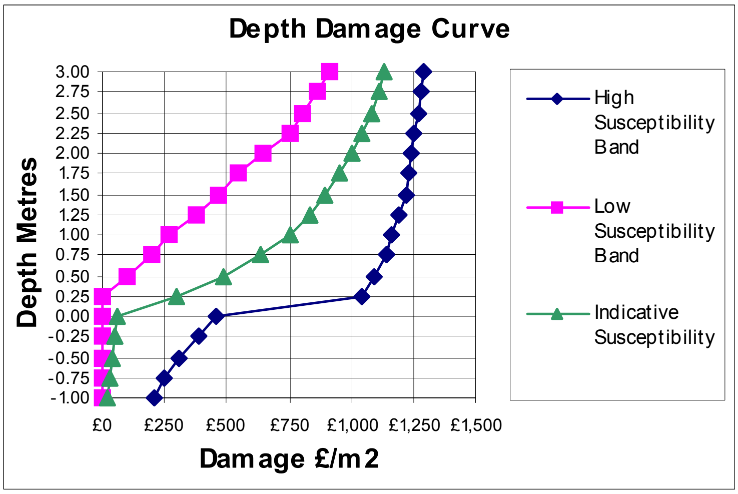


Source: Penning-Rowsell et al. 2003

The procedure for non-residential properties is a little bit different. Here, surveys are carried out in which responsible persons (managers etc.) in each firm were asked about the value of assets at risk (building fabric, fixture and fittings, moveable equipment, inventories), and about the susceptibility of these assets to inundation depth. From the results of this survey average depth-damage curves per square metre of property are derived for different economic branches.

Both residential and non-residential damage functions do not solely consider inundation depth. Additionally, it is distinguished between durations of flooding of more and less than 12 hours. For the non-residential damage function it is furthermore taken into account if a coastal flood is considered or not (salt or fresh water) and if a warning of more than two hours is received (which will lead to evacuation of parts of the movable equipment and inventories). Moreover, low, high and indicative susceptibility bands are constructed, representing the minimum, maximum and arithmetic mean of the survey sample. Figure 3.10 shows for example the depth-damage curve for high street shops.

Figure 3.10: Depth-damage curve for sub-category 211 (High Street shop)
Scenario: River flood, no warning and duration less than 12 hours



Source: Penning-Rowsell et al. 2003

In the UK, damage functions from FHRC build the basis for damage evaluation studies on all spatial levels (see Meyer & Messner 2005). For small scale project appraisals the full detail of the database is used. For meso- or macro-scale studies more aggregated damage functions are used, e.g. the software MDSF (see chapter 3.5.3) for damage evaluation on the catchment level uses only one sector average function for residential properties and about ten for non-residential properties.

B) Germany: HOWAS damage database and succeeding approaches
A typical example for the usage of actual flood damage data for the derivation of damage functions is the German HOWAS database (see e.g. IWK 1999; Merz et al. 2004).[20] It contains information on damages which occurred during nine flooding events between 1978 and 1994. About 3600 individual damages to buildings are recorded (IWK 1999, Buck 2004). The assessment of damages was carried out by insurance damage adjusters and can be interpreted as replacement costs.

A hierarchical 4-digit code is used for the classification of buildings. The six main sectors are shown in table 3.6. For one example of a residential building also an example is given for the full detail of the classification code. In addition the number of damage records in each sector is shown in the table.

Table 3.6: Classification of buildings in HOWAS and number of damage records

Code	Sector	Number of damage records
1***	Residential buildings	1930
12**	Detached, multi-storey	1322
121*	Pre 1924, solid structure	344
1211	No cellar, no garage	90
2***	Public infrastructure	157
3***	Service industries	630
4***	Mining and construction	69
5***	Manufacturing industry	291
6***	Agriculture and forestry	521

Source: IWK 1999

Each damage record provides information on the actual depth of flooding above ground floor and the damages that occurred, divided in damages to cellars and other storeys as well as in damage to

[20] HOWAS was initiated by the LAWA (Länder Working Group Water) and held by the Bavarian Water Management Agency in Munich. However, the database is currently not updated and available anymore.

building fabric, fixed and moveable inventories. Other information, for instance on the total value of each property or the ground floor area of buildings is unfortunately available for few records only (see Merz et al. 2004).

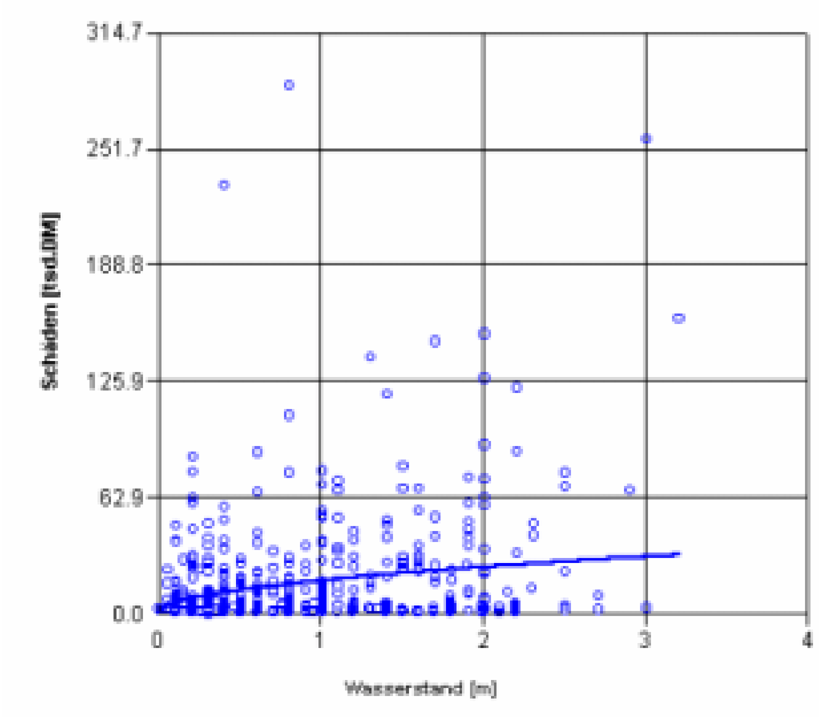
Analyses of the database (IWK 1999; Merz et al. 2004) showed that inundation depth can explain only a relatively small amount of the total variability of damages. This supports the notion that inundation depth may be an important, but not the only factor influencing the amount of damages (see chapter 3.3.1). Merz et al. (2004) expect that relative depth-damage functions are more appropriate, since they are at least independent from absolute asset values. Indeed, it is difficult to derive these directly from the HOWAS-database as total property values are recorded only for a few cases.

As further damage-determining factors are not recorded in the database, IWK (1999) nevertheless derived absolute depth-damage functions from HOWAS assuming that the damage functions could be approximated by a root function with only one parameter (a)[21]:

$$damage = a\sqrt{depth}$$

An example for a depth damage function derived from the HOWAS-database is shown in figure 3.11. The scatterplot demonstartes the great variability within the raw data.

Figure 3.11 Example for a damage function from the HOWAS database: Damage function for building structure in the first floor for detached houses with cellar



Source: IWK 1999

[21] Whilst there is no theoretical reason for expecting any functional form to be the most appropriate form for a depth-damage curve, the root function has some desirable characteristics as an approximation and is at least plausible.

While admittedly some of these damage functions are based on only few damage records and need further empirical substantiation, some basic functions (of the first and second hierarchy level) are used in several damage evaluation studies, for example in a study for the Upper Danube (ProAqua et al. 2001). For other studies (e.g. IKSR 2001, MURL 2000, Reese et al. 2003) also relative depth-damage functions are derived from HOWAS data, which requires some estimates and adjustments as the total property value is rarely documented in the database. Each of these uses a different set of about 5-10 damage functions which is matched with the land use classification used in the respective study.

It should be noted that because of the discussed deficits of the database and due to the fact that it is not updated anymore most German experts advise against using the HOWAS-data anymore (Buck 2004, 2006, DWA 2007). Instead, a working group of experts recommends a **synthetic approach** (or "what – if"-approach) which has some similarities but also some differences to the British approach (DWA 2007). The general idea is that expert assessors conduct an on-site investigation of residential and non-residential properties in the research area. For each storey the expected damages for about three different inundation depths are estimated. Based on this, depth-damage functions can be derived for every building and every building type, respectively.

In contrast to the British approach which uses standardised functions for the whole country, this approach allows to create region-specific damage functions which consider local conditions and susceptibilities. On the other side, it obviously requires some effort to carry out the site surveys for every area under investigation. The authors therefore recommend carrying out such site surveys for every property only within studies with a very high demand on precision (micro-scale). On the meso or macro level, i.e. for studies with lower demands on accuracy, site surveys should be carried out only for a random sample of the most typical building types in the area. For risk hot spots an object-oriented investigation is nevertheless recommended at all levels.

In the long run, such a study-specific creation of damage functions can of course also be used for the development of a damage database, in which all relevant damage-influencing factors are considered (see chapter 4).

On the other side there are other recent approaches which rely on **real flood damage data**. E.g. Thieken et al. (2006; see also Büchele et al. 2006) collected damage data of the August 2002 floods by means of a telephone survey. Based on this data a damage model is developed which considers inundation depth, building type and quality, as well as effects of precautionary measures and contamination (ebd.).

3.5 Step 4: Calculation and presentation of the expected damages

3.5.1 Summary & Recommendations

For the calculation of damages the information gathered in step 3 has to be related to each other. The damage of each land use unit considered is then determined by its affectedness (inundation depth), its value and its susceptibility. Summing up the estimated damages to each land use unit the total damage of each flooding scenario can be calculated.

Especially for meso- and micro-scale studies or when the objective of the study requires spatially differentiated results (identification of hot-spots, evacuation planning) we recommend not only calculating total damage amounts but also carrying out damage mapping by means of a GIS.
This chapter also gives some examples of software tools for flood damage evaluation used in different European countries. Such software tools may facilitate damage evaluation considerably. Especially if a standardised approach to damage evaluation should be developed it is advisable to create a supporting software tool.

Even the most detailed approaches of flood damage evaluation still contain uncertainties in their results. To provide good decision support, these uncertainties should be documented, e.g. by minimum and maximum damage amounts or by confidence intervals.

3.5.2 Damage calculation

The last step is to bring all the information described in chapter 3.4 together and to calculate the expected damages for each flooding scenario under consideration. As described above, methods of damage evaluation vary considerably regarding the type of data used. For example regarding the size of land use units considered (single properties or aggregated land use units), the categorisation of land use types, the kind and number of damage functions used (absolute or relative) and the inundation characteristics considered (solely depth or also others). Nevertheless, the general procedure followed in nearly all approaches can be described as follows.

First of all the information on inundation characteristics, land use, asset values and susceptibilities have to be related to each other. This means that inundation data and land use data have to be combined, i.e. intersected by means of GIS to find out, which land use units would be affected and to what extent. Furthermore the asset values and damage functions have to be assigned somehow to the different land use units. As mentioned in chapter 3.1 two basic approaches can be considered:

a) The **absolute or direct damage estimation approach** (Figure 3.2): Here, the total value of assets at risk is not calculated at any time. Instead, information on the value of assets and on their susceptibility against certain inundation depths is used to develop absolute damage functions. Combined with data on inundation depth and land use information, these absolute damage functions enable a direct estimation of the absolute damage amount for each property or unit of property.

b) The **percentage of property value approach** (relative damage function approach; Figure 3.3): By bringing together land use information and asset values the total value of assets at risk is calculated. This maximum damage potential is then overlaid with data on the specific flooding scenario, especially inundation depth. The resulting damage for each asset or unit of assets is then calculated by means of relative damage functions, showing the damaged share of the total value as a function of inundation depth (or other inundation characteristics).

So finally, for each land use unit considered (regardless whether this unit is a single property or a square metre or kilometre) the following information must be at hand:

a) the degree of affectedness (e.g. inundation depth) and an associated absolute damage function

or

b) the degree of affectedness (e.g. inundation depth), its value and an associated relative damage function

A general formula for the calculation of the estimated damage for on single unit can be described as follows (for the use of absolute damage functions):

a) *Damage*$_{unit\ i}$ *= f (susceptibility of i, inundation depth)*

When relative damage functions are used the formula would be:

b) *Damage*$_{unit\ i}$ *= value*$_{unit\ i}$ ** degree of damage f (susceptibility of i, inundation depth)*

I.e. the damage of one unit of a certain land use category i is the product of the value of this unit i and the degree of damage. This degree of damage depends on the susceptibility of the category i to inundation depth and the actual inundation depth.

To calculate the total damage of one flooding scenario the damage of each affected unit within the floodplain has to be summed up.

$$Damage_{total} = \sum_{i=1}^{n}\sum_{j=1}^{m} (value_{i,j} \times susceptibilty_{i,j})$$

with:

$$susceptibility_{i,j} = f(characteristics\ entity_{i,j},\ inundation\ \ characteristics_k,\ socioeconomic\ characteristics_l)$$

i = category of tangible elements at risk (n categories possible)
j = entity in a elements-at-risk category (m entities possible)
k = flood type/specific flood scenario
l = type of socio-economic system
susceptibility: measured in per cent

Of course this is only a general formula which should be matched to the data used in the respective study. As stated in chapter 3.4 the actual amount of damage does not solely depend on land use category, value and inundation depth. In more sophisticated approaches also other factors like additional inundation characteristics or e.g. indicators of preparedness can be integrated in the formula.

3.5.3 Damage mapping

Such a calculation leads to a single damage value for each flooding scenario considered. These values can be used for the calculation of the annual average damages (the risk) and subsequently for benefit-cost analysis (see chapter 1). For the purpose of such a benefit-cost analysis the calculation of a single value might be sufficient. On the other hand it is not only important to know the total amount of damages (or damages avoided) but also *where* these damages would occur. In other words, the spatial distribution of expected damages is also of high interest.

Flood damages are usually highly spatial diverse, i.e. they concentrate on urban areas. The information, where hot-spots should be expected may be important for example for civil protection. Furthermore, citizens are not primarily interested in the total amount of damages but rather if *they* would be affected in case of flood and how high *their* risk is. Moreover, benefit-cost analyses aim to lead to the most efficient measure to reduce the overall risk of flooding, but these benefits are rarely distributed equally: some areas will be protected by the planned measures, others will not benefit. It could also happen that the risk of some areas to flooding will be increased by the most efficient measure.

To show also the spatial distribution of flood damages (or damages avoided) the results of flood damage evaluation should not only be presented by a single value, but also by means of maps.

Damage and risk mapping could be carried out nowadays relatively easily by means of Geographical Information Systems (GIS). GIS with their ability to handle spatial information (in contrast to traditional databases) seem to be an appropriate tool for damage evaluation: As both inundation data and land use data have a strong spatial dimension and need to be intersected to determine the affected area, GIS are essential at least for some parts of the damage evaluation procedure.

3.5.4 Software tools

In terms of the reduction of the effort of the damage calculation procedure several software tools have been developed up to now. Some of them are GIS-based, others not, but there seems to be a trend that as GIS has become more common and user-friendly over the last years, it is being integrated in damage evaluation software tools more often.

Some examples of such software tools should be given in the following. Their functionality is often of course very much adapted to the data used for damage evaluation in the respective country. Furthermore these software tools differ regarding the number of features they cover: some are solely made for damage evaluation, others also include the whole procedure of risk calculation and benefit-cost analysis, i.e. provide comprehensive decision support in flood risk management.

One example for non-GIS-based software is the **ESTDAM** model developed by FHRC in England. It applies a property-by-property approach and is matched with the standard depth-damage data provided by FHRC (e.g. Penning-Rowsell et al. 2003).

In Germany the engineering consultancy ProAqua developed an Access-based tool called **HWSCalc**. The interlinkage with a GIS-based system (HWSMap) was planned but not implemented.

In the Netherlands a GIS-based software tool called **HIS-SSM** (*Flood Information System – Damages and Casualties Module;* Huizinga et al. 2002) has been developed on behalf of the Highway and Hydraulic Engineering Department. It implements the meso-scale Dutch standard method for evaluating flood damages and casualties (Kok et al. 2002, 2004) and can be applied for the whole Netherlands. It is part of the *Flood Information System* (HIS) which also includes other modules like for example a flooding simulation.

Another GIS-based software tool developed for decision support on the regional level is **MDSF** (*Modelling and Decision Support Framework*; DEFRA et al. 2004) in the UK. It includes a tool for the calculation of economic damages based on the standard damage data from FHRC.

An example from the Czech Republic is the *Flood Analysis Toolbox* (**FAT**) developed by the engineering consultancy DHI for the Morava Waterboard (Biza et al. 2001). It comprises a whole CBA tool including a GIS-based damage evaluation tool.

3.5.5 Documentation of uncertainties

Although good progress has been made over the last years to improve the precision of ex-ante flood damage evaluation, the results of even very sophisticated methods are still fairly approximate estimations (see also chapter 2.6).
Uncertainties in the results may arise from the land use data, the value assessment, and last but maybe most importantly from the susceptibility data, i.e. the damage functions. These uncertainties are caused for example by generalization and categorisation of land use data, the usage of aggregated data on asset values, a small empirical basis of damage data or faults and inaccuracies in the basic data used or in the methods to evaluate them (see also USACE 1996, chapter 6).

As it is simply impossible to estimate future flood damages exactly, the uncertainty of the damage estimate of the respective study should at least be documented. After all it is the goal of damage evaluation to support flood risk management and it would be a bad decision support if precision is pretended, when uncertainties are high. Consequently, the amount of measurement uncertainty in the results should be known by the decision makers or the public (Merz et al. 2004, p. 154). This is all the more important, as these uncertainties vary strongly among damage evaluation methods of different scale. Finally, if decision makers know how certain or uncertain the damage evaluation estimates are, they can judge for themselves, if these estimates are sufficient as a decision criterion for their decision. For example, a very approximate damage estimate might be sufficient for a high level strategy decision but not for the assessment of concrete protection measures.

USACE (1996, chapter 6) describes some approaches to document the uncertainty of flood damage evaluation parameters. E.g., if building values are assessed by expert judgement, minimum and maximum values can be estimated to show the range in which the real value most likely lies. If, for example, a sample of building values of a certain building class is at hand also other parameters of variability like the standard deviation can be calculated.

Merz et al. (2004) carried out an analysis of ex-post damage data from the German HOWAS-database, revealing an "enormous variability" of the depth-damage data. They furthermore state that damage estimates for single buildings on that basis are highly uncertain. This uncertainty decreases with an increasing number of buildings under consideration.

Examples for the integration of uncertainty parameters in damage evaluation would be for example the MCM in England (Penning-Rowsell et al. 2005). The depth-damage data for non-residential properties includes high and low susceptibility bands. The residential depth-damage data of the MCM includes a confidence interval for the absolute damage estimates.
In the damage evaluation methods developed by Satrapa et al. (2005) both, for asset values and susceptibilities, a minimum and maximum value is calculated to describe the variability within each building class and thereby document the uncertainty in the damage estimation.

However, the benefit-cost ratio is perhaps the best indicator of the confidence which can be placed in the decision as to what to do. A benefit-cost ratio of one is the point of maximum doubt: no distinction can be made as to the desirability of the proposed option as compared to the do nothing case. The further away from one is the benefit-cost ratio, the greater the confidence that can be placed in the choice of the do something or do nothing option (Green 2003).

3.6 Typical, exemplary approaches on different levels

In the foregoing chapters background information was given for each of the steps of damage evaluation introduced in chapter 3.1. In particular chapter 3.3 showed a spectrum of methods to derive land use data, asset values and damage functions. The purpose of this last chapter is now to show some comprehensive approaches, i.e. to illustrate in some typical examples, how these elements can be combined. But there are of course also other possibilities and intermediate ways how the different parts of the methods can be combined.

In the following, three or four approaches will be briefly described on each spatial level (macro, meso and micro). These approaches are examples for good practice in several European countries. However, it should be noted that **maybe none of these approaches is perfect**. E.g. some of these approaches are using damage functions derived from old databases or others do not consider all relevant damage categories. Nevertheless, they can be a good starting point for finding and creation of an appropriate method.
Each method is summarized in one table, showing the basic procedure. As not only the spatial level matters for the choice of an appropriate method, also the other aspects mentioned in chapter 3.2, i.e. the objective of the study and the availability of resources and pre-existing data will be taken into account. Figure 3.4 in chapter 3.2 gives guidance how to choose an appropriate approach.

The last chapters showed, that damage evaluation approaches differ – beyond other aspects – mainly in two points:

- Regarding the type of damage functions used: Either **relative damage functions** are used in combination with the assessment of the total value of assets at risk or **absolute damage function**s are applied.
- Regarding the spatial resolution: Either **single properties** ("object-oriented" or "property-by-property-approach") or **aggregated land use units** are considered.

The exemplary approaches show that it is possible to follow each of these variants on each scale level. Nevertheless, there is a trend in current European practice that, firstly, relative damage functions are combined with aggregated land use data and absolute damage functions are combined with object-oriented data and, secondly, object-oriented data is more likely to be used in small scale studies.

Table 3.7 shows an overview of the recommended approaches with a short characterisation. The numeration of the approaches within each scale level is of course no ranking, but should just allow a clear naming and differentiation. Most of the methods mentioned are also described in greater detail in Meyer & Messner (2005).

Table 3.7: Overview of the typical, exemplary approaches

		Example	Land use data	Determination of values of assets	Damage functions
macro	**1**	**Rhine atlas** (IKSR 2001)	aggregated data (Corine Land Cover)	approximate values for each land use category	relative
	2	**National appraisal of assets at risk (NAAR, UK)** (DEFRA 2001)	object oriented data (National property dataset)	-	Weighted Annual Average Damages
	3	**RASP High level methodology** (Sayers et al. 2002)	object oriented data (National property dataset)	-	absolute
meso	**1**	**German meso-scale approach** (Colijn et al. 2000; MURL 2000, etc.)	aggregated data (ATKIS-DLM)	- aggregated data from official statistics - disaggregation to land use units	relative
	2	**Dutch Standard Method** (Kok et al. 2004)	- aggregated data - geomarketing data	- approximate values per unit of each damage category - calculated from official statistics	relative
	3	**MDSF (UK)** (DEFRA et al. 2004)	object oriented data (National property dataset)	-	absolute
	4	**DWA-approach (Germany)**	object oriented data (cadastral data)	-	absolute, region-specific
micro	**1**	**MERK, German Coast** (Reese et al. 2003)	object oriented data (field surveys)	official building assessment guidelines	relative
	2	**Multi Coloured Manual, UK** (Penning-Rowsell et al. 2003) **Danube study, Germany** (ProAqua et al. 2001)	object oriented data (field surveys)	-	absolute
	3	**Czech method 3** (Čihák et al. 2005)	object oriented data (field surveys, address-point data, cadastral maps, also aggregated data)	values on building components from official statistics	relative
	4	**DWA-approach (Germany)**	object oriented data (field surveys)	-	absolute, region-specific

3.6.1 Damage evaluation approaches on the macro level

The approaches recommended in this section are considerably approximated methods, mostly developed for the application in large areas or for quick overviews.
Regarding **step 1** of damage evaluation (chapter 3.2) we therefore recommend the application of these methods if one or more of the following aspects are given (see also figure 3.4):

- **Spatial scale**: The following approaches should be chosen if large areas of national or even international size are considered. Also an application on the regional level is possible, for example for a quick, approximate overview.
- **Objective**: These approaches provide a relatively low level of precision and are therefore suitable to give a broad overview of the estimated amount of damages, for example for the justification of flood protection funding or a resource allocation. For the appraisal of concrete projects these approaches are generally not precise enough. At the most, a quick prioritisation of projects is possible.
- **Availability of resources**: These approaches require relatively low effort per unit of area.
- **Pre-existing data:** Basic data requirements of the selected approaches are described in each table. If some of this data already exists the selection of this approach seems to be advisable.

Table 3.8 Approach macro 1

	Example	**Damage Evaluation for the whole River Rhine (IKSR 2001)** (see also: Flood Protection Plans of Saxony (LTV 2003)
Step 1	**Data requirements**	- approximate values per land use category from other studies - aggregated land use data source
Step 2	**Damage categories considered**	- The approximate values per land use category should include all direct tangible asset categories. I.e. not only values of buildings and inventories, but also infrastructure, agricultural assets, cars etc.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- An **aggregated land use data** source like **CORINE Land Cover** (see chapter 3.4.2.4) is needed. Within IKSR, about 5 land use categories derived from CLC are used. - If at hand also a more detailed aggregated land use data source with more categories can be used. - In Saxony biotope-type data is used.
	Determination of values of assets	- **Approximate asset values per square metre** for each land use category used have to be derived from other studies. Within IKSR results from small scale damage evaluation studies are used and transformed to the CLC categories. - It has to be assured that the approximate values have been evaluated correctly and reflect depreciated values. - The approximate values have to be adjusted to regional economic conditions. GDP or purchasing power can be used as an indicator here.
	Damage functions	- 5 **relative depth-damage functions** are used, which are matched with the land use categories used. - These damage functions are derived and adjusted from the HOWAS database (see chapter 3.4.4.3), i.e. empirical damage data is used. - It would be also possible to use synthetically derived damage functions.
Step 4	**Damage calculation and presentation**	Within IKSR results are presented as damage amounts for extreme events by means of approximate damage mapping.

Table 3.9: Approach macro 2

	Example	Weighted Annual Average Damage Approach (WAAD), e.g. NAAR (DEFRA 2001, see also chapter 4, Annex 1)
Step 1	**Data requirements**	- weighted annual average damages - property database
Step 2	**Damage categories considered**	- The method described here just evaluates damages to properties (buildings and inventories). - Methods for an approximate estimation of damages on infrastructure like streets and railways should be added.
Step 3	**Inundation characteristics needed**	Only **inundation area** is required.
	Land use data	- Object-oriented information on single properties is used (the **National property dataset**, based on address-point data). - At least residential and non-residential properties should be differentiated.
	Determination of values of assets	- **not needed**
	Damage functions	- Instead of depth-damage functions **WAAD** are used. These show the annual average damages to properties, independent of inundation depth. - WAAD are derived from empirical flood damage data. The derivation is explained in greater detail in chapter 4, annex 1.
Step 4	**Damage calculation and presentation**	In contrast to all other approaches, the WAAD approach does not evaluate damages for single specific flooding events. Instead annual average damages due to all possible events are estimated directly (see chapter 2.3)

Table 3.10: Approach macro 3

	Example	**RASP high level methodology (Sayers et al. 2002)** Czech method 1 (Satrapa et al. 2005)
Step 1	**Data requirements**	- property database - damage database
Step 2	**Damage categories considered**	- The method described here just evaluates damages to properties (buildings and inventories). - Methods for an approximate estimation of damages on infrastructure like streets and railways should be added.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- Object-oriented information on single properties is used (the **National property dataset**; see chapter 3.4.2.3). - At least residential and non-residential properties should be differentiated. The National Property Database allows furthermore a differentiation of non-residential properties in more than ten different branches.
	Determination of values of assets	- **not needed** (the value of the assets at risk is integrated in the absolute damage functions
	Damage functions	- two or more **absolute damage functions** (depending on the differentiation of land use data), representing sector averages. - These stem from the damage database from the Multi-Coloured Manual (Penning-Rowsell et al. 2003; see chapter 3.4.4.3), a synthetically derived database.
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping
	variants	**Czech method 1** (Satrapa et al. 2005) for macro scale damage evaluation: Based on results from a very detailed approach (see micro 3) approximate damage functions are derived for five different building types. This approach uses solely secondary land use data (address-point data, aggregated land use data etc.), i.e. no site surveys are required.

3.6.2 Damage evaluation approaches on the meso level

The three approaches recommended tend to be somewhat more precise than the macro approaches described above but will also require more effort.
Regarding **step 1** of damage evaluation (chapter 3.2) we therefore recommend the application of these methods if one or more of the following aspects are given:

- **Spatial scale**: The following approaches are mainly developed for the application on the regional level.
- **Objective**: Approaches of this scale are suitable to give slightly more detailed information on expected damages. Regarding their level of precision they are also appropriate for the justification of funding and resource allocation, but furthermore for evacuation planning, spatial planning or the identification of hot spots. Additionally, they can be used for an approximate appraisal of protection measures, e.g., for a prioritisation of planned measures.
- **Availability of resources**: These approaches require medium effort per unit of area.
- **Pre-existing data:** Basic data requirements of the selected approaches are described in each table. If some of this data already exists the selection of this approach seems to be advisable.

Table 3.11: Approach meso 1

	Examples	**German meso-scale approaches (e.g. Klaus & Schmidtke 1990, Klaus et al. 1994) Coast of Schleswig-Holstein (Colijn et al. 2000) Rhine in North Rhine-Westphalia (MURL 2000) Jade-Weser Estuary (Mai et al. 2004)**
Step 1	**Data requirements**	- aggregated land use data - aggregated data on value of assets from official statistics
Step 2	**Damage categories considered**	- official statistics mainly provide data on fixed assets (buildings and equipment) - Other categories (household goods, inventories, infrastructure, cars etc.) have to be added from other sources (adjusted insurance values, expert information, literature etc.)
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- **Aggregated land use data** like the German ATKIS (see chapter 3.4.2.4) - At least 5-10 different categories should be used. - Additional small scale socio-economic data could be added for example from geomarketing data (chapter 3.4.2.5)
	Determination of values of assets	- Aggregated data on fixed assets from **official statistics** on state level is used and broken down to municipality level (see chapter 3.4.3.3). - The value of each asset category or economic branch is then further disaggregated within the municipalities to corresponding land use categories ("spatial modelling", see chapter 3.4.3.3). - Geomarketing data can be used for a refinement of this spatial modelling (see chapter 3.4.3.3).
	Damage functions	- 5-10 **relative depth-damage functions**, matching with the asset categories used - These can be derived either from real damage databases or synthetic data.
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping.

Table 3.12: Approach meso 2

	Examples	Dutch standard method (Kok et al. 2004)
Step 1	**Data requirements**	- aggregated land use data - additional land use data, like e.g. geomarketing data - official statistics on asset values
Step 2	**Damage categories considered**	- buildings - inventories - infrastructure - cars - agriculture
Step 3	**Inundation characteristics needed**	For different scenarios: - area - depth - velocity, waves (here only considered for damage estimation for residential building damages)
	Land use data	- A mix of different data sources is used: **Official aggregated land use data** is supplemented by **geomarketing data** on buildings and employees in economy, as well as by official data on the street and railway network (see chapter 3.4.2.4). - All sources are merged to one file, presenting land use information for the whole country in a 100 metre grid.
	Determination of values of assets	- approximate total assets values (maximum damage) per unit (either per square metre of land use category, metre of street/railway, per flat or employee are calculated for the whole country. - Mainly **official statistics** on assets values are used which are broken down to the units described above, but also insurance values or other publications.
	Damage functions	- 11 **relative depth-damage functions** are used, which can be assigned to asset categories. - The functions are derived synthetically, but also based on some ex-post damage data. - For residential buildings, the damage functions also consider velocity and waves
Step 4	**Damage calculation and presentation**	- Damages can be calculated for each grid cell and therefore easily presented in maps. - A standard GIS-based software tool (HIS-SSM) has been developed to facilitate damage calculation and mapping. It already contains land use data and damage functions.

see also: Huizinga et al. 2002; Briene et al. 2002; Kok et al. 2002

Table 3.13: Approach meso 3

	Examples	MDSF (UK) (DEFRA et al. 2004) Czech method 2 (Satrapa et al. 2004; Čihák et al. 2005)
Step 1	**Data requirements**	- property database (address-point data) - damage database
Step 2	**Damage categories considered**	- The method described here just evaluates damages to properties (buildings and inventories). - If other categories, like infrastructure, cars or agriculture should be included, methods for an approximate estimation of these categories have to be added.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- Object-oriented information on single properties is used (the **National property dataset**, see chapter 3.4.2.3). - The National Property Dataset distinguishes residential and non-residential properties and allows furthermore a differentiation of non-residential properties in more than ten different branches.
	Determination of values of assets	- **Not needed,** because the value of the assets at risk is integrated in the absolute damage functions. Nevertheless, the National Property Dataset contains information on the rateable value of properties.
	Damage functions	- 10 or more **absolute damage functions** (depending on the differentiation of non-residential properties used), representing sector averages. - These are taken from the damage database from the Multi-Coloured Manual (Penning-Rowsell et al. 2003; see chapter 3.4.4.3), a synthetically derived database.
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping. - MDSF (Modelling and Decision Support Framework) is a GIS-based software tool for damage calculation and mapping (see chapter 3.5.3).
	variants	**Czech method 2** (Satrapa et al. 2005; Čihák et al. 2005), which was used in the Czech Republic for a nationwide appraisal of flood protection measures. Based on results from a very detailed approach (see micro 3) approximate damage functions are derived for five different building types. This approach uses mainly secondary land use data (address-point data, aggregated land use data etc.), i.e. site surveys are only carried out in special cases.

Table 3.14: Approach meso 4

	Examples	German DWA-approach (Buck 2006, DWA 2007)
Step 1	**Data requirements**	- Object-oriented land use data (can also be collected in field surveys)
Step 2	**Damage categories considered**	- Residential properties (Buildings & inventories) - Non-residential properties (Buildings & inventories)
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- Information on type and age of residential and non-residential properties from secondary sources, e.g. the German ALK cadastral data
	Determination of values of assets	- Not needed
	Damage functions	- Building type-specific damage functions are derived synthetically by expert assessors for the most common building types in the region (on-site investigation for a random sample)
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping (for each object).

3.6.3 Damage evaluation approaches on the micro level

The approaches described in this section will provide the most detailed and precise results but are on the other hand the most extensive and time consuming approaches. Nearly all of them will for example require field surveys for the collection of land use information.
Regarding **step 1** of damage evaluation (chapter 3.2) we therefore recommend the application of these methods if one or more of the following aspects are given:

- **Spatial scale**: Due to the effort required to carry out these approaches they are mostly restricted to areas of local scale
- **Objective**: Because of the relatively high level of precision provided by these approaches they are appropriate for objectives like detailed project appraisals, prioritisation of projects, evacuation plans and detailed information of policy makers and the public.
- **Availability of resources**: These approaches require a high effort per unit of area.
- **Pre-existing data:** Basic data requirements of the selected approaches are described in each table. If some of this data already exists the selection of this approach seems to be advisable.

Table 3.15: Approach micro 1

	Examples	**MERK (Germany) (Reese et al. 2003)**
Step 1	**Data requirements**	- Assessment guidelines for buildings - Maps of ground floor area of buildings
Step 2	**Damage categories considered**	- The basic method described in this table estimates values of buildings - other categories have to be assessed from other sources: - e.g. household goods from insurance values - e.g. equipment and inventories from surveys, interviews or publications
Step 3	**Inundation characteristics needed**	For different scenarios: - area - depth
	Land use data	- Information on type, age, height of residential and non-residential buildings has to be evaluated in **field surveys** (see chapter 3.4.2.3) - More than 50 building types are differentiated in this way. - Ground floor area can be derived from topographic maps - As an alternative to surveys cadastral maps might be used.
	Determination of values of assets	- Values per square metre of different building types can be derived from **official assessment guidelines** (see chapter 3.4.3.3 D) - The total value of each building is then determined by multiplication by the ground floor area. - Other asset categories have to be evaluated from other data sources like insurance values, interviews, publications etc (see above).
	Damage functions	- MERK uses about 10 **relative depth damage functions** (different building types, equipment and inventory, cars etc.) - The functions are derived and adjusted from the German HOWAS database, i.e. real damage data (see chapter 3.4.4.3). - An application of synthetically derived functions would also be possible
Step 4	**Damage calculation and presentation**	- Results can be presented as total damage amounts per municipality or in damage maps (in MERK by a 250 metre grid).

see also: Sterr et al. 2005

Table 3.16: Approach micro 2a

	Examples	Project appraisals UK (MCM; Penning-Rowsell et al. 2003)
Step 1	**Data requirements**	- absolute damage functions
Step 2	**Damage categories considered**	- The method described here just evaluates damages to properties (buildings and inventories). - Methods for an approximate estimation of damages on infrastructure like streets and railways should be added.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth - duration
	Land use data	- Information on type and age of residential and non-residential properties have to be evaluated in **field surveys**. - Additionally, data on social status of households could be derived from census data - Up to 100 residential and up to about 50 non-residential properties types can be distinguished.
	Determination of values of assets	- **Not needed,** because the value of the assets at risk is integrated in the absolute damage functions.
	Damage functions	- About 120 **absolute damage functions**, representing each residential and non-residential property category mentioned above. - These are taken from the damage database from the Multi-Coloured Manual (Penning-Rowsell et al. 2003), a synthetically derived database (see chapter 3.4.4.3).
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping (for address-points). - The ESTDAM software tool has been developed to calculate damages from the standard depth-damage data.

Table 3.17: Approach micro 2b

	Examples	**Danube study (ProAqua et al. 2001)** Flood Action Plans North Rhine-Westphalia
Step 1	**Data requirements**	- absolute damage functions
Step 2	**Damage categories considered**	- The method described here just evaluates damages to properties (buildings and inventories). - Methods for an approximate estimation of damages on infrastructure like streets and railways should be added.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- Information on type and age of residential and non-residential properties has to be evaluated in **field surveys**. - Additionally, topographic or cadastral maps can be used. - About 20 residential and non-residential properties types are distinguished.
	Determination of values of assets	- **Not needed,** because the value of the assets at risk is integrated in the absolute damage functions.
	Damage functions	- About 20 **absolute damage functions**, representing each residential and non-residential property category mentioned above. - The functions are derived from the German HOWAS database, i.e. real damage data (see chapter 3.4.4.2). They are furthermore adjusted by insurance data.
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping - The software-tool HWSCalc has been developed to facilitate damage evaluation

see also: Beyene 2000, BWK 2001

Table 3.18: Approach micro 3

	Examples	Czech method 3 (Čihák et al. 2005)
Step 1	**Data requirements**	- damage database - different land use data sources - data on asset values
Step 2	**Damage categories considered**	- The most sophisticated damage evaluation method described here evaluates building damages. - Other damage categories are evaluated in a little less detail (household goods, industrial equipment & inventories, technical infrastructure, agricultural damage.
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- A **mix of several data sources** is used: - Topographic maps - address-point data (with information on inhabitants and households) - register of firms - orthophotos - cadastral maps - additionally, **field surveys** are carried out to evaluate building type and height of storeys - About 200 different building types are differentiated
	Determination of values of assets	- Values per cubic metre per storey for different building categories are calculated based on official data on building component prices. - The total value per storey can than be calculated by multiplication by the storey height and ground floor area. - Other asset categories (household goods, equipment and inventories, technical infrastructure) are evaluated also by official statistics or surveys
	Damage functions	- For buildings, about 200 different relative depth-damage function are derived synthetically, adjusted by actual damage data
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping (for each object).

Table 3.19: Approach micro 4

	Examples	German DWA-approach (Buck 2006, DWA 2007)
Step 1	**Data requirements**	- Object-oriented land use data (can also be collected in field surveys)
Step 2	**Damage categories considered**	- Residential properties (Buildings & inventories) - Non-residential properties (Buildings & inventories)
Step 3	**Inundation characteristics needed**	For events of different frequency: - area - depth
	Land use data	- Information on type and age of residential and non-residential properties have to be evaluated in **field surveys**.
	Determination of values of assets	- Not needed
	Damage functions	- Object-specific damage functions are derived synthetically for every property by expert assessors.
Step 4	**Damage calculation and presentation**	- Results can be presented as damage amounts or by damage mapping (for each object).

3.6.4 Conclusion

As we already stated above, we do not intend to recommend unified damage evaluation approaches in the EU with these guidelines. The choice of an appropriate method depends on too many different factors and not least on the data availability, which still varies considerably among EU member countries. Consequently, this chapter on direct, tangible damage evaluation provides a set of possible best practice approaches, so that the most appropriate could be selected and adjusted to national or regional conditions.

Nevertheless, it should be noted that the hierarchical system of damage evaluation methods used in Britain (macro 3, meso 3, micro 2a) seems to be the most sophisticated in Europe at the moment. Based on an object-oriented land use database and a synthetically derived database of damage functions, very detailed damage estimations could be carried out here from the local to the national level, all based on the same data. A similarly hierarchical system has also been developed in the Czech Republic over the last years. In the long run, the development of such a system of object-oriented damage evaluation methods seems to be advisable. However, the application of these methods presumes the existence of a) a detailed land use database and b) a detailed damage database. The following chapter 4 will give guidance on the development of damage databases. An alternative – not only for countries in which such a database does not exist yet – is the application of the DWA-approach (meso 4 & micro 4). Here, the pre-existence of a damage database is not necessary as region-specific depth-damage functions are created within each study.

Last but not least, table 3.18 provides a checklist for all methods of direct, tangible flood damage evaluation, summarizing some of the most important points to remember from each step.

Table 3.18: Checklist for direct, tangible damage evaluation studies

Step 1	**Spatial Scale**	- For which area do I have to evaluate potential flood damages? - Is this area of local, regional or national size?
	Objective	- **What is the objective of the study?** - Are detailed results required or are approximate results sufficient to achieve this objective?
	Availability of resources	- How much time and money is available to carry out the study?
	Pre-existing data	- Which data required for damage evaluation is already pre-existing (inundation data, land use data, asset values, damage functions)? - Of which type is that data? Can it be combined? - Which data has still to be gathered?

Step 2	**Damage categories**	Are the main damage categories considered?
		- Residential properties:
		  - buildings
		  - household goods
		- Non-residential properties:
		  - buildings
		  - machinery and equipment
		  - inventories (stocks)
		Also the following categories should be taken into account somehow, especially if it can be expected that they make up a significant damage share:
		- Infrastructure: Streets, railways (mainly if flash flood areas are considered)
		- Vehicles, cars
		- Agricultural products: livestock, crops

Step 3	**Inundation characteristics**	- Minimum required: area & depth. - To receive more detailed results, also other characteristics, like duration and velocity can be helpful. - To calculate annual average damages, at least three events with different return period (e.g. HQ 10, 100, 200) have to be considered.
	Land use data	- Data on number, location and type of assets at risk is needed - This can be derived either by field surveys or from secondary sources, like address-point data, cadastral maps or more aggregated land use maps - It should be checked if all damage categories included in the study are included in the land use data source used or if additional sources have to be integrated - The categorisation of land use types should be matched with the asset categories and damage functions
	Determination of values of assets	- The total value of assets only has to be determined if relative damage functions are used. - In an economic analysis depreciated values, not full replacement values should be used to describe asset values. - Possible sources: other studies, official statistics or object-oriented assessment.
	Damage functions	- Is there a suitable & reliable damage function at hand for every land use / asset category? - Possible sources: derivation from damage databases (see chapter 4); creation of study-specific functions; transfer from other studies
Step 4	**Damage calculation and presentation**	- Damage values should express depreciated values, not full replacement values. - Uncertainties in the results should be documented.

4. Developing flood damage databases

Contributed by Edmund Penning-Rowsell

4.1 Introduction

This chapter reviews the development of databases for flood damage data, which has been one way that user-friendly systems have been developed by researchers to make flood damage data accessible to end-users. In that respect it is not easy to separate the development of databases and the systems of data analysis that they serve, so to an extent these are discussed together here, inevitably involving some repetition of material covered in other chapters.

In terms of rationale, one of the principal purposes of developing flood damage databases is to ensure policy consistency. If flood risk management (or flood defence) projects are assessed using the same sort of data, then there will be fair comparison between flood warning systems, flood defence arrangements, land use planning and other non-structural measures (Defra, 2004, 2005).

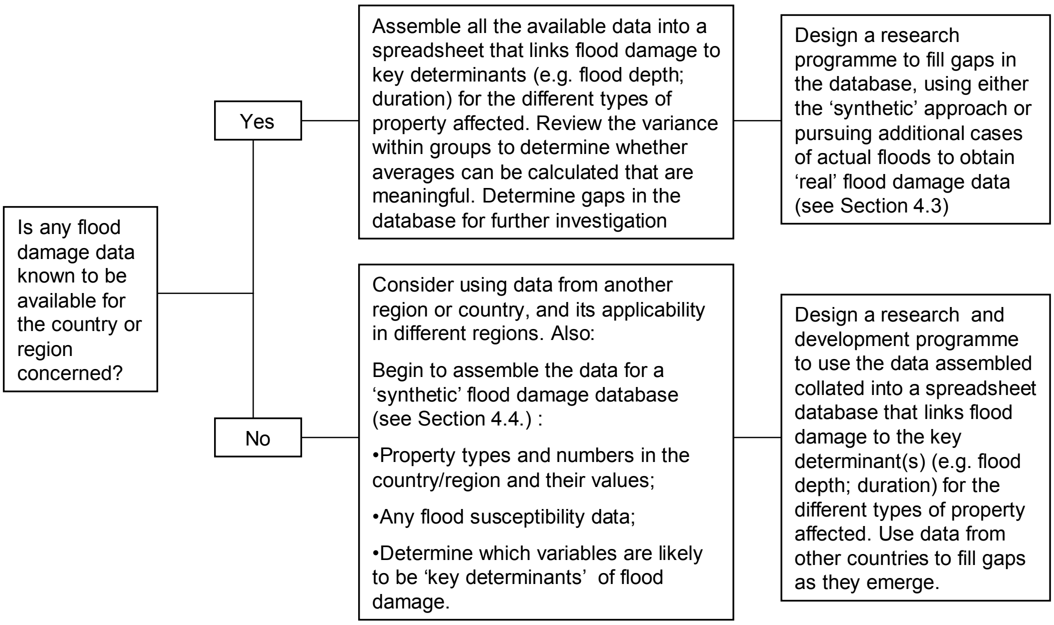
This has occurred in the UK over the last 28 years, following the production of the Middlesex University FHRC "Blue Manual" (Penning-Rowsell and Chatterton, 1977). Such a move was supported by the UK government, which had to reassure the HM Treasury that the basis of investment appraisal was consistent across the country, and through time, hence the need for a consistent set of flood damage data (or more accurately, potential flood damage data).

In essence, therefore, one of the fundamental pre-requisites of a flood damage data base is a consensus as to the appropriateness of its data for prescribed purposes. If there is no such consensus, then the database will not be widely adopted, and the measure of consistency outlined above will be lost.

This in turn means that the flood damage database needs to be rigorously researched, preferably by an organisation which has no inherent interest in the outcome (unlike an insurance company, which will wish to see damage totals at the lowest possible), and with full knowledge of the consequences of flooding derived from a number of typical or important flood events.

However it is recognised here that some countries and some agencies are some way behind in this field. Some countries have no flood damage information that is collected systematically, and others have very rudimentary systems. One of the objectives of this part of the Floodsite project is to give guidance on the development of better systems so that consistency across Europe can be sought. Figure 4.1 gives a first overview how to proceed when building up a flood damage database. It is recognised in this respect that the use of data from other countries is difficult, and this approach should be used only after a careful review of that data and its derivation.

Figure 4.1: Early first stages in the development of flood damage databases



4.2 Why we need to develop flood damage databases

As indicated above, there are a number of different reasons why we should develop flood damage databases, and therefore a number of different uses to which these databases may be put (for a summary of these, see Chapter 1).

To a certain extent these different purposes require different sorts of data, or a different structure to the database, and this is something that needs consideration when designing systems to produce such a damage database.

4.2.1 Justification of public funding: Flood damage data for investment appraisal (economic values)

Flood defence and other flood risk management measures tend to be public goods: this is something provided by government, because in its provision it is impossible to prevent people benefiting from it, when it is provided, even if they are unwilling to contribute to its cost.

This tends to mean that flood defence or flood risk management is provided by governments or similar state organisations. Economies of scale are also important, and therefore the large capital resources available to government and state agencies encourages them to act to provide this public service.

For the appraisal of public sector investment in this respect (HM Treasury, 2003, 2005) national economic values are needed. This is because they need to match the locus of payment for these public services, which in the case of the UK comes from general taxation, even if it is routed through the Environment Agency, from the Department for the Environment, Food and Rural Affairs (Defra). If flood alleviation expenditure were from private sources (such as a factory providing defences for itself), then financial values for losses avoided would be appropriate to compare with the necessary costs (see 4.2.2 below).

Such economic values, with a national base, ignore transfers within the economy (such as taxation), and seek to determine the gains and losses to the nation as a whole from floods or from flood defence investment (see Chapter 2 for the key principles underlying this). Therefore, for example, the loss from one particular retail establishment of sales during a flood is likely to be compensated by gains elsewhere in the retail environment. One baker's shop loses, whereas another one gains (people do not generally consume less bread overall as a result of a flood).

Similarly, in the assessment of damage to domestic properties, the assumption is made that the loss during flooding is a function of a diminution of the pre-flood value of household contents. Therefore, for example, floor coverings may be damaged during a flood but the loss of value of those floor coverings in that flood is from the depreciated value of the floor coverings prior to the flood event.

Therefore in the UK we have coined the term "Average Remaining Value" to represent the depreciated value of the floor coverings and other household goods prior to a flood. In the UK, with some notable exceptions, the Average Remaining Value of these goods is 50% of their new value (excluding any taxation element). For certain goods such as DVD recorders or laptop computers the Average Remaining Value may be more than 50%, reflecting the fact that these goods are in general on average less than half way through their lives.

Bearing these points in mind, it is important in the construction of flood damage databases which are to be used for national economic investment appraisal of flood defence works undertaken by government or within the public sector that care is taken to exclude taxation and allow for the depreciation of values to pre-flood conditions (again, see Chapter 2). This is not a difficult process but has to be borne in mind right throughout the assembly of flood damage data and the construction of the necessary flood damage databases.

4.2.2 Private investment: appraisal for individuals or companies (financial values)

A comprehensive flood damage database should contain information for use by individuals or companies seeking to assess their exposure to a range of flood events. They may need to do that so they can take action themselves, or purchase insurance, or lobby governments to seek public sector investment in flood risk management measures. They may need this information, also, in order to see whether insurance is necessary at all, or whether they can take the risk of flooding and whether that risk can be accommodated within their business planning processes. So, information for the public should be one aim in designing flood damage databases (se Chapters 2 and 3).

In this case, flood damage data should be collected which excludes the depreciation of values to pre-flood conditions, because the loss of assets or other fittings and fixtures may have to be compensated for by the purchase of new equipment and new furnishings and fittings, thereby costing the company or individual concerns 100% of the replacement costs (including any purchase taxation such as VAT/TVA).

Similarly, if a flood damage database such as we are envisaging is to be used by individuals (perhaps to assess the worthwhileness of them taking action themselves), then the damage data values will have to include all taxation elements to be incurred in the repair and recovery operations following a flood (see Chapter 2). Financial values will need to be set at repurchase or replacement cost, and the full costs of repair and renovation of the fabric of the building itself.

Such a set of data, including all financial values, will make the flood damage database quite complex, because each individual property will have a range of different flood damage values, depending on the purpose to which the data is put.

In the case of retail or commercial organisations, financial values within the flood damage database will need to include all effects to the property and business concerned, irrespective of national economic values. These full effects, again, will include the replacement of equipment, fittings and furnishings at full replacement cost values, rather than values depreciated by use or by taxation. It will also include loss of trade at its full (financial) value.

4.2.3 Insurance rate settings (financial values)

Many insurance companies, and their associated data gathering organisations, collect flood damage data in order to assess premium levels and levels of risks to particular properties.

As with the investment appraisals for individuals/companies, above, financial values are needed here, because the insured will require or demand full replacement of assets damaged or destroyed during a flood. Naturally, loss adjusters will assess these damages, but increasingly with new-for-old insurance policies, householders and companies will demand full replacement with new fittings, fixtures and equipment, rather than the salvaging and repair or renovation of old assets harmed during a flood, as in the past.

For insurance purposes, it is often the case that damage data is needed for extreme events, including the demolition of property as a result of fast-moving flood waters. This is not common in the UK, but in continental Europe such flash flood conditions are not uncommon.

A re-insurance company, being the insurer of last resort, will need to know the maximum exposure of their portfolio of insurance contracts, so as to determine the viability of their total portfolio. What this means, in effect, is that any flood damage database to be used by insurance or re-insurance companies must include the full effects of extreme flood events which by any standard are rare. Re-insurance is usually not triggered until such a rare event occurs, and therefore its assessment of viability needs to be based on extreme flood damage data, rather than typical averages.

4.2.4 Flood damage data for warning prioritisation and evacuation planning (financial values)

Many flood warning schemes, within comprehensive flood risk management measures, are assessed on the basis of damage saving. These schemes may be either private sector initiatives, but are more commonly public sector systems.

Therefore, for these purposes, a flood damage database needs to include data on the damage-reducing effects of flood warnings (Parker, 1996). Such data is sparse, because there is relatively little research undertaken on this matter which looks at precisely what effects warnings have on damage reduction for particular types of household or company.

Recent research (Penning-Rowsell *et al.*, 2005) has sought to quantify the damage reducing effects of warnings and, to generalise, we have found that these have declined over the three decades over which FHRC has been operating.

In 1977 (Penning Rowsell and Chatterton, 1997) we judged that about 70% of total potential damage could be avoided as a result of flood warnings being delivered to individual householders or businesses. More recently (FHRC, 2005) we find that this value is much lower than hitherto we had appreciated. This may be because people are now not responding as well as they might do to flood warnings as issued, but perhaps it is more likely that it is a result of new-for-old insurance policies now being available, which discourage householders somewhat from taking action to reduce potential flood damage.

Be that as it may, any comprehensive flood damage database needs to contain data on realistic potential damage, assuming that warnings are given. In the UK, our experience is that flood damage reduction is not made much more efficient with many hours or even days of warnings; residents and other property owners tend to wait until flood waters are near to occupying their property before talking action, for fear that this action is unnecessary.

4.2.5 Land use planning (economic values)

Any sensible approach to planning the use of flood plain areas should take on board the damage potential of land uses allocated to such areas.

It is clearly sensible not to locate in flood risk areas properties which have high damage potential, but at the same time it might be sensible to allocate land uses such as recreational areas, car parks, nature conservation facilities to such areas, owing to the low damage potential and the benefits that come from locating these facilities in terms of opportunity costs.

Therefore some indication is necessary of the damage potential of these land uses in flood plain areas, so that sensible decisions can be made about land use and spatial planning allocations. This indicates that any flood damage database used for these purposes needs to have land use and property categories that are relevant to spatial planning processes and decisions.

4.2.6 Other purposes

It often cannot be anticipated what a flood damage database will be used for, and the sub-sections above give insight into many possible uses.

What has to be borne in mind, quite simply, is that whenever a flood damage database is constructed, the eventual purposes of that data are reviewed and the database organised and structured accordingly.

In this way the maximum potential use of the database is guaranteed, whereas it is often difficult to alter a database subsequent to its construction to fit a new use as it becomes appreciated.

4.3 Philosophy

There are different approaches to flood damage data collection and the presentation of these data in databases. The following include some of the different approaches adopted, reflecting different purposes and the availability of source data.

4.3.1 Real flood damage data

By the term ‘Real flood damage data’ we mean data that quantifies the impacts of floods that have occurred, after those events. This assessment is usually undertaken by quantity surveyors or loss adjusters, but sometimes through social surveys. Given the direct relation between the flood and this data, it is usually tempting to try to incorporate as much real flood damage data as possible from recently floods into a database.

The difficulty that we have experienced in the UK is that this often biases the results, by over-emphasising damage to building contents (which appear to be devastated following a flood), and underestimating long term effects on the building fabric. This is partly because the assessments of real flood damage data are usually done in the immediate aftermath of a flood, when salvage and other recovery values cannot realistically be known. Or it is done some time later, when damaged items may be missed but damage to the building becomes more easily identified. There is therefore no ideal time to do such an assessment of real flood damage to individual properties, and often the appraisal falls between two stools.

Having said this, it is obviously important to use insight and information obtained from real floods to populate any flood damaged database.

4.3.2 Synthetic approaches

By the term ‘synthetic’ we are deliberately making a contrast with the ‘real flood damage data’ (4.3.1 above), and these approaches are sometimes misunderstood. By the term “synthetic” we do not mean arbitrary or artificial. What we mean is that the approach involves a synthesis of all available data, from both secondary sources and from the real experience of floods.

This is the approach which had been adopted in the UK. Flood damage data is built up from an accumulation of knowledge about the effect of floodwaters on household or building contents and the effect on the fabric of the building and its repair and renovation. Many thousands of items of data are looked at in this respect, based on typical properties flooded to a range of depths from floods with different severities. In this way we can obtain data on the range of experiences that are likely in flood risk areas, rather than the one-off situations represented by individual actual (historical) floods.

This synthetic approach has the limitation that it is not necessarily applicable for measuring the effect of particular floods (all of which are likely to be different), and therefore experience of damage by particular owners in particular properties may not fit the average synthetic set of data. On the other hand there are advantages in that the synthetic data set can be more comprehensive than otherwise would be the case.

4.3.3 The unit area approach: The "absolute damage estimation approach"

This approach looks at individual properties and assesses damage per square metre of the floor space. We have found in the UK that this is appropriate for commercial, retail and industrial premises, where size is an important variable affecting flood damage potential. If residential properties vary widely in their floor plan area for a given type (e.g. detached properties), then this approach would also be appropriate here.

This approach can be adopted by those constructing real flood damage databases or using the "synthetic" approach above, and is simply designed to allow for one particular variable (size) in assessing flood damage potential.

4.3.4 The "relative damage functions" approach

This is a completely different approach (commonly they are termed "relative damage functions") and is used commonly in several continental European countries. The approach seeks to related flood damage to property values.

It uses the market value of the property concerned, preferably just for the building rather than the land the building occupies, and expresses flood damage potential as percentages of that value. Therefore, for example, a particularly serious flood might cause damage to the extent of 65% of the total value of the property concerned, if substantial rebuilding was necessary and majority of the contents were destroyed. A minor flood might result in just 10% of the property's value being representative of flood damages.

The advantage of this approach is simplicity, because many data sources are available on the value of property in flood risk areas. Thus in the UK we can use data from the Land Registry or from commercial databases to determine the value of both residential and industrial/commercial properties.

On the other hand, the market value of a property is related to the demand for that property (and, in the commercial sphere, goodwill values), and it is not necessarily correlated with flood damage potential. Thus some property might have substantial value because of the value of the land it occupies. In another case, the flood damage potential of a warehouse will be related more to the value of the contents of that warehouse rather than the value of the building itself. But property databases containing information on property value tend not to include the contents of the property, quite naturally, but only record the value of the land and buildings.

Nevertheless, and notwithstanding those limitations, this approach could well be one that is most applicable across Europe, rather than the unit area "synthetic" approach developed in the UK.

4.3.5 Weighted annual average damage approaches

One limitation of all the above approaches to flood damage potential is that it only records the damage from one particular flood event. Yet in many applications what we need to know is the total exposure of a property or land use item to the full range of floods that might cause it damage, thus recording its total hazard exposure.

To do this, it is necessary to incorporate flood probability into the assessment of flood damages. Ideally, the full range of flood probabilities need to be deployed, and the annual average damage calculated weighted by the appropriate flood exposure. This can be a complex operation, incorporating data from a range of floods, and in the UK has only been attempted on a regional basis. An example of such data set for the UK, developed by John Chatterton and incorporating the results from several dozen individual project appraisals, is given in Annex 4.1.

What this does is to weight damage potential by the probability of flooding of particular depths, taken from a range of project appraisals, resulting in the weighted average. This approach has the great advantage in producing data which calculates or records total exposure to a range of floods, but is a complex operation to achieve and requires considerable data to be successfully accomplished.

4.4 How to start building a flood damage database

A simplified structure for the construction of a flood damage database is contained in figure 4.2.

The essential ingredients and decisions involved here are as follows:

1. Values of the assets at risk.
2. The susceptibility of those assets to flood damage.
3. Key variables affecting the extent of damage, which are likely to vary in different flooding circumstances.
4. The level of aggregation of the data required.
5. Some information as to flood probability,
6. in order to convert event damages into annual average damages.

Steps 5 and 6 here are only necessary for Annual Average Damage calculation, not for event damage evaluation. A key difference here across countries experiencing different types of floods will be item 3 above (the key variables affecting the extent of damage).

In the UK experience, where floods are generally characterised as slow moving, slowly accumulating, shallow and short-lived, it is generally considered that flood depth is the most important variable affecting flood damage (other than flood extent, which brings properties into the flood risk area).

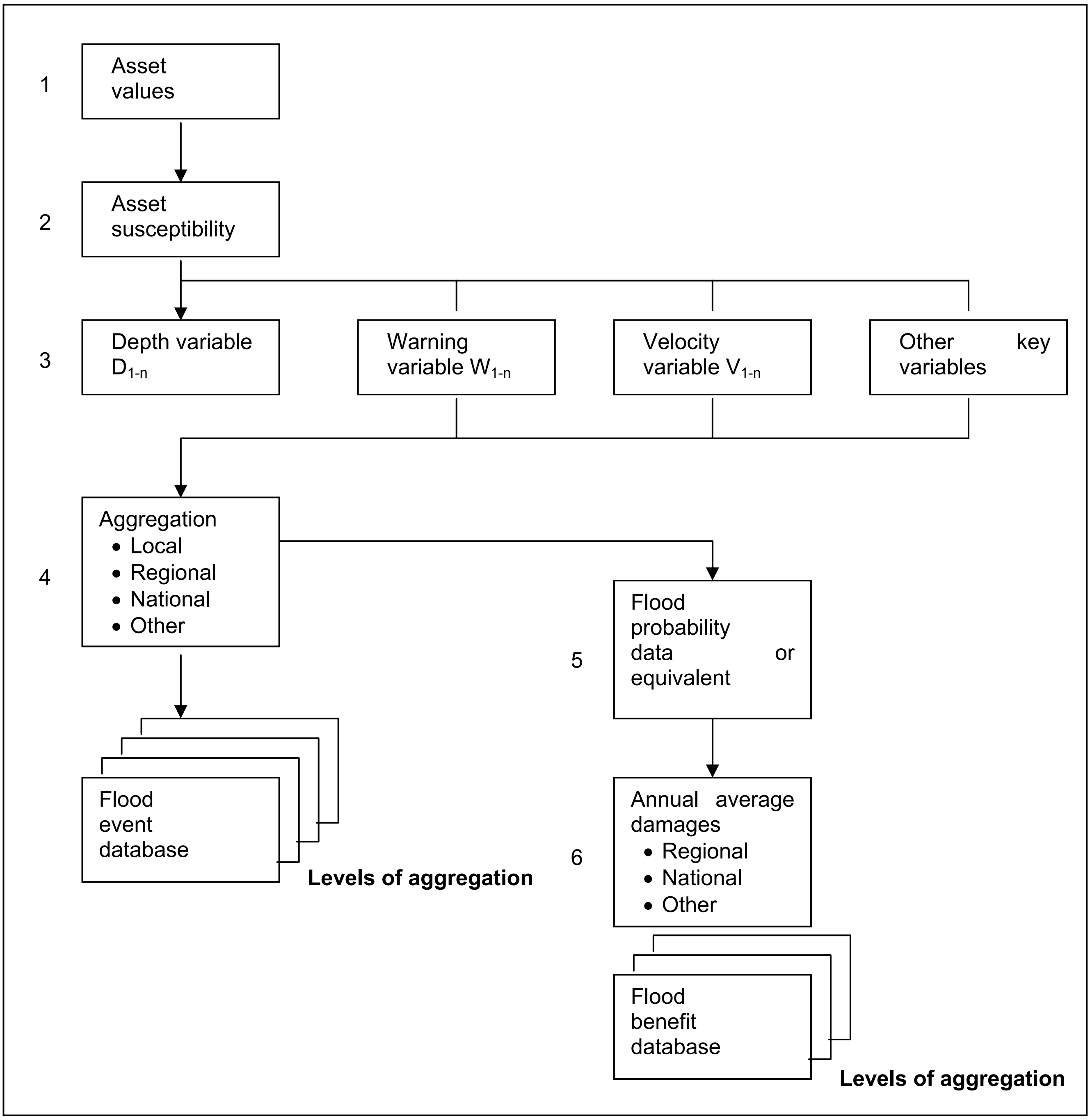
In other circumstances it will be other variables that dominate this calculus, such that, for example, in mountainous areas the flood water velocity might be the dominant characteristic, such that extra damage is caused where flood velocities are particularly high.

This point emphasises that appraisers will have to be aware of local circumstances when populating their flood damage database with appropriate data suitable for their circumstances.

4.5 Assembling the components of a flood damage database

As indicated in figure 4.2, a flood damage database is composed of a number of components. Each of these has to be considered when the database construction is evaluated, so as to facilitate easy incorporation of the data into the total system.

Figure 4.2: Simplified structure: flood damage database construction (synthetic approach)



4.5.1 Asset values and land use data

An important starting point for any flood damage database is the assets at risks (figure 4.2) and their value. These can be characterised from field surveys, secondary sources, or synthetically (see above).

What is needed here, is the market value of the assets at risk, including buildings, land and the contents of buildings. Other assets at risk could be infrastructure components, such as telecom facilities, water utilities and gas and electricity systems. These contribute to an assessment of the indirect affects of flooding, and it is not therefore the asset at risk that is important here but the value of that asset to maintaining the system provided by the infrastructure.

In terms of building contents, the asset value determines the maximum potential damage suffered by the facility or property at risk. In the UK, we have determined values by summing the total value of each component within the building (building repair operations and inventory values). An alternative approach (see above) is to assess the total value of the whole property, using market values or information from rateable or taxation databases.

The treatment of land here is problematic. Obviously, in a flood the land is not lost, but it could be damaged in some way. Contamination from sediments could occur or erosion might reduce soil depths or land stability. Notwithstanding this, the total value of land is likely to over-estimate considerably the potential flood damage, and therefore this item needs to be treated with caution.

Similarly, most floods do not damage buildings totally, although exceptions do occur. This means that the total asset value will over-estimate the flood damage potential, unless susceptibility values are appropriately determined (see below). In the same way, building contents represent maximum flood damage potential, and allowance needs to be made in the database construction for the damage reducing effects of flood warnings (see Section 5.3 below), because building contents damage will be thereby reduced.

As with all flood damage assessments, the treatment of taxation elements within values must also be approached cautiously. The implied value of inventory items in properties will be inflated by taxes such as Value Added Tax (TVA in France), yet the loss of these values are transfer payments rather than an opportunity cost. For financial damage evaluations, however, taxation has to be included, because this is the loss to the organisation or individual concerned. In almost all other circumstances, taxation has to be deducted from values.

Some values may be intangible. Thus historic buildings may have a value far greater than their repair and replacement cost, in the same way that the value of contents of buildings will include items of sentimental or nostalgic value for which market values inappropriately measure their true worth.

Finally, it must be remembered that some assets are movable, and therefore not necessarily potentially all at risk. Mobile homes and other facilities may be moved away from flood risk areas, given sufficient warning, and household and building contents may also be treated similarly.

4.5.2 Asset susceptibility for determining damage functions

It is generally easy to obtain information on the value of property at risk from flooding. Secondary source or even field surveys backed up by estate agent sources provide the appropriate access to that data.

Much more problematic is the susceptibility of property to flood damage (Figure 4.2). By "susceptibility" we mean the percentage loss or reduction in value with immersion by flood water. Thus, for example, a television may be completely destroyed and lose all of its value by immersion in flooding (susceptibility 100%), whereas a ceramic tile floor may suffer virtually no damage, or only require inspection to determine that no damage has occurred (susceptibility in this case might be measured as 5% of total value).

The concept of susceptibility should not be confused with Average Remaining Value measures of the depreciation in value of some items of property contents or fabric as a result of age; a five year old television might only be worth 20% of its purchase price as new. The Average Remaining Value of a DVD player might be 80% of its purchase price as new, because most DVD players are still less than 5 years old.

Susceptibility is assessed in many different ways. After a flood it is possible to assess the value of damage as the price new less the re-sale value of the flood damaged contents of that property, as determined by quantity surveyors or loss adjusters. Simple inspection may review items that are completely valueless after a flood (the television example), as above, or free from damage (the ceramic floor, above). In some cases considerable technical knowledge is required to assess susceptibility, such as the damage to a central heating boiler or antique furniture.

Therefore to assemble a database incorporating accurate or appropriate susceptibility values takes time, and the incorporation of specialist knowledge into the assessment of flood effects. Notwithstanding this, this is an essential stage, and has to be approached by assembling experts or specialists in the field or those with knowledge of valuation techniques (e.g. quantity surveyors) or insurance claims (loss adjusters). Often a "common sense" approach is necessary, for many items, leaving the residual difficulties to these specialists.

Flood damage potential is assessed as susceptibility times Average Remaining Value, since the damage potential is at pre-flood conditions, where items such as DVD players or televisions are part way through their lives. In the UK, an Average Remaining Value of 50% has generally been assumed but susceptibility values vary widely.

An additional dimension of the construction of a flood damage database is incorporating other key variables (see Section 4.5.3, below) thus, for example, in the UK flood depth is considered to be an important variable, and therefore different susceptibilities for different depths of flooding have to be determined. In the case of flood warnings, a similar approach would apply, varying susceptibility levels by duration of warning, or flood water velocities in the case of that being the determining variable.

4.5.3 Key determining variables: inundation characteristics

As indicated above (Section 3) certain key variables will determine overall flood damage potential in different circumstances, such as flood water velocity being the crucial variable in certain areas (e.g. mountainous regions), whereas in the UK the natural flood characteristics mean that flood depth is the one variable seen as critical in determining flood damage potential.

This means that the construction of a truly useful flood damage database will therefore depend on local circumstances. What is important is identifying the effects of these key variables on susceptibility values, or repair and renovation costs for building fabric operations, and assembling the appropriate information or expertise accordingly (Figure 4.2).

For example, in the UK, as indicated above, flood depth is seen to be the key variable. Therefore in the construction of the FHRC database considerable effort was expended in determining different susceptibility and asset values by height/depth within properties liable to flooding. This was done partly by field survey (in the early years of database construction), but also by consulting appropriate specialists (quantity surveyors; engineering surveyors; loss adjusters). The result was a suite of depth/susceptibility/asset curves, from which flood damage potential was calculated. The full details of this process cannot be covered here, but are to be found in the initial Manual produced by FHRC in 1977 (Penning-Rowsell and Chatterton, 1977; see also Penning-Rowsell et al., 2005).

It has to be recognised, however, that few floods in the UK exceed 1.0 metres in depth. Therefore while damage data and depth data is provided up to 3.0 meters of flooding in the FHRC database, the data items for depths of flooding greater than1.0 meters are rarely used. The situation may be very different to different countries, and in different circumstances. Therefore, for example, if flood warning lead time is the key determining variable, warning lead time may vary from a few minutes to many days or even weeks. Such a consideration will affect the way that data is collected and stored in the flood damage database.

4.5.4 Levels of aggregation

The fourth step in Figure 4.2 indicates that different levels of aggregation are possible and desirable within a flood damage database. Thus some data may be obtained on individual buildings, whereas others sum those values for localities, regions or indeed the whole nation.

The level of aggregation within the database is an important consideration determining the character of that database. The FHRC database at Middlesex University is highly detailed, and contains data at many different levels. However many project appraisal exercises require only data for a particular region, or even the nation as a whole. Nevertheless this aggregated data usually has to be built up from more detailed assemblages of information, containing individual properties from which higher level averages are derived. Again, much of it will depend upon the use to which the data is to be put.

In the context of the above, any high level averages need to be based on weighted data. Thus, for example, if one is assembling a database on residential flood data, from information obtained in specific localities perhaps concerning individual properties, then it is important to know the weights of those individual properties within the national total before calculating the weighted averages.

This is not a process that can be accomplished by field surveys. It will be important to have knowledge of the numbers of each type of property within the region or nation concerned, in order to derive the appropriate weights. Thus, for example, the number of detached, terraced and semi-detached houses is known to the whole of the UK, and these have been used as weights within the FHRC database. We also know the numbers of different types of non-residential properties in the indicative flood plain within England and Wales, based on postal information sources, and therefore that information can be used both as a sampling frame work for field surveys and as a basis for averaging data collected from particular localities or regions.

The process of aggregation would need to be pre-determined for the particular database being constructed. In general it is necessary to use information collected at as high a level of aggregation as possible, because this is likely to be more generally applicable than locally-based individual survey results. This assumes that some secondary source data is available on property types and numbers at a regional or national level, and this needs to be pursued vigorously in order to make the database as generally applicable as possible.

4.5.5 Incorporating flood probability data

All the above guidance has been designed to collect and aggregate flood damage data for damage from an individual flood event. This can be used in a number of ways, as indicated in Section 2 above.

However, increasingly it is necessary to assess the full exposure of property or land to a range of flood events likely to be experienced at that particular location. Thus a property exposed to a flood with a return period of 1 in 10 years will also be exposed to the flood that occurs once in 100 years. Many uses of flood damage data need to know the full range of risks and consequences, in the form of an annual average damage value. This is the potential flood damage from the full range of floods likely to be experienced at that location, including both the 10 year flood and the 100 year flood in the example above.

Incorporating flood probability data in this way is not easy. What one needs to know is the depth or duration or velocity of the individual floods from which the property is at risk (depending on the key variables: Section 5.3 above), and the consequences of those different events. In effect, a loss-probability curve has to be established for the individual property, from which the area under the curve is the value of the annual average damage. In addition, that annual average damage needs to be weighted by the appropriate property concerned, in the same way as described in the section on aggregation, above.

A full description of the calculation of weighted annual average damages is beyond the scope of this report, which is fundamentally concerned only with the construction of databases. Annex 1 gives an example of how this has been done in the UK, the principles from which could be extracted for applications elsewhere.

4.5.6 Aggregation of weighted annual average damages

In the same way that the flood event damage is aggregated for application at regional or national levels, so the weighted annual average damage values need aggregation.

This again depends upon exactly the same principles as contained in Section 5.4, by knowing the proportions of properties within different classes in the appropriate regions or nations involved. The result is a database of flood benefit values and different levels of aggregation for different types of application, mainly regional projects or national evaluations.

4.6 Data structure and formats, etc

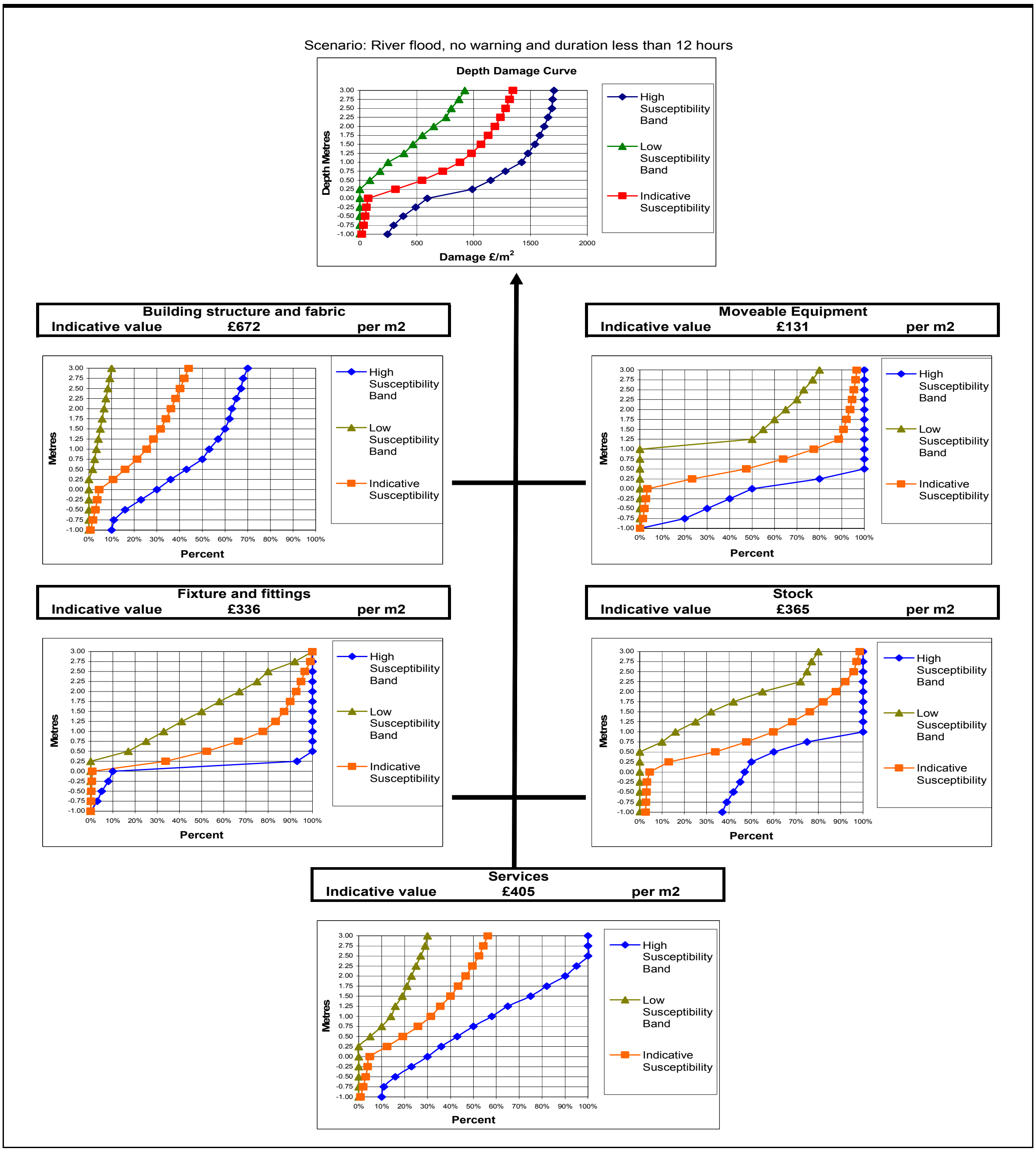
There can be no universal rules for the development of databases for flood damage, because they vary in the uses to which the data will be put and hence the required level of complexity of the database. However, there are perhaps some lessons from experience that warrant discussion:

- The database is likely to be used with other computer programs, so the data needs to be stored electronically.
- The most common use of flood damage data is with hydraulic models, seeking to assess damage potential for different flood extents and depths, so a common data structure relates flood damage to flood extent and depth.
- Perhaps the most flexible approach is to store the flood damage data in Excel spreadsheets, with flood depths as the columns and the different elements that make up flood damage in rows (damage to inventory items; clean-up costs; etc). One example of this is given in Figure 4.3.
- In this way the data can be converted into an Access database if this is desired, or used within Word documents.
- Procedures for up-dating the flood damage data need to be incorporated into the data storage system, so that up-dating can be a routine exercise.

Ion terms of the structure of the database, again some lessons from experience may be useful:

- The database needs to be structured in relation to the types of property that is covered, hence with Excel worksheets for different house types, non-residential property types, or other land uses.
- If this is done it is desirable to record also, if possible, the number of each of these property types within the country or region concerned, so that weighted high level averages can be derived for the nation or region concerned (e.g. the weighted damage for all houses, derived from flood damage data for each type and the number of each type in the country or region).
- The above approach allows the database to have a hierarchical structure: (a) detailed data and (b) data averaged across the database to produce these high level averages, so that the user can select the level of detailed required.
- It is not easy to incorporate all flood loss data in the same format. For example, data ion the indirect effects of floods may not be depth-related, hence the depth-related structure illustrated in Figure 4.3 may not be relevant.
- A similar format may then be needed that has flood duration as the columns of the database, rather than flood depth. In certain circumstances flood velocity will be a key determining variable or flood characteristic, and this may affect the structure of the database, with different velocity bands being used to contain different levels of flood damage.

Figure 4.3: Excel based system for structuring a non-residential flood damage database which has flood depth as the key determining variable or inundation characteristic.



Users need to consider carefully the above advice, and begin to structure their databases with at least the following fundamental characteristics:

- Electronic data storage
- The structure of the database related to its key variables and its potential use
- Consideration given at the initiation of the work to systems for up-dating the data in the database

4.7 Quality assurance procedures

Flood damage data can be manipulated to achieve certain aims (such as furthering levels of government investment for local communities). The data that therefore is used to ensure policy consistency needs to be quality-assured.

How this is best done will depend on local circumstances. The following are important:

- An audit trail back from the data to its sources
- Broad stakeholder acceptance of the data and the assumptions that have been used in its derivation
- Some form of peer review of the resulting data and its database
- An acceptance of the data by government (because much of its use will be related to government activities)

In addition, use over time brings confidence that the data is valid and dependable.

4.8 Updating routines

All data bases get out of date. Given that they are developed to ensure policy consistency over space and time, the updating of the data is important. What is needed is:

- Advice on price updating indices to use over a 1-5 year period
- Regular more systematic updates of the data sources on a 3-7 year cycle
- More fundamental updates and revisions to reflect new uses of the data on a 5-10 year cycle.

The first of these will depend on the nature of the database (i.e. its sources data) and the availability of relevant census bases updating indices on a regional or a national basis. The second and third items above depend upon a continuing research capability in the organisations responsible for the database and its maintenance.

Annex 4.1: Combined probability and flood damage data (i.e. assessing risk)[22]: Derivation of Weighted Annual Average Damages (WAAD)

Benefit appraisals of capital flood defence schemes usually involve detailed land use and property threshold surveys and in depth hydraulic and terrain modelling to determine potential flood depths for successive return period events.

However, it is not usual to have this data available when there is a call to prioritise, for example, maintenance expenditure for a range of urban benefit scenarios. Indeed the collection of this data for the myriad of scheme appraisals is usually out of context of the scale of the assessment. A representative method is therefore required for both routine justification of maintenance or indeed any broad scale modelling at the pre-feasibility level.

In the late 1980s the Flood Hazard Research Centre, in association with the then Gould Consultants (now Entec UK), during the research leading up to the development of Standards of Service data for Thames region of the National Rivers Authority, devised an algorithm to estimate for all property sectors (residential, and non-residential) the weighted average property damage data, irrespective of frequency and depth of flooding.

This normalisation of damage/frequency data was utilised in the derivation of House Equivalents, which became the cornerstone of Standard of Service evaluations in the NRA's Flood Defence Management Manual. This approach obviates the need for both property threshold levels and flooding threshold levels in the broad scale evaluation of annual average damages.

Research by J Chatterton Associates in the late 1990s[23] improved and extended the sample base in the derivation of weighted depth/damage data by flood frequency to some 9,000 properties within 14 flood plain locations, covering 11 flood return periods. Although the data utilised is restricted to the English Midlands, it fairly represents the typical damage that might be expected for selected UK flood events if there is no knowledge of the location of the property in the flood plain nor its threshold in relation to the flood hydraulic surface. Attempts to improve the database of properties in other locations of England and Wales did not noticeably change the weighted distribution function.

Summary details of this analysis are provided in Table A4.1 (for residential property) and graphically represented for 5 return period band groupings (see also figure A4.1).[24] The groupings illustrate that, taking a large property sample size, the resultant statistics represent expected patterns. Thus, the method 'quantifies the obvious' such that properties flooded frequently (5 and 10 year return periods) exhibit a skew to shallow flooding, whilst properties flooded rarely exhibit a skew to deeper flooding. Work done by FHRC in 2002[25], confirmed from a large sample of modelled flood events that the majority of property flood depths even in extreme flood events are less than 1.2 metres.

Depth/damage data from the 2003 MCM (Penning-Rowsell *et al.*, 2003) for both residential property (Sector Average) and Non Residential property (the 4 bulk classes defined by Valuation Office Agency (see Appendix to this Annex) were assigned to the appropriate depth banding within the flood depth distribution/flood frequency matrix (Table A4.1) and a weighted damage derived for each return period banding.

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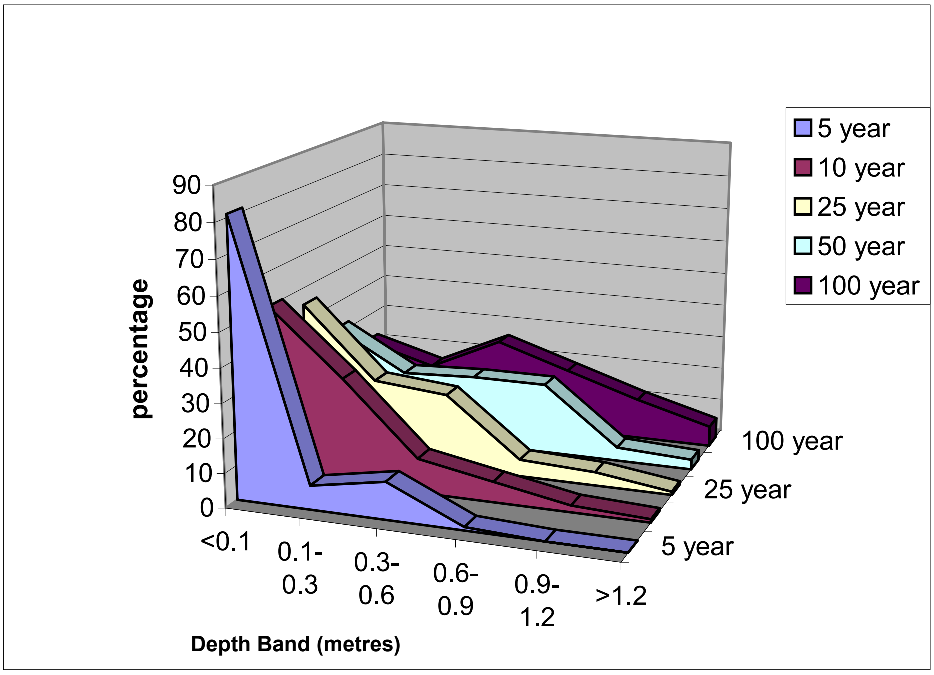
[22] John Chatterton, Birmingham, 15th November 2004
[23] JB Chatterton Associates: Maintenance Operations-Urban Benefits, R&D Technical Report W126, 1998
[24] Illustrated here for Residential property only
[25] Penning-Rowsell EC and Chatterton JB (2002) Flood Depth model: Development and specification, Unpublished report for Experian

Figure A4.1: Property Flood Depth Distribution by return period



Summing the weighted damage for each depth within each flood frequency return period gives the total weighted damage for that return period. The weighted annual average damage (WAAD) is derived in the normal way advocated by Defra guidance except the damage axis of the loss probability curve is represented by the weighted damage data for each return period (see Table A4.2)

Assuming no standard of protection for the flood plain to which the broad scale method is being applied then the weighted annual average damages for the 5 property types is as follows:

Property	***WAAD***
Residential	£3,847 per property
Manufacturing	£50/sq.m
Retail	£78/sq.m
Warehouse	£147/sq.m
Office/Other	£162/sq.m

Clearly, many flood plains have a degree of flood protection either natural or human made so the above figures should be reduced, depending on the threshold of flooding usually represented as a Standard of Protection. Table A4.3 provides WAAD values for successive degrees of protection with WAAD reducing as protection increases. The figures are not adjusted to account for breaching of flood protection standards.

NRP WAAD is area-dependent and the floor space of these properties can vary enormously from location to location. The floor space can be derived from statistics within Office of Deputy Prime Minister “Commercial and Industrial Floor space and Rateable Value Statistics 2003”. This data is available by Bulk class for each local authority, though the mean floor space for each Bulk Class for England and Wales is:

Bulk Class	***Mean Floor Space***
Retail	198 sq.m
Office	307 sq.m
Factory	865 sq. m
Warehouse	755 sq. m
All	442 sq. m

Although this weighted AAD method is valid where no threshold data or geocode data on property location is available it cannot be assumed that the same number of properties flooded for the 200 year event will be affected for lesser floods. Assuming this will grossly over-estimates the cumulative WAAD for the benefit area in question. However (and see Flooding in Scotland report for Foresight, Table 10) the number of properties affected reduces as flood frequency increases. For the Scotland broad scale analysis (which is a useful template for application of the broad scale method) a number of PAR's (Project Appraisal Reports) of recent vintage were scrutinised and the following statistics were deduced:

- The 5-year flood affects 5% of 200-year flood plain properties
- The 10-year affects 10% of 200-year flood plain properties
- The 25-year flood affects 25% of 200-year flood plain properties
- The 50-year flood affects 80% of 200-year flood plain properties
- The 100-year flood affects 93% of 200-year flood plain properties

Thus WAAD should always be adjusted to reflect these percentages, so that if the maximum (say 200 year) property count is derived from the National Property Dataset then this data should be pro-rated to reflect the reduction in flood impact for more frequent floods. If property numbers for successive flood return periods are known then these percentage reductions are not at issue.

Table A4.1: Weighted Damage Calculations by Flood frequency

Residential	*Flood Depth*	*% Distribution*	*Damage*	*Weighted Damage (£)*
5 years	<0.1	81	577	467
	0.1-0.3	7	22360	1565
	0.3-0.6	11	26900	2959
	0.6-0.9	1	29640	296
	0.9-1.2	0	30660	0
	>1.2	0	32460	0
	Total Weighted Damage			**5288**
10 years	<0.1	50	1229	615
	0.1-0.3	31	25195	7810
	0.3-0.6	10	29995	3000
	0.6-0.9	6	32510	1951
	0.9-1.2	2	33560	671
	>1.2	1	35170	352
	Total Weighted Damage			**14398**
25 years	<0.1	45	1229	553
	0.1-0.3	24	25195	6047
	0.3-0.6	22	29995	6599
	0.6-0.9	5	32510	1626
	0.9-1.2	4	33560	1342
	>1.2	1	35170	352
	Total Weighted Damage			**16518**
50 years	<0.1	32	1880	602
	0.1-0.3	20	28030	5606
	0.3-0.6	21	33090	6949
	0.6-0.9	21	35380	7430
	0.9-1.2	4	36460	1458
	>1.2	3	37880	1136
	Total Weighted Damage			**23181**
100 years	<0.1	22	1880	414
	0.1-0.3	16	28030	4485
	0.3-0.6	26	33090	8603
	0.6-0.9	19	35380	6722
	0.9-1.2	12	36460	4375
	>1.2	6	37880	2273
	Total Weighted Damage			**£26,872**

5 years = short flood duration
10 years and 25 years = mean short & long
50 years plus = long flood duration

Table A4.2: Weighted Annual Average Damage calculations (WAAD)

RP	*Exceed Prob*	*Damage*	*Prob of flood in interval*	*Mean Damage*	*Annual Interval Damage (£)*
2	0.5	0			
			0.30	2644	793
5	0.2	5288			
			0.10	9843	984
10	0.1	14398			
			0.06	15458	927
25	0.04	16518			
			0.02	19850	397
50	0.02	23181			
			0.01	25027	250
100	0.01	26872			
			0.005	26872	134
200	0.005	26872			
	Weighted	Annual Average Damage			**3487**

Table A4.3: Weighted Annual Average damage by Standard of Protection

Standard	**1/RP**	**Residential**	**Manufacturing**	**Retail**	**Warehouse**	***Office/other***
Of		£/unit	Bulk Class	Bulk Class	Bulk Class	*Bulk Class*
Protection			(£/m2)	(£/m2)	(£/m2)	*(£/m2)*
None		3487	50.40	77.50	147.40	*161.80*
2	0.500	3222	40.60	60.70	118.30	*122.00*
3	0.333	2958	36.23	53.27	105.37	*104.77*
4	0.250	2693	31.87	45.83	92.43	*87.53*
5	0.200	**2429**	**27.50**	**38.40**	**79.50**	***70.30***
6	0.167	2199	25.16	34.84	72.34	*64.74*
7	0.143	1968	22.82	31.28	65.18	*59.18*
8	0.125	1738	20.48	27.72	58.02	*53.62*
9	0.111	1507	18.14	24.16	50.86	*48.06*
10	0.100	**1277**	**15.80**	**20.60**	**43.70**	***42.50***
15	0.067	1057	13.17	17.03	36.17	*35.20*
20	0.050	836	10.53	13.47	28.63	*27.90*
25	0.040	**616**	**7.90**	**9.90**	**21.10**	***20.60***
30	0.033	547	7.04	8.82	18.78	*18.34*
35	0.029	477	6.18	7.74	16.46	*16.08*
40	0.025	408	5.32	6.66	14.14	*13.82*
45	0.022	338	4.46	5.58	11.82	*11.56*
50	0.020	**269**	**3.60**	**4.50**	**9.50**	***9.30***
55	0.018	249	3.33	4.16	8.79	*8.60*
60	0.017	229	3.06	3.82	8.08	*7.90*
65	0.015	208	2.79	3.48	7.37	*7.20*
70	0.014	188	2.52	3.14	6.66	*6.50*
75	0.013	168	2.25	2.80	5.95	*5.80*
80	0.013	148	1.98	2.46	5.24	*5.10*
85	0.012	128	1.71	2.12	4.53	*4.40*
90	0.011	107	1.44	1.78	3.82	*3.70*
95	0.011	87	1.17	1.44	3.11	*3.00*
100	0.010	**67**	**0.90**	**1.10**	**2.40**	**2.30**
200	*0.005*	***44***	***0.45***	***0.55***	***1.20***	***1.15***

Appendix 4.1: MCM codes and their main primary descriptions included in the Bulk classes

Retail			Office			Factory			Warehouse		
Code	Description	MCM	Code	Description	MCM	Code	Description	MCM	Code	Description	MCM
CG3	Car showroom	223	CO	Office	310	CG1	Vehicle repair	221	CG4	Road haulage	430
CL1	Wine Bar	234	CO1	Computer Centre	311	CG2	Garage	221	CW	Warehouse	410
CL2	Social (club)	234	MH	Surgery	620	CG3	Car Showroom	223	CW1	Storage land	420
CR	Restaurant	235	MH1	Health Centre	620	IF	Factory	820	CW2	Storage depot	410
CR1	Cafe	236	ML	Office Local Government	310	IF1	Mill	820	CW3	Store	410
CR2	Food Court	236	MP	Police Station	650?	IF2	Works	820			
CS	Shop	211				IF3	Workshop	810			
CS1	Bank	320				IF4	Business unit	310?			
CS2	Betting Shop	232				MS1	Fire Station	650			
CS3	Hairdressing salon	231				MS2	Ambulance Station	650			
CS4	Kiosk	216									
CS5	Launderette	233									
CS6	Post Office	237									
CS7	Showroom	215									
CS8	Hypermarket	213									
CS9	Superstore	213									
CS10	Retail warehouse	214									
LT1	Amusement arcade	524									
CG?	Filling Station	222									

Notes:

Depth/damage data currently available

- No Focus code for Plant Hire Depth damage code =224
- Hotel MCM code 511 has depth damage data focus code CH
- Bingo MCM code 517 has depth damage data focus code LT2
- Theatre/Cinema MCM code 518 has depth damage data Focus code LT/LT3
- Sports and leisure Centre MCM code 523 has depth damage data Focus code mainly LC
- School/university MCM code 610 has depth damage data Focus code mainly EL/EN/EP/EU
- Residential Home MCM code 650 has depth damage data Focus code not apparent code as 1-residential

Top 20 Focus categories representing over 90% of addresses in Indicative Flood Plains
Also includes (in the top 20):

- Self catering units (MCM 515; Focus mainly CH10 and CC2/CC7)
- Beach Huts (MCM 514; Focus LH/LX)
- Boarding house (MCM 512; Focus CH2)
- Hall/community centre (MCM 630; Focus LC/LC3)
- School/University(MCM 610; Focus mainly EL/EN/EP/EU)
- Car Park (MCM 910; Focus mainly CP)
- Public conveniences (MCM 920; Focus MX/NX)

Depth Damage data available and in top 20 of Focus categories, representing almost 75% of focus categories within Indicative Flood Plain

5. Indirect economic damage: concepts and guidelines

Contributed by Colin Green and Anne van der Veen

5.1 Introduction

This chapter reviews the difficult areas of indirect flood losses which, in very particular circumstances, can be more important than direct flood losses.

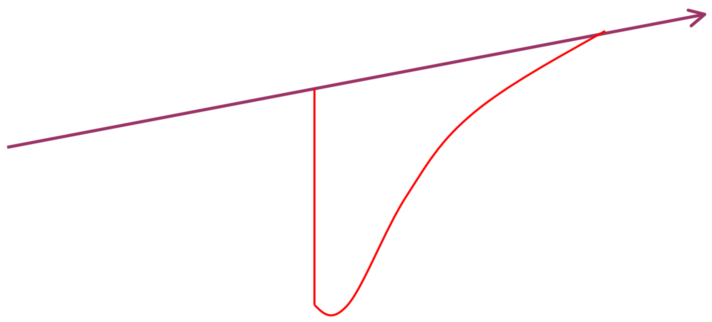
Indirect losses or damages are those where the loss is not the function of contact with flood water (such as a house that suffers damage through flood waters adversely affecting its contents) but where the loss is suffered by some item or activity that is distant from the flood but affected by it. Thus, for example, a factory might be deprived of raw materials owing to a flood in a neighbouring area creating communication problems for its suppliers, and thus be unable to operate and hence sell its products (thereby incurring financial losses), or traffic may be disrupted by the congestion on roads used as diversions during a flood and thereby incur extra fuel costs.

The evaluation of these indirect losses presents greater problems both conceptually and practically than do those of evaluating direct damages. In part, this is because in the idealised world of economic theory, indirect costs would not exist. In that ideal world of perfect competitive markets and general equilibrium, if any one producer ceases to produce, there are no effects upon either the quantity of the good produced or on its price. The whole economy instantaneously and costlessly adjusts to the loss of one supplier, whether that supplier closes temporarily as a result of a flood or permanently as a result of bankruptcy. Since the idealisation extends to assuming that a perfect competitive market is always homeostatic and optimising, there is no need either to consider how the market will adjust in response to any perturbation such as a flood.

Within this world, there are also no frictional costs in the form of transaction costs (Coase 1937) and information costs (Mirrlees 1996); indeed, in this ideal world, there are no transport costs. Because the perfectly competitive market is homeostatic and optimising, and so change takes care of itself, this view of the world tends to result in a rather static perspective. But at the same time, because all resources are already being put to their best possible use, there is no slack in the system to absorb the effects of any perturbation. The only way to cope with perturbations is to divert resources from other uses.

Indirect losses arise because the real world is a system of systems in which adjustments to perturbations take time and those adjustments incur costs. This process of dynamic adjustment means that the immediate effects of the flood ripple out through the system as adjustments are made. The more specialised each activity becomes and the greater the degree of concentration, the greater the difficulty in coping with a perturbation. Both effects are illustrated by the recent fire at the Buncefield oil depot in Hertfordshire, which supplied 30% of aviation fuel to Heathrow airport. In consequence of the shortage of aviation fuel, it was reported that aircraft were having to fly in with a proportion of the fuel load required for their next flight or having to make an additional stopover in order to take on more fuel. In both cases, the result was to increase the operating costs of the airlines concerned and in the latter case, increasing the congestion at other airports. A more detailed discussion of the economy as a system and the process of adjustment to perturbation is given in the Annex.

Figure 5.1: Perturbation of an economic system hit by a flood



Nor can the system be relied upon to optimally adjust upon its own. **Figure 5.1** represents the trajectory of the performance an economic system over time, once that economic system is hit by a perturbation from which it slowly recovers, although it might never return to the original trajectory. Historically, some civilisations have been hit by natural disasters which effectively totally destroyed those civilisations (Fagan 2004). The close parallel between indirect losses and the concept of resilience is clear. Equally, there are sharp conceptual differences between the approaches taken to the assessment of direct losses and those that have to be taken to evaluation of indirect losses (**Table 5.1**).

Table 5.1: Conceptual differences between assessment approaches for direct and indirect damages

Direct damages	**Indirect damages**
Static viewpoint	Dynamic adjustment
Focus of concern: elements of the system	Focus of concern: interactions between elements in the system
The whole is the sum of the parts	The whole is a function of the elements and their inter-relationships

As a result of these differences, it is easy to become confused in moving between the two different approaches when assessing indirect damages. In evaluating direct and indirect damages, the importance of not counting both stock and flow changes has already been emphasised (Chapter 2). The practical problem is that different resources are naturally quantified as either a flow or a stock so, for example, the conventional economic discussion of the factors of production combines a flow (labour) with a stock (capital) with natural resources, where natural resources include both stocks (land) with flows (solar energy).

More generally, if we could evaluate the overall response of the system to a perturbation such as a flood, then that assessment would include direct damages which would not need to be evaluated separately. But we would then still have an interest in separating out direct and indirect damages to the extent to which different intervention strategies may be effective to different degrees in reducing the damages from a flood. Critically, the magnitude of the perturbation is not measured by direct damages.

There are two major problems in applying the model:

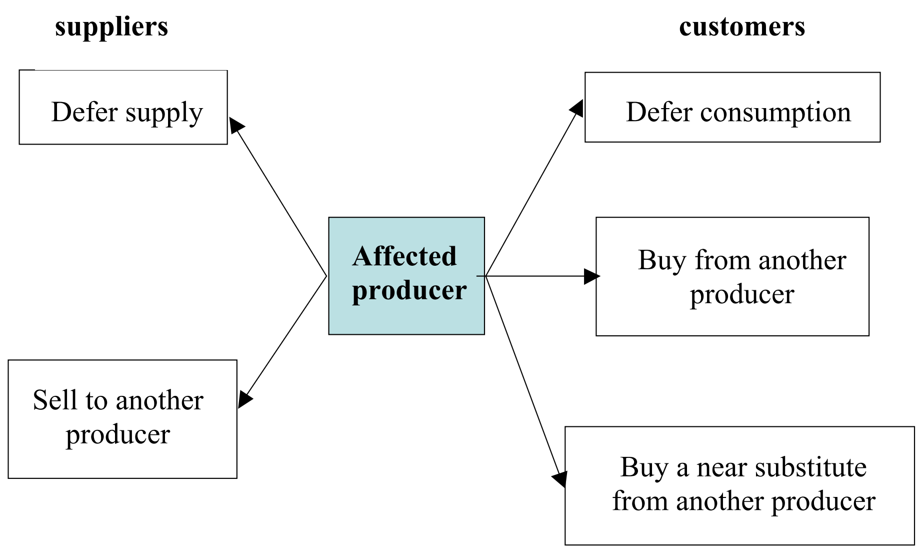
1. lack of any measure of the performance of the system; and
2. scale effects.

Ad 1. In general terms, we can argue that the objective in managing an economy is to maximise the ratio of the value of the outputs, consumption, to the costs of the resources required to produce that consumption, the inputs. The effect of any perturbation, at least in the short term, is to reduce either the outputs whilst inputs are held constant; to increase the inputs required to produce a given quantity of consumption; or to both increase the required inputs and decrease the outputs.

The conventional economic assumption is that the individual household wishes to maximise its utility and that a society should seek to maximise some sum of those utilities, or welfare. Utility is defined as the satisfaction gained by the individual from the consumption of each good or service, whether or not that good or service is priced. Unfortunately, we do not have any economic statistics which measure individual utility, and some economists argue that any interpersonal measure of utility is impossible. An everyday interpretation of utility is as the quality of life. Nor do we have any generally accepted measure of welfare. Crucially, National Income, measured by the GDP (Gross Domestic Product) family of measures do not measure welfare, nor do they measure the ratio of outputs to inputs; they are essentially accounting tools rather economic measures. There are a number of proposed measures which are intended to provide an indicator of individual utility, such as the Life-Satisfaction index (Donovan et al 2002) or the quality of life of a society as a whole. The latter include the 'Human Development Index' HDI (UNDP 2005) and the Economist's 'Quality-of-Life Index' (Economist Intelligence Unit 2005). An issue with these latter indices is that the state at any given time is lagged, representing the success or otherwise of investment decisions taken in earlier periods. For example, the HDI includes as indicators life expectancy at birth, adult literacy rate and the enrolment rates in education. The values of these parameters in any given year depend upon the investments made in health and education in previous years. These measures are also exclusively of outputs. An equivalent measure of changes in inputs is also required.

Ad 2. The second problem is that of scale; if the effects of any perturbation ripple out through the economic system, then the smaller the initial perturbation, the more likely it is that the ripples will only spread a very limited distance outwards from the point of initial perturbation. What then is measured locally as a significant perturbation may be largely dissipated at a larger scale. Hence, to measure the local effects requires knowledge of the local economic system and that local knowledge will often not be available, not least for reasons of the protection of privacy; if there are only two bakeries in an area, then even the statistics for averages of turnover, return on capital and so on will contain data that is commercially sensitive.

Figure 5.1: Options of suppliers and customers of an affected producer



If a producer is affected by a flood (**Figure 5.2**), then both those who supply that producer and those who consume the products from that producer will be affected. The suppliers have only two options: to defer production until the flooded business is in a position to buy their production; or seek another outlet for their product. The consumers of the flooded business's production have three options. The first is to defer their purchases until the business is back in production. The second is buy an identical product from another producer; and the third is buy a near substitute product from another producer. In the latter two cases, the consumers experience some loss and there is a national loss if they shift their purchases to a company abroad. The consequence of these varying adaptations is that if any single firm is flooded, we want to follow these effects forwards and backwards to all its suppliers and consumers, where the adjustments they make will mean that their consumers and suppliers, respectively, will have to make adjustments. This is extremely difficult and very data intensive.

5.2 How to model indirect damages?

The magnitude of indirect damage has been argued to be determined by three factors (Cochrane, 2004):

1) where the economic boundary is drawn (city, standard metropolitan statistical area, state or the nation);
2) the degree of economic integration; and
3) pre-disaster economic conditions (level of unemployment and the ability to substitute imports for regionally produced goods and services).

Cochrane (2004) identified six categories of techniques to calculate and estimate indirect damage:

1. Linear programming models providing guidance as to the optimal allocation of scarce post-event production capacity.
2. Post event economic surveys.
3. Econometric models reflecting historical trading patterns (and thus unable to take shocks into account).
4. Input-output models, as demand driven models that reflect an accounting stance of an economy; it is unlikely that without adaptation these models can capture severe shocks.
5. Computable Equilibrium Models, as an extension of Input-Output models taking into account price and quantity effects.
6. Hybrid models (computational algorithms) addressing supply shocks, post event supply constraints and time phased reconstruction.

For most floods, except the most extreme, the spatial scale of the economic models for which data is available will be much wider than the area affected. In addition, the resolution of the models is rather coarse (e.g. the number of different industrial sectors that are included). Hence, these models are most appropriate for large scale events. Of course, this coarse resolution fits a national perspective, but regional scale analysis or a local economic focus will be different, and here post-event economic surveys are perhaps the most appropriate approach, certainly at the local scale. In essence this means that the spatial scale must be kept in mind when assessing indirect damages, hence the discussions below (Sections 5.2.1 to 5.2.3).

5.2.1 Micro scale analysis

A basic understanding is needed on the geographic concentration, it is important to know whether or not sites that were damaged are unique to estimate the criticality of its loss. Post event economic surveys can give an overview of the number and types of businesses that were lost. This is the basic test on a micro level, as it is highly likely that if the affected area is only very small (size of communes) the indirect economic effects at a higher level can be ignored. However if in the affected area unique installations have been built, these installations could be critical. Typically installations like these are the bigger industrial complexes that produce half-fabrics. Installations like oil-refineries, chemical plants, etc. are quite likely to be big enough to be unique in their character, production and products. Therefore closure of or damage to these installations are likely to have major repercussions.

At the small scale, an approximation of the costs of some of these adjustments can be gained from interviews with firms that might be flooded. If they expect their consumers to have to defer their consumption then, although the costs to the consumers of that deferral cannot be readily quantified, we can determine the additional costs to the firm of seeking to make up the deferred production. If the firm believes that consumers can buy an identical or approximate substitute product from abroad, then that a proportion of that loss of sales is a loss to the national economy. But this estimate will not include the additional costs to the consumer of buying elsewhere. In theory, the flooded firm might be able to assess the responses of its suppliers but this has not apparently been attempted. Interviewing representative samples of consumers and suppliers to determine their adaptations and the costs of those adaptations has, so far, been regarded as too expensive.

5.2.2 Meso scale analysis

Based at the same surveys, these surveys are aimed at gathering information on the number and types of businesses that sustained damaged because of the disaster. Combined with other existing datasets (local tax registries, cadastre, land survey and land-use information) these will give an overview of the extent of damage.

As the size of the study area increases the more likely it is that indirect economic effects will occur. EUROSTAT database can give an idea on the extent of indirect data by looking at a regions added value combined with post economic surveys this results in basic assessment of indirect damage. Indirect damage will then be measured by the value added that can no longer be produced - in addition to assessing how unique a certain damaged site or lost installation is within the region.
With more detailed accounts typically having information on import and export per sector, repercussions throughout the economy can be assessed based on the lower general level of output reached. This lower level of output can be assessed by each sector's contribution to regional output. The repercussion can be assessed by the amount to which import and export plays a role in production. Limitations of input-output tables are the high level of aggregation usually involved and that the coefficients are long-run averages rather than short run marginal changes.

5.2.3 Macro scale analysis

On macro level, typically the same kind of data is available as is at a meso level. The same approach can be used as on a regional level. The main thing is to asses which sectors are hit and how hard. (See Benson and Clay (2000), ECLAC (1991), Freeman et al., (2002)). However on more higher scales it is typical for substitutions to arise (van der Veen and Logtmeijer, 2005). Sellers and buyers are, on this scale, more likely to have found alternatives. Therefore uniqueness and information on geographical spread of some major suppliers is still essential.

However, at a recent EU workshop on the methodologies and techniques to compute direct and indirect damage (van der Veen et al., 2003); Bočkarjova, Steenge and van der Veen (2004 and 2006) conclude that the major hindrance to estimate indirect economic damage is the inability of economists to deal with structural economic changes after a shock. See also Rose and Lim (2002), Rose (2004), Cochrane (1997) and EPA (2000).

It is our belief that more work is necessary in order to understand the structural economic effects of large scale inundations.

5.3 Post flood recovery

In the post-recovery phase of flooding, a government will need to decide which is the best strategy for promoting as rapid and complete a recovery as possible (Freeman *et al.,*, 2002). This is clearly a dynamic question; in turn, the implication is that the way in which a government and indeed the individual households and companies seek to promote recovery can influence the magnitude of the indirect damages. From the long term perspective, the diversion of expenditure from long term capital investment will reduce long term growth. Hence, it is likely to be preferable to finance the replacement of production and household durables by reducing immediate consumption. So, a household may find it preferable to pay to replace damaged household durables such as the home, televisions and furniture by cutting back on short term leisure expenditure (e.g. meals out) rather than draw down on its savings. Similarly, a government would possibly be unwise if 500 schools are destroyed in a flood to fund the replacement of those schools by either reducing the number of teachers employed or postponing the planned construction of 500 new schools. Doing either would have the effect of reducing economic growth in the future. Hence, the German government's action of funding the reconstruction after the recent floods in 2002 by delaying a reduction in income tax may have been an appropriate response.

The alternative approach is to build up funds for recovery prior to the flood through an insurance or financial mechanism (Kunreuther and Linnerooth-Bayer nd). The limitation of the insurance mechanism is that flooding is a risk that is only generally insurable through some form of public-private partnership (Gaschen et al 1998).

5.4 Guidelines for incorporating indirect economic effects

Based on the analysis in the preceding sections and the remarks in the Annex we recommend to pay ample attention to possible indirect economic effects in case of:

- Long duration flood (several weeks)
- Event affecting significant proportion of the area (region, country) of interest
- Impacts on highly concentrated and specialised industry or services
- The economy already running at full capacity
- Nodal points in communications networks (transport, energy, information) are affected.
- Stocks are low.

Further research is necessary to investigate structural economic effects of large-scale inundations.

Annex 5.1: Modelling the reaction of producers and consumers on floods: some economic notions

An economy is a system which like other systems can be visualised as an interconnected web of stocks, flows and transformations. Flows are transformed in order to produce a more desirable product; flour, yeast, labour, and energy are transformed into bread, for example. There is then a distinction between transformations which involve a stock of some kind (e.g. a machine tool) and those stocks, such as warehouses, which exist solely in order to buffer variations in flows.

In describing this system, the distinction brought out in Chapter 2 between stocks and flows has to be refined because there are a number of different forms of stock which must be distinguished. In particular, we need to differentiate between *stocks* which are permanently depleted by withdrawing a flow and other forms of stocks. These may be termed 'stores' and they include not simply such artificial stores as warehouses, shops or oil tanks, but natural resources such as fossil fuel. Artificial stores exist largely to buffer variations in supply and demand. Secondly, there are stocks from which a flow can be withdrawn, provided that the rate of withdrawal does not exceed the rate at which the stock is naturally replenished; for example, a fishery or a forest from which timber is harvested or a lake from which water is abstracted. Conventionally, these included in *renewable resources*, but, confusingly, renewable resources are elsewhere taken to include flows, such wind and solar energy. Next, there are the artificial stocks in the form of roads, machine tools, televisions and so forth. These may be defined as durables and a distinction made between a *production durable*, such as machine tool, and a *consumption durable*, such a television or a house. A production durable may produce consumption durables, or immediate consumption such as food or drink. It may also enable the flows within the system, as do such production durables as roads and telecommunication facilities.

As previously discussed, these inputs, the factors of production, are transformed into some output. This transformation can be defined as a function, such as a Cobb-Douglas production function:

$$Q = a.NE^{b}.L^{c}.K^{d}$$

Where: NE is the natural endowment
L is labour
K is capital

A more complex production function is the CES production function:

$$Q = A[\alpha x_1^{-p} + (1 - \alpha)\ \alpha x_2^{-p}]^{-1/p}$$

What is significant here is that such determinants of the output, given specified inputs, as technology, institutions and education are embodied in the coefficients and constant rather than entering as factors of production in themselves.

The practical problems of implementing a production function approach are four-fold:

1. What is the appropriate functional form?
2. How to calibrate that function?
3. Those of scale
4. Time

Input-output modelling uses the Leontief production functions; this is a linear function so that it is assumed that if electricity constitutes 25% of inputs, then an electricity blackout will reduce production by 25%. This is not a very plausible assumption. CGE generally uses the CES production function which is still linear unlike the Cobb-Douglas function.

The second problem is to calibrate the function, to estimate the necessary coefficients. There is not generally sufficient data to estimate these with any precision.

These problems are related to those of scale. Conventionally, the industrial and commercial activities of the economy are categorised into a number of sectors. As elsewhere in damage estimation, the ideal is that each sector is homogenous; in this case, the coefficients are the same for all firms within each particular sector. But the discussion on specialisation means that this is not likely to be entirely true; that some firms will differ either or both in the inputs they require or firms in other activities will have input requirements which are specific to particular firms. For example, manufacturers of margarine, butter and olive oil based spreads have different requirements for the basic foodstuff. In turn, a butter manufacturer is unlikely to be able to substitute its demand for milk by a supply of olive oil. In turn, this argues for a high degree of differentiation, a large number of sectors, being used. This increases the demand for data and also the computational problems.

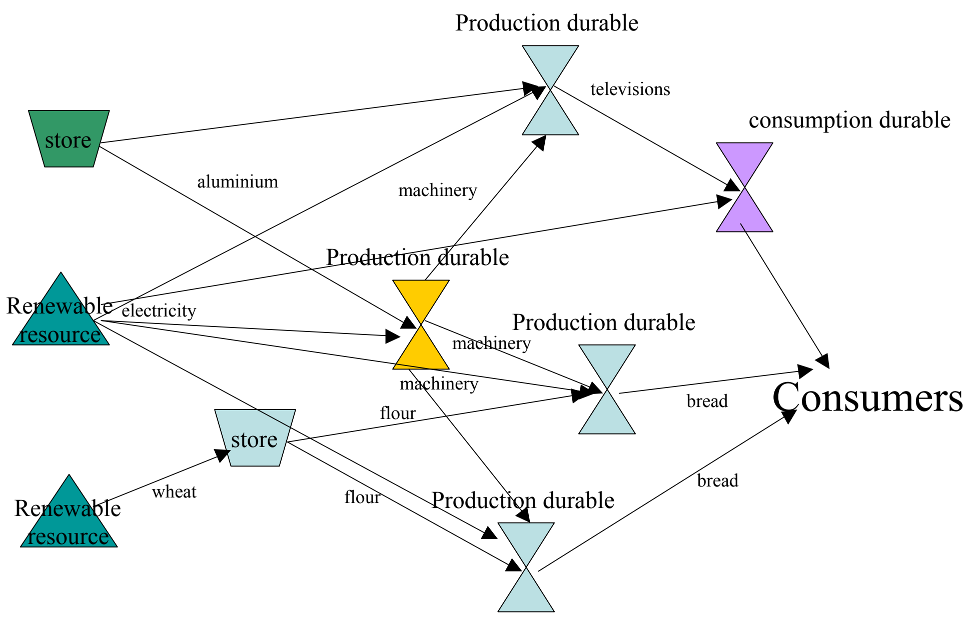
At a large scale, national or regional, then provided that industrial and commercial activities are not also highly concentrated then the regression to the mean effect may reduce the distortions brought about by aggregation. At the small scale, the distortions are likely to be greater from using sector average coefficients rather than locally and plant specific coefficients, but a large proportion of the effects may then be made up by changes outside of the flooded region.

The fourth problem is that of time. The adjustment of the economy to the perturbation takes time and different responses take different lengths of time to occur. For example, a shop could increase its order of margarine and olive-oil based spreads readily quickly. But if road and railways have been damaged then it may not be possible to deliver those goods. Hence, in the absence of time weighted coefficients, it is necessary to decide the time scales of different adjustments exogeneously.

The related concepts of capital and income also need to be carefully defined. Hicks (1939) defined income as what a person can spend and still be as well off at the end of a period as at the beginning. That is, without reducing their savings. In turn, we can define capital as that which will yield a Hicksian income: the amount or value of the capital remaining unchanged at the end of the period in which the income was taken. It is clear, therefore, that some stocks are not capital. Neither *production durables* nor *consumer durables* are capital because both wear out; indeed, they wear out whether or not they are used as a result of such natural, time related processes as corrosion.

The basis of conventional economics is that the individual consumer seeks to maximise the satisfaction gained from the totality of their consumption, and chooses what to consume, within the limits of their income, so as to maximise this satisfaction, or utility. The assumption is then made that the objective in societal decision making is to maximise some aggregate of the individuals' utilities. At the same time that the individual is assumed to make those consumption choices which result in the maximisation of his or her utility, it is further assumed that in a perfect competitive market, resources are put to their highest possible use so as to maximise the aggregate of individual utilities. In addition to being optimising, a perfect competitive market is further assumed to be homeostatic: after any disturbance it will automatically move to the new optimum. The perfect competitive market also involves a number of further assumptions; in particular, it responds to any such disturbance instantaneously and there are no costs involved in making the adjustment. Substantial modifications have had to be made to this conceptual model with Coase (1937) identifying the importance of transaction costs, the costs of doing business, and Mirrlees (1996) and Stiglitz (2001b) the issues of information availability. When Stiglitz (2001a) asserted that "Today, there is no respectable intellectual support for the proposition that markets, by themselves, lead to efficient, let alone equitable outcomes", he was making assertions about those who still claim that markets are efficient rather than reporting widespread agreement amongst economists that the problems with markets mean that they cannot deliver efficiency. What is much more generally accepted is that a perfect competitive market is nearer to the concept of the gas underlying the gas laws rather than being something that is ever found in everyday life. In practice, real markets are always imperfect to some degree or another; Coase (1991), for example, argued that transaction costs should be a central concern of economics.

Figure A5.1: Economic system (highly simplified)

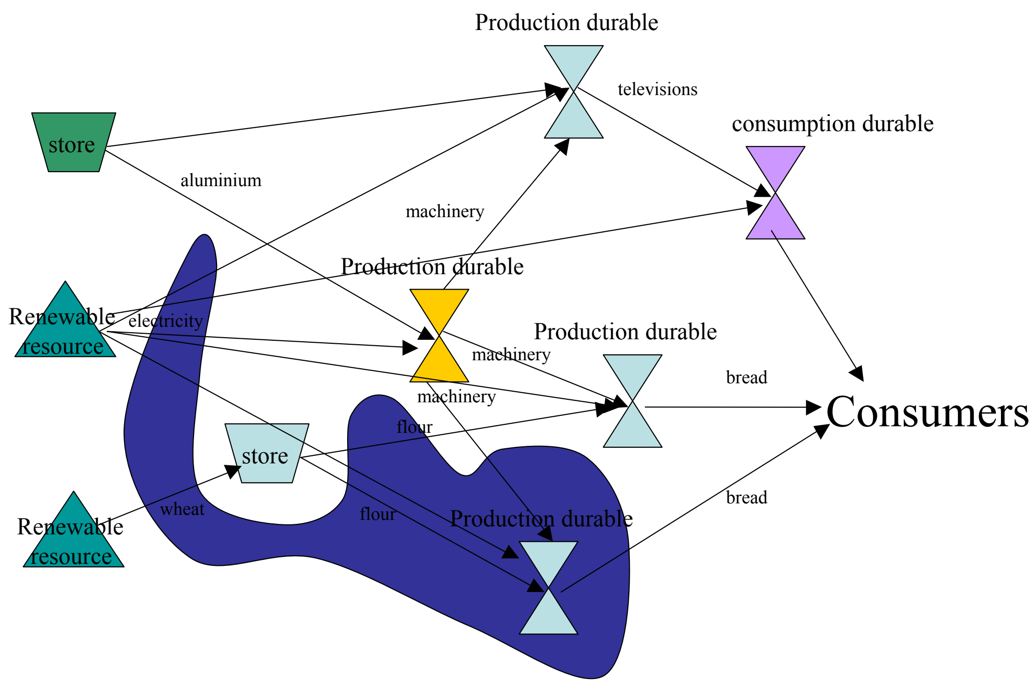


A highly simplified economic system is shown in **Figure A 5.1**. In this simple model, there are two plants, bakeries, which both produce some final consumption good, such as bread. There is another plant which produces a consumption durable such as televisions; a plant which can produce either machinery with which to bake bread or machines to make televisions; and a granary which stores wheat harvested from the natural endowment. From the natural endowment three different resources are being harvested: aluminium, a depletable resource; renewable energy; and wheat. For simplicity, assume that the only resource necessary to harvest these resources is labour.

This conceptual model is embodied in a physical system, a physical system which importantly involves such physical laws as the 3rd law of thermodynamics. Time's arrow operates from left to right in that physical system: once flour and energy have been transformed into bread, the process cannot be reversed. Importantly, the conceptual system, the economist's model of the system, as a right to left directionality and well as a left to right directionality: the consumers' demand influences what the producer decide to produce and at what price whilst, simultaneously, what is produced at what price influences the quantities consumed.

In that physical system, the flow arrows are manifested in the forms of roads, railways or canals and power cables. The physical characteristics of that space including distance between the different points in space at which producers and consumers are located are important. The physical system is brought together through a symbolic exchange system based upon credit and denominated in money, each arrow in the above diagram being mirrored by a flow in the opposite direction of credit. The labour and capital inputs necessary to support the system are similarly rewarded by opposing flows of returns to labour and capital respectively which enable the consumers to purchase the goods on offer. Out of that income, the consumer chooses to save some of that income which capital is then available for investment. Other capital investment, and much of the investment in technological innovation, institutions, education and training comes out of involuntary taxation. That the flows of credit and the economic evaluation of the flows and stocks are both denominated in money terms is a potential source of confusion. If, for example, someone's television is destroyed in a flood and that person buys another television then it might appear that there is a simple transfer of credit from the flood victim to the retailer, the gain to one cancelling out the lost to other. But the flood victim is now down a television plus the cost of a new television whilst the retailer has only gained the price of a new television to balance the reduction in the retailer's stock of one television.

Figure A5.2: Economic system (highly simplified) affected by a flood



Let us assume that a flood then occurs which floods one of the two bakeries and disrupts transport of wheat to the granary serving the two bakeries, and it also disrupts electricity supplies to both bakeries, the granary, the factory producing machinery and the television factory (**Figure A 5.2**).

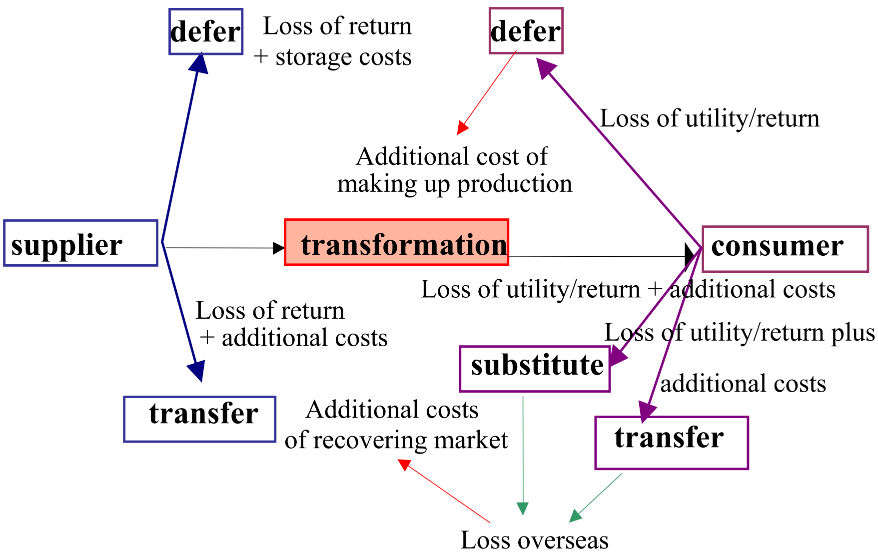
The immediate result is the physical damage to bakery. But, because there is no electricity, the unflooded bakery is unable to make bread and neither is the television factory able to produce televisions. This perturbation both feeds forward to the consumers who now cannot get bread or televisions or watch television because there is no power. It also feeds backwards to those who supply the inputs to the granary, both bakeries and both factories.

In general, those downstream of the affected productive activity have only three options (**Figure A 5.3**):

- Shift to another source of an identical resource.
- Substitute the required input by another resource.
- Defer their requirement for the resource in question.

Those upstream have only two options:
- Transfer their outputs to another user.
- Defer their outputs until the affected producer or consumer is able to use them.

Figure A5.3: Options of suppliers and customers of an affected producer



There are limits in each case upon the scope for the consumer in adopting each action. Where the value of the consumption is time dependent, then they cannot defer; for example, if they miss seeing the World Cup finals on television. The obvious examples of time dependent consumption are food and drink: delaying either for a sufficient period results in death or a permanent decrease in capacity. If consumers can defer, they defer the consumer surplus on their consumption. But, the greater the degree of concentration and specialisation within an industry, the lower the extent to which it is possible to either shift to another source or find a substitute for the input in question.

Since it is assumed that the consumers optimised their choices prior to the flood, whatever the strategy adopted by the consumer, there is a loss. The shift to another source may involve travel and other costs. The substitution by another resource which is not identical to that to which there is no access results, by definition, in a loss of utility: by definition, because if this was not the case, the consumer would have chosen this resource before the flood forced him or her to do so. In the absence of television, we have to assume that they engage in some other leisure activity which is not affected by the absence of power. Since in normal circumstances, they preferred to watch television rather than engage in that next best leisure activity, they again suffer a loss of utility.

On the input side, in the ideal world of the perfect competitive market, the inputs, the labour, capital and resources which previously had been used to make televisions and bread would be costlessly and instanteously transferred to other purposes. Since the assumption of the competitive market is that resources are allocated optimally, there is a real economic loss because those resources are now being put to second best uses. For example, grain intended for bread production could be sold as feedstock for animals but only at a lower price. As feedstock, it would then displace other feedstocks which might or might be in turn capable of being redeployed to other uses. Either those resources are being used less efficiently in which case output is lower or the desirability of the output, its value, is lower.

In practice, not all resources can be redeployed and redeploying those resources incurs costs. The labour currently used to build televisions and bake bread cannot be instanteously shifted to, for example, nursing in hospitals or teaching in schools, and then back to building televisions and baking bread. Capital inputs are particularly sticky because capital is made productive through its expression in physical objects and hence left stranded in those physical objects. The ovens designed to produce bread cannot readily, if at all, be converted to producing other goods. If the production line can only produce bread then the capital invested in those production lines cannot be liberated and if bread cannot be produced, that capital is largely lost, except for the scrap value of machinery. Again, flow inputs which cannot be stored are lost: the labour which would have produced bread, televisions and machinery is lost to the economy since yesterday's labour cannot be used to-day. Those whose labour is not used gain to the extent to which they have some unexpected leisure but since they would have preferred to work for money, the gain in leisure does not fully compensate for the loss in income. If instead they are paid whilst unable to work, the loss is simply redistributed: the workforce gain some leisure time, the company loses the wages. The consumer, as already discussed, suffers a loss.

Once the flood goes down, the bakery that was not flooded can get back into production, as can the factories, as soon as power is restored and the roads reopen. The flooded bakery is likely to be closed for some time whilst it is cleaned up, the machinery replaced and it is restocked. Since there are only two bakeries, it is very unlikely that the operating bakery will be able to full replace the lost production from the flooded bakery. Hence, there is likely to be a shortage of bread; that bakery could in fact increase its prices to bring effective demand into line with its capacity to produce, increasing the producer's surplus at the cost of the consumer. It will probably in any case cost more per loaf to produce a larger number of loaves from the remaining bakery. Equally, prior to the flood, some people choose to buy their bread from one bakery whilst others preferred the other bakery. Those preferred the product of the bakery that is flooded may have done so because it was cheaper, or they preferred type of bread produced, or because it was nearer to them and hence it was cheaper to travel to that bakery in order to buy bread. Thus, all those who previously used the bakery which is now flooded experience some degree of loss through the necessity of buying their bread from the bakery that was not flooded. What happens is then a myriad of small changes spreading out through the economy.

The producer has the option of responding to the adaptation strategy of the consumer. If the consumer has deferred, then the producer may choose later to make up the deferred production. If they do not do so then that production is lost forever; if they do make up the deferred production, then additional costs are likely to be incurred which may generally be expected to be less than the loss of that production. If the consumer has been able to transfer their demand to another producer or to substitute the product by a different one then there is a national loss if that demand is shifted to an overseas producer. If the producer is able to recover their market share by some marketing strategy then the costs of that strategy are a real loss.

6. Guidelines on social issues

Contributed by Colin Green

6.1 Introduction

Floods are well established to have other impacts on households and society as a whole in addition to the physical – and hence direct - damage done by floods to buildings and their contents. We term these, here, the 'social impacts' of floods[26], and this chapter reviews this field. These social impacts should not be confused with indirect flood effects; they can be both direct (loss of treasured possessions) and indirect (the disruption cases by a flood). Research in the past, as catalogued in this chapter, has shown that these 'social impacts' can be more important to the victims of floods than the financial losses that they suffer. Hence they warrant careful attention and, incidentally, more research.

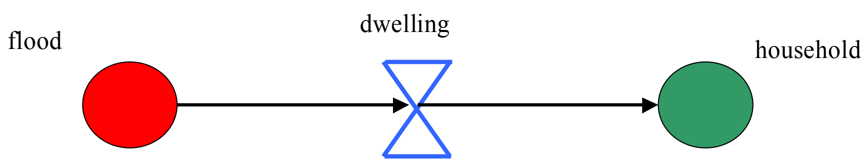
These social impacts include:

- the loss of irreplaceable items, such as baby photographs;
- the stress induced by the flood itself;
- temporary evacuation of the home whilst the damage is repaired;
- the disruption caused by the flood to the life of the individual household and to the community as a whole; and
- the effect of floods upon the health of those affected.

If a community is more than the sum of the individual households of which the community is comprised then a flood may have wider effects upon the community (Eriksen 1976). Whilst 'social capital' (Aldridge et al 2002), essentially the relationships between households, may help those households recover from the flood, it might be reduced either in the process or by the flood itself. In that case, there will be adverse consequences to the functioning of the community as a whole.

Figure 6.1 is the simplest possible model of the relationship between a flood and the impacts of that flood upon that household. The dwelling acts as a lens which either attenuates or magnifies the effects of the flood upon the household. A dwelling which provides a safe place of refuge for the household and its possessions attenuates the flood; a dwelling which collapses in even a slow, shallow flood magnifies the effects of that flood.

Figure 6.2: Impacts of flooding upon households



This is an area where there is no established good practice and the guidelines are therefore defined at the level of good enquiry. This requires that we start by establishing what are the criteria for good practice. We are seeking to measure something, a state or set of relationships, and to do so with the minimum random or systematic error. That measurement must satisfy both requirements of validity and reliability. We can want to measure the impact of a flood upon a particular household but we also often want to be able to determine how those impacts vary according to the nature of the flood and the characteristics of the households: to understand the dynamics of the relationships. Hence, a key

[26] This is recognised to be somewhat of a misnomer, because ‚social' implies collective or the impacts on a group, whereas many of the impacts discussed here can equally well apply to individuals.

criterion for a methodology is: to what extent does it provide new understanding? We want that understanding to be real and not simply an artefact of the experimental method so we also require that the methodology provides valid and reliable results.

Secondly, theory and methodology are intertwined: the methodology is built upon an underlying theoretical model and consequently applying that methodology is a test of that model. If we want better methods, we also want better theories, ones of greater explanatory and predictive power. In particular, the concept of 'vulnerability' is the conceptual concept underlying the methodologies and vulnerability is a necessarily contested concept (Green 2004).

Hence, this chapter has three elements:

- The main text which is centred upon what we want to learn and how we may go about learning more effectively.
- An annex (Annex 6.1) on current best practice principles by which to implement that learning approach. These are unlikely to change over time except by addition.
- An annex (Annex 6.2) listing what are currently the best practice instruments. It is to be hoped that at least some of these instruments will be replaced in time by better ones.

6.2 What is 'better' practice?

A key question in any decision process is: what do we mean by 'better'? The answers to those questions must define the basis first of the principles of good enquiry and secondly of good practice. In assessing the social impacts of flooding, it is argued here – and part of the pursuit for 'better' measurement techniques should be the improvement and refinement of what we mean by 'better' - that 'better' has two aspects: the purposive and the instrumental; the 'why' and the 'what'.

We seek to quantify the social impacts of flooding primarily in order to better assess the most effective means of intervention in order to reduce those impacts. The purposes of quantifying the social impacts is firstly to predict how severe those impacts will be in some situation and, secondly, to provide a basis for assessing the effectiveness of alternative intervention strategies. Hence, the overall objective in measuring the social impacts of flooding is to gain a better understanding of the key variables and the relationships between them as these affect the magnitude of the social impacts of flooding. We want, in short, to learn.

In this respect the material in this chapter may appear to be 'different' from that in other chapters. That this is so is a measure of the less advanced state of research on the social impacts of floods, for example in relation to studies of direct flood damage. This means that we are still at the beginning of the learning process outlined above, rather than at the end: there is more that we do not know than we know.

The surveys designed to enhance our understanding of the social impacts of floods will either be about past events, past floods, or about possible future floods. In studies of past floods, the problems of memory stand in the way of obtaining precise recall; it is well known that people are very poor witnesses, what they see and hear being interpreted, and sometimes remembered in terms of what ought to have happened rather than what did happen. Studies of responses to future floods are similarly limited: this time by the difficulty of anyone being able to predict and take account of the full range of circumstances that will influence their actions at that time.

The variables involved can be grouped into four classes:

- *Phenomenal* – the physical phenomena of the world e.g. the depth of water in a house.
- *Behavioural* – what people did, say that they did, or say that they would do.
- *Psychological and social*– the range of perceptual and cognitive processes that determine how people interpret the world, and decide which action it is appropriate to take upon the basis of

that interpretation. Individual values, attitudes, beliefs, personality, and experience are likely to influence those perceptual, cognitive and decision processes. In turn, those values, attitudes and beliefs are likely to be influence by the process of socialisation, social norms and other social factors.
- *Characterisation* – the characterisation of individual households and individuals in terms of such factors as age, life stage, prior health, social, demographics, and income.

Memory issues may extend to phenomenal variables as well as behavioural and psychological variables. Behaviour is a surface phenomena which is the outcome of some perceptual and cognitive processes; one single behaviour can consequently be the outcome of a number of different interpretations and decision processes. Consequently, those decision processes and the basis for the decision are generally of more interest that any particular behaviour, and behaviours are perhaps most use as indicators of the extremity of the challenge as perceived by the individual. Thus, that someone tried to help his elderly wife climb on to a chest of drawers so as to be able to climb into the attic is of significance primarily because it shows a very real fear of death.

The perceptual and cognitive processes are essentially latent – it is impossible to directly observe them - and require the development of specific measurement instruments by which to quantify the relevant values, attitudes, beliefs and other factors. Risk, distress, anxiety, and stress are all cognitive variables which require measurement in this way. Many standard instruments have been developed to measure such variables and where a well-tested instrument exists, it is desirable to use it rather than to invent a new one from scratch. Extensive tests of validity and reliability are required before any new instrument should be accepted and such tests may not be practical within the time frame of a practical study. Existing instruments also have the advantage that values for the parameter in question are likely to be available for other situations or other populations, against which the results for the sample of people affected by flooding can be compared. Where it is necessary to invent a new instrument, it is desirable simultaneously to use an existing instrument which is nearly comparable to the new instrument. The differences and similarities in the results from the two instruments should be as predicted before the study was undertaken.

In general, we are interested in sequences which are both causally and temporally ordered, but where the elements in those processes are latent. We may, for instance, hypothesise that psychological and psychiatric well-being is determined by prior health, the stress of the flood, anxiety about future flooding and the degree of different forms of social support received. Obviously, whilst health prior to the flood may influence the stress experienced in the flood itself and health now, it is illogical to expect any determining influence in the opposite direction.

The purposive sense of ‘better’ is to gain a greater understanding of the nature, extent and causes of social impacts of the flooding in order that we can determine what are the best means of intervening to reduce those impacts. It is not curiosity that drives us but the desire to do something, and the greater understanding exists only in so far as we gain greater insight into what action to take. In particular, we want to be able to predict:

- *which populations will be most vulnerable to which kinds of floods; and*
- *what are the most effective means of intervening to reduce that vulnerability.*

We are therefore interested in causation, with relationships between variables, including the discovery that there is no measurable influence of one variable upon another. Associations, or correlations, are only of interest if they can bear a substantive causal interpretation. Hence, in the statistical analysis, any relationship must satisfy the twin tests of substantive significance – whether the direction of the relationship makes logical sense - and of statistical significance. The problem is that any statistically association may occur in multiple ways of which only one is substantively meaningful.

6.3 Survey approaches

6.3.1 Qualitative studies

There are some almost ideological arguments over the relative merits of qualitative (see, for example, Gilbert (2001)) versus quantitative surveys, but the two approaches should be seen as complements rather than as complete substitutes. The core of the argument between qualitative and quantitative approaches lies in the extent to which individual attitudes, beliefs, preferences and actions are:

- *Considered to be socially rather than individually determined.*
- *That the answers people give are acts of recall or whether they are constructed when the question is asked.*

If it is argued that individuals have to construct an answer to a question, for example, about what were the worst effects of the flood, and that answer will be influenced by the opinions of others, then it follows that a group discussion format is the only means by which to gain both any understanding of that process and meaningful answers. Conversely, if it is considered that the individual relies only upon that individual's own cognitions, already has knowledge of the appropriate answer to the question being posed, and the process by which they reached that conclusion is irrelevant, then questioning individuals will be quite adequate. In orthodox economics, the assumption is that it is the individual alone that matters and that all questions can be answered through recall so that it is only state that matters, process being entirely irrelevant; unfortunately, this assumption is entirely at odds with the results of social science research. The possible combinations of the two factors given above and the appropriate qualitative or quantitative technique to adopt are summarised in Table 6.1.

Table 6.1: Appropriate survey techniques

	Answer generation	
Attitudes & preferences	**Constructed**	**Recall**
Socially determined	Group discussion	In-depth interview
Individually determined	In-depth interview	Interview schedule or questionnaire

In practice, the importance of the two factors should be expected to vary according to what it is sought to measure. Preferences and attitudes most likely to be constructed through a social process; individual preferences simply being the starting point for this process. The processes of stakeholder engagement and means to enable such engagement are outside of the scope of these guidelines.

The limitation of qualitative methods is that it is only ever possible to involve a very small number of people in the processes involved; breadth, in terms of the representative nature of the sample, has to be sacrificed to depth. Equally, the processes involved in the qualitative studies are likely to have changed the respondents so that their views are no longer typical of the population of which they are part. Therefore, it is necessary to undertake quantitative studies as well. A secondary, but critical function of qualitative studies, is then to inform the design of those quantitative studies.

6.3.2 Quantitative approaches

Quantitative approaches (see, for example, DeVaus 2002) include interview schedules, self-completion questionnaires and telephone interviews; they are characterised by closed ended questions. The principles governing the development of such a study are; firstly, a conceptual or theoretical model should form the basis of the design of the survey instrument, the sampling plan and the statistical analysis of the data. Secondly, the market research literature (e.g. Kotler et al 1999; Shiffman and Kanuk 1994) is probably the best single starting point in the development of this model. Since real money hangs on the outcome of market research studies, there is real pressure to get it right, and the market research literature provides syntheses of material from a variety of disciplines. Thirdly, avoid involving economists except in an advisory capacity. Economists are not trained in social survey methods; in disciplinary terms, they are very parochial and, finally, economists are much more interested in theory than reality.

6.4 Vulnerability indices

The concept of 'vulnerability' is necessarily highly contested (Green 2003b) but it needs to be distinguished from related concepts of deprivation, and from the economic concepts of declining marginal value of income and income distribution. Vulnerability is the degree to which some people, or classes of people, are more susceptible to, or suffer a greater degree of harm from, some hazards than do other people or from other hazards. It is necessarily contested because the definition of vulnerability adopted necessarily implies particular forms of intervention in order to reduce it. In exploring vulnerability, the intention is to identify 'hot spots': combinations of people and events that will result in unusually severe impacts. A vulnerability index seeks to provide a way of predicting where those hot spots will occur. As a form of evaluation, a vulnerability index, such as the Middlesex Social Vulnerability Index (Tapsell et al 2002) is particularly appropriate for use in MCA.

Vulnerability must be distinguished from deprivation (Sen 1992): a measure of the degree to which some people lack entitlements to access to resources, including income, but which also may include access to education, health and other social resources. The deprived and the vulnerable may form overlapping sets but the concepts are different; that of deprivation being much more generalised. Equally, whilst the fewer the entitlements that a household has, the more they can be said to be deprived, a single factor might be sufficient to make some household vulnerable to some event.

Again, vulnerability must be differentiated from the question of the marginal value of income. It is accepted in economics that the greater a household's income, the less significant is the loss of a given amount or the payment of such a sum. The value of a given amount thus varies according to the income of that household[27].

A common theme in this report is that a key issue is always the functional form assumed or adopted for some relationship. This involves not only the independent variables included; those, in this case, intended to predict vulnerability, but also the functional relationship between them. In particular, where a greater degree of one desirable attribute can offset an undesirable attribute, and whether the increase in vulnerability for a household with a high degree of two undesirable attributes is simply the sum of the vulnerability which would result from a high degree of one undesirable attribution plus that from the other. Care should be taken not to assume an additive model by default; for example, if vulnerability is taken to be a function of two characteristics, A and B, then $V = f(A, B)$ and the additive model assumes that $V = a.A + b.B$. Hence, even if a household has a high level of characteristic A, this would be offset if it was characterised by a low level of characteristic B. Conversely, it might be expected that a household that has high levels of two characteristics is much more vulnerable than if it has only a high level of one characteristic or if it has moderate levels of two characteristics.

Care must also be taken not to unintentionally impose a functional form on the material through statistical manipulation. For example, income distribution is generally highly skewed and, if it is intended to include income as a factor which contributes to vulnerability, it may be appropriate, and where statistics assuming a normal distribution are to be used it will be necessary, to apply a logarithmic transform to that data. But, if for example, the result of transforming the different variables to normality is:

$$\ln.(v) = a.\ln(x) + b.\ln(y) + c$$

[27] To adjust for such distortions in value by income, income distributional weights may be applied; for example, in the UK, the finance ministry requires flood impacts to be weighted in such a way (H M Treasury 2003).

Then it is being asserted that:

$$V=c.xa.yb$$

This may or may not be logical.

The issue is then which characteristics of a household create a predisposition to vulnerability and what is the functional relationship between those characteristics. There is in general little value in any theoretical claim which does not define the anticipated functional relationship. Where there is insufficient theoretical or empirical grounds to support the assumption of one functional form rather than another, an approach which makes the weakest assumptions about the functional form may be preferred.

Since the intention is to use the equation to make predictions about the vulnerability in different areas, there is a constraint on the characteristics that can be included. It is only useful to include those parameters for which data is publicly available, from census or other sources, about the populations at risk of flooding. For example, suppose that vulnerability were to be found to be very strongly correlated with personality type and previous life experiences, then those two parameters would be of little help in predicting the vulnerability of particular populations because the only way to get the necessary data would be to undertake a social survey of the populations at risk. There are also parameters which are believed to be of importance but for which valid and reliable measures may not yet exist; for example, 'social support' is widely regarded as an important factor in reducing vulnerability, but, using existing measures of social support, whilst flood victims say that social support was important, no affect of social support upon outcome has been found (Ketteridge and Green 1994).

This requirement for available data means that it will generally be necessary to use surrogate factors, those correlated with or dependent upon the predicted determinants of vulnerability, in deriving an Index of Vulnerability. For example, the elderly are commonly regarded as being more vulnerable but the most recent research (RPA/FHRC 2004) found that once prior health was taken into account, the elderly were no more prone to suffer health damage as a result of a flood than anyone else. The elderly are thus vulnerable to flooding not because they are elderly but because they are more likely than others to be in poor health prior to the flood. Whilst data is often available on the age profile of the populations at risk, it is less likely to be available on prior health status and hence it will then be necessary to use the age profile as a surrogate parameter for prior health.

A further problem with available data is that it will be aggregated and aggregated across a geographical area which is unlikely to have the same geographical boundaries as the flood plain. The area across which this data is aggregated may include the flood plain or the flood plain may cut across several different geographical areas within each of which data is aggregated. That data is generally aggregated at population level rather than individual level. Thus, supposing that it is considered that being elderly and being poor are both determinants or correlates of vulnerability, it is likely that the available data will give the proportions of the population who are poor and the proportion who are elderly, but not the proportion who are poor AND elderly. At the same time, in some cases it is data about individual households that is desired and in other cases about the population as a whole. For example, we want to know which are the poor and elderly households, but social capital, for example, is a characteristic of the community as a whole.

Finally, research conclusions as to the critical determinants of vulnerability are by no means clear cut. As noted above, it was considered that the elderly tend to be more vulnerable than others but the most recent research indicates that this is only because they tend to be in worse health than others before the flood occurs. The fundamental problem here is that the larger the number of parameters that are considered might be involved, the larger the sample size required to disentangle the effects.

What this means in practice is that Vulnerability Indices tend to be based upon commonsense, tempered by the availability of data. If there is uncertainty about the role of individual potential determinants in creating vulnerability, there will be even greater uncertainty about the relative importance about the different determinants, and the functional form of that relationship.

For example, suppose that only three determinants are used and there is aggregated data for each in the form of the percentages of the population in different income groups, age ranges and so on for different geographical units (in the UK, for census areas). The frequency distribution of the geographical units for each parameter of concern can then be derived. Any geographical unit which then falls in the upper quartile can then be scored one and all other geographical units scored zero. The same procedure can then be applied for all other parameters of interest. Hence, there are four possible outcomes for each geographical units: each falls into 3, 2, 1 or zero upper quartiles. If we take account of in which combinations of upper quartiles it falls, there are three ways in which it could fall into two upper quartiles and three ways in which it can be in a single upper quartile. Hence, there are a total of eight possible combinations.

If the probability of being in the upper quartile of the distribution on each parameter were to be independent of the probability of being in the upper quartile for every other parameter (in practice, we should expect these probabilities to be coupled) then the percentages of census units in each category should be as follows:

Table 6.2: Probabilities of a household falling into combinations of the upper quartiles on three parameters

Condition	Probability of the combination	Probability of the specific condition
All three upper quartiles	0.015625	
Any combination of two upper quartiles	0.140625	
Any single pair of two upper quartiles		0.046875
Falls into one and only one upper quartile	0.421875	
The upper quartile on a particular parameter		0.140625
In the upper quartile for none of the three parameters	0.421875	

The probabilities will not of course be independent; some will be negatively associated as it is, for example, even at the aggregate level it is unlikely that high proportions of single parent families are associated with high proportions of the elderly. At the same time, we hope that there will not be independence, that those units that fall into one upper quartile are likely to fall into the upper quartile on at least one other parameter.

If we are prepared to adopt an additive function for the form of vulnerability, a vulnerability index can be created simply as the number of times any geographical unit falls into the upper quartile. That approach assumes, of course, that when a unit falls into the upper quartile on two determinants, vulnerability is the same irrespective of which two determinants are involved. If it is not judged appropriate to make that assumption of additivity then the different geographical units can be categorised according to into which of the eight possible combinations each falls.

One vulnerability index is that developed at FHRC for use in developing Catchment Flood Management Plans. This makes use of the data available from the Census in the smallest reported spatial unit. For each output area, the Census reports the proportions of households in a number of different categories. In order to construct the Social Vulnerability Index, three socio-demographic variables were used. These are the proportion of the population who are:

1. aged 75 years or older.

2. single parents.
3. long term sick.

There is no data available for household incomes so four surrogate variables have been used, again using the proportion of the population who are:

1. unemployed.
2. live in overcrowded houses.
3. do not own a car.
4. do not own their home.

In order to construct an index, each output area is scored one if it falls into the upper quartile on each parameter and zero otherwise. The total score is then summed across the seven parameters.

6.5 Methods of monetary evaluation

In any assessment of the reduction in damages from flooding, what we are seeking to measure is the reduction in the expected value of future flood damages: $\Sigma p_i e_i$. Here, p_i is the probability of some damage e_i. Conventionally, we do this through the simplification of the loss-probability curve. In most of the techniques described below, it is impractical if not impossible to simultaneously vary the probability and the outcome. Hence a decision has to be made whether to focus upon the value of reducing the probability or the outcome, and, if so, what relationship to assume between the probability and damage. The soft option is to assume some linear relationship between probability and damage. The second issue is that direct damages can already be estimated using the techniques that are already widely adopted; it is the additional social impacts we wish to measure, either separately or in addition to the direct damages, or by netting those direct damages out of some gross value so as to estimate the social impacts as a residual.

6.5.1 Expressed preference approaches

The practical problem in evaluating social impacts is that there are no market prices which can be observed. There are then only two generic means of deriving values for social impacts: to ask people what value they would put on those impacts; or to infer those values from what can be observed. The potential drawback of the first approach, the social survey approach, lies in whether respondents can actually perform the task in the particular setting in which they are set that task. As a task, it should be viewed in ergonomic terms (Green and Tapsell 1999). Orthodox economists also have the presumption that people will naturally tend to lie, although to be able to lie successfully requires that the task is one in which they can first define what the truthful answer would be. If being honest is difficult, lying successfully is more difficult.

The second approach, the inferred methods, are often misleadingly termed ‘revealed preference’. This label is misleading because what is observed is some gross behaviour, buying a house at a particular price, whereas what we seek to infer is to what extent the price of a particular property is affected by the risk of flooding. The problem is one of statistical inference, and the problem is that of selecting a particular statistical function to fit some set of data. A further limitation is that there has to be reason for assuming that there is a reasonably free market: thus, that property prices or rents are not constrained by such factors as price controls.

6.5.1.1 Contingent Valuation

Contingent Valuation (Bateman et al 2002; Bateman et al 1992; Mitchell and Carson 1989) is simply a social survey approach in which respondents are asked how much they would be prepared to pay for a reduced risk of flooding.

Sterland (1973), in what was one of the first ever CVM studies, asked a convenience sample how much each person would require in compensation to live in a house exposed to various degrees of flood risk. A number of other similar exploratory studies using CVM with convenience samples were also undertaken at about the same time. More recently, four large scale surveys using random representative samples have been undertaken: two in the USA (Daun and Clark 2000; Giese et al 2000; Shabman et al 1998) and two in the UK (Green et al 1992; RPA/FHRC 2004). Of these, the studies at Roanoke are perhaps the most interesting. Following a referendum as to whether the city should issue a bond to part finance a local flood alleviation project, Shabman et al (1998) carried out a telephone survey of 492 voters; the sample was a random sample of registered voters in the city. The referendum itself had been passed by a vote of 56% on a 19.6% turnout of electors. There were some differences (significant at 5%) between those who choose to vote and those who did not. There were more marked differences between those who supported and those who opposed the proposed bond issue. The main reason that those who voted for the bond issue gave voting this way was to help those who suffer from flooding. This result is very interesting; the problem, as already noted, is that economic theory provides no theoretical rationale as to why people should behave in this way. Until there is some adequate theory, there is no basis upon which to design a social survey. Hence, whilst there is a fascinating theoretical issue here, the current state of the art is not one where it is possible to do more than exploratory studies to try to gain insights into what is going on. A problem, when such an understanding has been gained, will be to separate those impacts which are currently evaluated using present methods from the social impacts.

What all of these surveys have found is, firstly, that the amount which individual households at risk report that they are prepared to pay is below the expected value of future flood damages. Secondly, that those who are not at risk of flooding are prepared to pay towards the costs of reducing the losses to those at risk. People do not seem to behave in the ways expected by economic theory and it is not clear why this is, and finding out the basis of their behaviour is an important theoretical and practical question.

General guidelines for the use of Contingent Valuation are given in Chapter 7.

6.5.1.2 Conjoint analysis

Conjoint analysis is a technique that originated in Market Research (Green and Wind 1973) and spread to transport studies as well as other areas (Bennett and Blamey 2001; Louviere 1988) where it is known under a number of other names. Compared to Contingent Valuation it has the great advantage of avoiding the question of who pays. Respondents are to make a series of choices, each between a pair of alternatives, in this case, between properties with varying bundles of characteristics. A possible example is shown in Table 6.3.

Table 6.3: A hypothetic choice in Conjoint Analysis

	A	**B**
Risk of flooding	1 in 10	1 in 200
Monthly housing cost	600 euros	1000 euros
Number of bedrooms	3	2
Proximity to park	1 kilometre	100 metres

Each respondent is asked to indicate their preference or strength of preference between the two options. Various forms of statistical analysis can then be used in order to infer the rate at which respondents are prepared to sacrifice one characteristic for another characteristic. This requires making two assessments: the rate at which preference changes with variation in a single characteristic and the rate at which respondents are prepared to trade-off one characteristic for another. Thus, it could be classed as an inferential method alongside the Hedonic Price approach and so shares some of the same drawbacks. Those drawbacks include:

1. The different characteristics used are necessarily treated categorically rather than as continuous variables.

2. As the number of characteristics and levels within each characteristic increase, so the number of possible combinations that can be compared increases exponentially. This makes it impossible to ask any single respondent to make all possible comparisons. Hence each respondent is only asked to make a sample of the possible comparisons, and the comparisons made by the sample as a whole generally only amount to a sample of the total number of possible comparisons (although this is in principle solvable by increasing the sample size). In turn, that makes it impossible to differentiate statistically between a number of functional relationships.
3. The number of possible characteristics which may be important to an individual's choice between properties may exceed 7, but Miller's classic paper (1956) demonstrated that 7 is the maximum number of characteristics that average person can deal with at any one time.
4. The task of comparison is very tedious for the respondent. There is evidence that the respondent's performance varies over the duration of task: performance initially being poor whilst the respondent learns the task and falling off again after a while when they become bored with it.
5. It is necessary to look for market segmentation; in the example above, it might be anticipated that household at different stages in the lifecycle would have very different preferences with regard to the number of bedrooms in a property where that preference is itself in the form of a step function.

As a technique, it has the advantage that it avoids the explicit question of who pays for flood alleviation works. But it is likely to only be possible to obtain a total sum for all flood impacts, from which direct damages would then have to be removed. Overall, the wide usage of the technique in market research gives credence to it. But the author's own experience as a participant in market research studies is that making the choices is very tedious and difficult. Similarly, the author's experience in applying the technique to evaluate traffic nuisance is that the statistical analysis is very time consuming, not least because the UK housing market proved to be segmented, each group requiring a separate analysis. It is best seen, therefore, as a back-up option, to be adopted if simpler techniques are not judged to be viable.

6.5.2 Inferential approaches

Market based approaches and the Contingent Valuation method share the advantage that a directly observable number emerge from the exercise. In the first case, this is a market price; in the latter case, it is a frequency distribution of the amounts different individuals state that they are prepared to pay for flood alleviation. Inferential approaches start with some gross observed behaviour and seek to infer both the reasons why people adopted that behaviour and the relative importance that they gave to different reasons when making the choice to adopt that behaviour.

6.5.2.1 Hedonic price method

This method is commonly misleading labelled as a 'revealed preference' technique, implying that people's preferences can be observed from their behaviour. In practice, inferences are made about their behaviour through statistical analysis of data on the market prices of properties and the characteristics of those properties, so that the value of lower flood risk is inferred from the relevant coefficient in some multiple regression equation. The problems with the technique are consequently those associated with any form of sampling and statistical analysis in which one statistical function is fitted to some set of data. The issues are thus vary similar to those predicting the return period of a flood of a given magnitude from some stream flow data or of deriving some regional growth curves for flood magnitude. Notably, there is a risk of mis-specifying the regression equation either or both in terms of the independent variables included or the functional form of the equation assumed. These risks are increased because there is no theoretical reason for determining either what variables ought to be the independent variables or the functional form of the equation.

The key condition before this method can be considered is that something approximating to a free market exists; if a large proportion of the housing stock is rented and price controlled in some way then this method cannot be used. The method has a number of other limitations:

1. Data notably upon property prices or values must be available, generally this is should be on the actual price at which a property was sold.
2. The area affected by flooding must be large enough to result in a sufficiently large sample of properties upon which to carry out the statistical analysis.
3. Only those potential explanatory variables for which data at individual property level is available can be included.
4. There is evidence that housing markets are commonly segmented both demographically and also geographically.

Sugden and Williams (1978) made the interesting suggestion that house prices should be expected to vary in relation to flood risk only in relation to those damages which could not be recovered through insurance and/or compensation. If true, then the method has the strong advantage of separating those damages in which we are interested from the direct damages already included in economic analyses of flood alleviation schemes. However, insurance is a luxury good, the proportion of households buying insurance increasing as household income rises.

In practical terms, this method is of interest largely for experimental purposes rather being likely to yield valid and reliable results in any particular circumstances. A competitive rental market might be the most promising context in which to test its use.

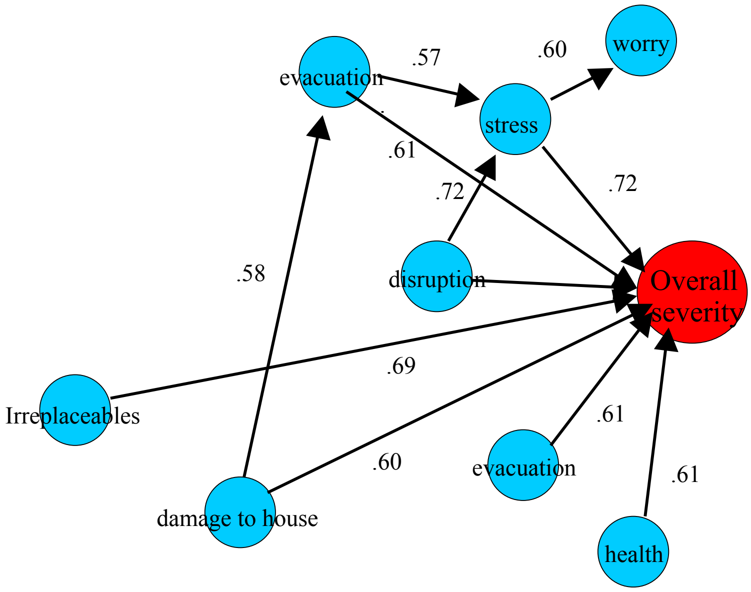
6.5.2.2 Bootstrapping

This technique was developed at FHRC some twenty years ago (Green and Penning-Rowsell 1986; 1989), being inspired in part by the pioneering Tug Fork study (Allee et al 1980). It is grounded in the orthodox economic assumption that value is subjective; economic value is simply how much someone wants something compared to their desire for other things.

In its simplest form, the bootstrapping approach involves a social survey of flood victims. In the course of that interview, the flood victims are asked to rate subjectively the relative severity of the different impacts of the flood upon their household's life. Those impacts include those impacts conventionally included in the cost-benefit analysis of flood alleviation schemes: the direct damage to the dwelling and its contents. But they also include some of the social impacts of flooding, including: the stress of the flood; disruption to the life of the household, and the effects of the flood on the life of the household. In addition to these subjective assessments of the different impacts of the flood on the household, the interview schedule also includes questions asking for quantitative information where appropriate (e.g. the value of the damages to the household, whether or not any member of the household sought medical help, how many days it took to get the home back to normal and so on).

The respondents are also asked to rate overall the effect of the flood upon their household. It is then a reasonable assumption that the individual respondents' assessments of the severity of the different impacts of the flood should explain the differences in their assessments of the overall severity of the flood. For example, the regression coefficients obtained in one study (Green et al 1994) are shown in Figure 6.2. As that figure shows, the subjective severity of some the impacts are themselves inter-related, some variables affecting the subjective overall severity of the flood indirectly through their effect on immediate variables. Hence, it is necessary to use causal analysis (e.g. Asher 1976) to disentangle the different inter-relationships. The figure also shows that respondents appear to have responded differently to the question on stress to the interpretation that we intended.

Figure 6.3: Example for regression coefficients of flood impacts derived by bootstrapping technique



The relationships imply that stress should be understood in terms of the overall experience whereas the intention was to ask about the stress of the event itself. The figure also shows that whilst damage to the house has both a direct and an indirect effect on the overall severity of the flood (through its effect on evacuation, and evacuation's effect on stress), damage to the replaceable contents does not have any significant effects.

The procedure used to put a money value on the social impacts starts with the orthodox economic assumption about the nature of value: that this is the individual's subjective desire to gain goods or to avoid some consequence. Thus, for the impacts which are priced (e.g. the damage to the house and damages to replaceable contents), if there is some relationship between the subjective severity of the damages and the monetary value of the damages, this relationship can be used to infer the monetary value of the other impacts. For instance, and to over-simplify, if a subjective severity for the damage to a building of 6 corresponds to a loss of 5,000 euros, then a subjective severity of 6 for health damage is taken to imply a monetary equivalent loss of 5,000 euros. It is obviously necessary in doing this to net out indirect effects in order to avoid double-counting.

As an approach, it scores highly as a means of gaining understanding but the lesson is that it requires very large samples in terms of the combinations of affected populations and flood conditions in order to disentangle the different effects and relationships. Notably, the effectiveness of both flood warnings and social support in reducing the social impacts of flooding remain ambiguous.

6.6 Conclusions

We want to make 'better' choices about interventions to mitigate the effect of floods; to do so requires that we gain a better understanding of the nature of each choice which we must make (including about the social impact of floods).

This is a process of learning, and in the course of learning about the nature of the choice, we also hope to invent a better option: a better type of intervention. Hence, these guidelines are not about what to do but how to learn, what techniques can help us discover more about the nature of the choice that must be made. Quite clearly, this chapter shows that there is still a lot to learn.

Which techniques are most useful in assisting us with our choices must then reflect the approach being adopted to making the choice. As stakeholder engagement increasingly becomes the central feature of decisions about flood risk management, Deliberative Multi-Criteria Analysis is likely to become the critical project appraisal technique. Here, a vulnerability index is likely to be a useful technique and this will involve the analysis of the social impacts of floods that has been the subject of this chapter: the effects of floods on people.

But as always in flood risk management, nothing is that simple. A key group of stakeholders who are likely to be under-represented are those who will bear the costs of the intervention strategy, the general taxpayer. Some measure of 'value for money' is the minimum required to provide accountability (e.g. benefit-cost analysis). However, currently we lack not only any knowledge of what are the priorities of the taxpayer with respect to flood alleviation, and their willingness to pay, we also lack any economic theory as to why they are willing to pay. In essence that means that we may know more, by learning, about the social benefits of flood interventions (by studying the social impacts of floods) but we remain almost entirely ignorant of the social costs of flood intervention and the sizeable investment that it often involves.

Annex 6.1 Summary Guidelines

1. The purpose of the exercise is to gain understanding; numbers are useful in so far as they summarise that understanding.
2. Do not give the responsibility for the development of the methodology to traditional economists but commission social scientists with a wider perspective instead.
3. The market research literature is a good starting point for the development of a survey methodology.
4. The starting point for any study has to be a concept model showing the key concept and the predicted relationships between those concepts. Questions, sampling design and statistical analysis should always be based upon that conceptual model.
5. Remember that words matter; that is why we have so many of them. Changing a word can completely change the meaning of a question. It is essential to be clear both what you mean by a word and also how it is understood by the respondents. When translating a questionnaire or interview schedule from one language into another, it is desirable to do a back translation in order to check for words that do not have exact equivalents in the second language. For example, the word 'right' in English can carry connotations of both 'correct' and 'just'; so, in some contexts, it would be incorrect to translate 'right' as simply 'correct'.
6. Measurement is a social act; the respondents will seek to interpret the purpose of the survey and its form and nature will provide them with information as the basis of this interpretation. When the survey is of flood victims, there is the ethical question of why they should agree to participate, and what will be the effects of taking part in the survey upon those flood victims?
7. It is always tempting to design any interview schedule or questionnaire from scratch. This temptation should be resisted, not least because it means that the results from no two studies will ever be comparable. Given the amount of testing that is required to establish any measurement instrument as being valid and reliable, it is preferable as far as possible to borrow from the tried and tested.
8. Reliability is almost invariably enhanced by the use of multiple questions intended to measure the same concept.
9. The basis for validity is the clear conceptualisation of what it is intended to measure and the reasons why that variable is of significance.

Annex 6.2 Current 'best of breed' survey instruments

Parameters	'best current practice'	Reference
General interview schedule for flood victims	Standard household interview schedule	Penning-Rowsell et al 1992
Event stress	Event stress scale	Parker et al 1987
Distress	Impact of Event scale	Zilberg et al 1982
Health status index	General Health Questionnaire 12 (GHQ-12)	Goldberg and Williams 1988
Worry about future flooding	Guttman scale of worry	Parker et al 1987

7. Making choices on the quality of the environment: Contingent valuation and cost-benefit analysis

Contributed by Anne van der Veen and Joerg Krywkow

7.1 Summary

Contingent valuation (CV) is a relative novel method to monetise environmental changes. This survey-based method has been emerging due to an increasing societal interest in representing the appreciation and valuation of intangibles such as nature, biodiversity, clean water and many more in complex assessment methods and decision support. CV enables scientists and practitioners to directly compare environmental goals to goals such as decreasing unemployment, keeping the inflation down, keeping the governmental budget balanced and others in a societal economic context.

The incorporation of environmental changes into decision support tools appears to be difficult since no actual prices can be determined for environmental goods. With a CV scientists or practitioners try to recover non-use or existence values. This is fundamentally different from cost-benefit analysis (CBA), where welfare changes are attempted to be measured via prices of goods and services.

CV provides a 'workaround' by applying methods that measures the "willingness to pay" and the "willingness to accept", and this way creates artificial market prices. Parameters for an artificial market can be found through interviews and surveys eliciting environmental interests and preferences of involved stakeholders. Based upon the "hypothetical approach" and in combination with empirical data CV supports the incorporation of environmental goods in a CBA.

The literature holds many examples for applications of CV, which will be briefly discussed in this report. Furthermore, some emphasis is put on the way monetisation of environmental goods can be accomplished. Since CV was firstly introduced in the US, and is successfully applied there, the role of CV in the US is discussed as well as applications in Europe and the criticism of applications in both regions. At the end of the report we give some recommendations of how CV techniques can be applied in the context of the European Union.

7.2 Introduction

Many flood effects cannot be the subject of valuations derived from conventional markets, but are nevertheless known to be very large and important. This chapter looks at techniques for assessing these effects.

Due to an increase in social awareness with regard to environmental degradation over the past decades, the quality of the environment is becoming increasingly important in decision-making processes. Next to traditional goals such as stimulating employment, keeping inflation down and keeping the government budget deficit under control, the environmental quality is an important aspect on which public policy is based. Therefore, environmental changes will have to be incorporated in decision support methods. In the flooding context environmental change mean a loss of or damage to 'environmental' goods. This can be a mere loss of CO_2-absorbing biomass, biodiversity or the loss of rare species, the loss of recreational or aesthetic value or 'cultural' landscape. If costs and benefits of flood mitigation measures are calculated, these values must be included in the evaluation. If multi-criteria analysis is used as decision support method, no special adaptations are required to incorporate environmental aspects. Environmental impacts are dealt with in the same manner as other non-monetary criteria such as the number of jobs or the number of years it takes a project to achieve its purpose. However, if benefit-cost analysis is used as a decision support method, we are faced with the problem that no prices are available for environmental goods. So there is a need for a procedure which converts the changes in environmental goods into monetary terms. Put more precisely: because benefit-cost analysis aims to measure welfare changes, an alternative method should be used to demonstrate *Willingness-To-Pay* (WTP) or *Willingness-To-*Accept (WTA) for a given amount of environmental goods. If this approach proves to be successful, benefit-cost analysis will be more complete.

The literature (Freeman, 1979; Johansson, 1987; Pearce & Markandya, 1989) describes a number of environmental evaluation methods, such as the Cost-of-Illness method, the Averting Behaviour method, the Hedonic Pricing method, the Travel Cost method and the Contingent Valuation method. A main distinction between these methods is whether it is based on *revealed* preferences, or *expressed* preferences (Contingent Valuation method). Revealed preferences methods are more familiar to economists and traditionally inspire them with more confidence than expressed preferences methods as the Contingent Valuation method, because the former makes use of the *observable behaviour* of individuals. In contrast, the Contingent Valuation method creates an artificial market for a good by means of a questionnaire, where an individual shows *hypothetical* behaviour by *expressing* his/her monetary valuation for the proposed change in the availability of a good. So, the main difference between revealed preferences methods and the Contingent Valuation method is that the latter method puts individuals in a *hypothetical* position and elicits the monetary valuation of a certain environmental change by means of a questionnaire or survey. An artificial market is the representation of monetary values that have been determined throughout the survey-based valuation of non-market resources. Although these resources have utility, they do not have market value. However, for the sake of comparability these resources receive a value that can be seen as monetary equivalent to market prices. Since individuals can receive benefit from resources such as the beauty of a landscape, fresh air, the diversity of species and many more, these value must be considered as loss, similar to a loss of property and production capacity.

In the following we will concentrate on Contingent Valuation as a method to monetise environmental changes. We will highlight recent contributions to the valid and reliable application of the CV method. We will discuss experiences in the US with the method and the consequent rules that were designed for a proper application within CBA. Finally, we will shortly discuss the role CVM plays in European decision making. It is our view that this role is limited. We will formulate recommendations for applying CV analysis within a European institutional context.

Part of the theory on CV analysis as presented below is based on in his PhD on CV analysis at the University of Twente.

7.3 Brief History of Contingent Valuation

The origins of Contingent Valuation are credited to Ciriacy-Wantrup (1947), as cited by, who suggested the use of the 'direct interview method' to obtain the economic values of natural resources. However, it was Davis (1963) who played a key role in the development of CV. He argued that it would be possible to approximate a market for non-marketed goods by means of surveys; the survey should carefully describe the artificial market, including alternative options, while market behaviour could be simulated by putting the interviewer in the 'position of a seller who elicits the highest possible bid from the user for the services being offered' (Davis 1963: p.245). Davis applied his ideas to measure the economic benefits of a particular recreational area, specifically recreation activities in the woods of Maine. For this purpose he personally interviewed 121 hunters and recreationers. His study was followed by several others, of which the study reported by Randall, Ives and Eastman (1974) was a remarkable and influential one, because they were the first to obtain estimates of benefits of an environmental good, namely aesthetic improvements (air visibility), which could *not* be compared with other valuation methods.

A strong stimulus for the development of monetary valuation methods was given by Reagan's Executive Order 12291 in 1981, which stipulated that all proposed regulations on environmental policy should be subjected to benefit-cost analysis. New environmental regulations would only be carried out if a positive net present value for society could be obtained. Therefore, the social benefits of environmental improvement (or prevention of environmental degradation) had to be monetized. The flexibility and general applicability of CV is the main reason that this method has since then received the most attention.

7.4 The CV method

The Contingent Valuation (CV) method is based on survey research; its aim is to elicit people's preferences by asking whether they are prepared to pay for changes in the availability of a public (specifically, an environmental) good (Mitchell & Carson, 1989). In the survey, an artificial market is created in which the respondents are given the opportunity to 'buy' (or ‘sell’) certain goods. The main distinction between CV and the other valuation methods is that CV is based on *expressed* preferences instead of *revealed* preferences; that is, the results of CV can be seen as *intended* behaviour, while revealed preferences methods are based on *actual* behaviour.

At the moment, the Contingent Valuation method is the most promising monetary valuation method for environmental changes. This is partly due to the following two important features (Pearce & Markandya 1989: p.35):

- Contingent Valuation is often the only technique for assessing benefits
- Contingent Valuation should be applicable to most contexts of environmental policy

The advantage of the hypothetical nature of this method is that goods can be valued which cannot be valued by methods based on revealed preferences. The CV method should be able to value environmental changes which have never occurred yet and changes with which respondents are not familiar. This implies that CV could be a useful instrument in ex ante decision making. Conversely, the hypothetical nature of CV is also its main source of criticism, because it creates the possibility of giving an arbitrary response without bearing the consequences of (wrong) decisions. Therefore it is doubtful whether the stated valuations are valid. On the other hand, an advantage of the hypothetical nature of the CV method is that, as opposed to the other methods, the validity of a specific application of CV can actually be *tested*. Finally, CV measures total economic value, including non-use value.

7.4.1 Non-use values

Non-use value is an indicator of the utility derived by individuals ‘from an amenity for various reasons other than their expected personal use’ (Mitchell & Carson 1989: p.63). This differs from the traditional concept of economic value in two respects: firstly, the wider concept of use benefits does not necessarily have to be accompanied by direct and observable financial transactions (such as noise pollution and air visibility); and secondly, economic benefits might arise even if the individual is not personally and physically affected by a change in the amenity, which we then label 'non-use value'. And, as argued by (Randall, 1991) ‘both of these ideas are well within the purview of the standard economic model of benefits’. The intellectual origin of the concept of non-use value comes from (Krutilla, 1967), who remarked that there are people who are willing to give up scarce resources for the continued or improved existence of wilderness even though they never would visit that area. This was labelled *existence* value. Contingent Valuation is the only monetary valuation method which, from a theoretical point of view, is capable of measuring non-use values.

7.4.2 Measuring non-use values and welfare economics

In a CV study respondents are asked to value an environmental change which will (usually) have an effect on his/her level of welfare. This change in welfare is made operational by assessing changes in utility. In benefit-cost analysis, the change in utility is frequently measured by the change in consumer surplus.

Welfare analysis, which is part of neo-classical economic theory, deals with welfare changes resulting from price changes. The analysis of welfare changes due to changes in the availability of public goods requires only minor adaptations.

7.4.3 Structure of a CV Study

The CV method is based on survey research; its aim is to elicit people's preferences by asking to what extent they are willing to pay for changes in the availability of a public (specifically, an environmental) good (Mitchell & Carson 1989). The survey creates an artificial market, where the respondents are given the opportunity to 'buy' certain goods. To this end the survey has to meet a number of methodological conditions with respect to survey research, but also with respect to economic theory[28].

Basically the survey consists of three parts (Mitchell & Carson, 1989: p.3):

- Firstly, a precise description of the good which has to be valued and of the hypothetical circumstances in which the public good is made available to the respondent. The purpose is to create an artificial market which comes as close as possible to a real market for that particular good. During this stage information is given about the present condition of the good, the proposed changes in quantity or quality of the good and the means of payment (e.g., tax increase, entrance fees or membership dues).
- Secondly, a number of questions should be asked which are intended to elicit the respondents' WTP for the defined change in availability of that good. The respondents may be asked to value different levels of availability of the good, so that a demand function for the good in question may be estimated. Moreover, in the course of these questions the respondents should be confronted with their previously stated WTP and be given the opportunity to revise their WTP.
- Thirdly, questions are asked about certain characteristics of the respondents (such as values, current use of the good, age and income). These characteristics are used to explain the WTP of the respondent and to determine the validity and reliability of the CV method as a measuring instrument of WTP for (environmental) goods.

7.5 CV analysis in the US

As stated above a strong stimulus for CV analysis in the US was given by Reagan's Executive Order 12291 in 1981, which stipulated that all proposed regulations on environmental policy should be subjected to benefit-cost analysis. New environmental regulations would only be carried out if a positive net present value for society could be obtained. Therefore, the social benefits of environmental improvement (or prevention of environmental degradation) had to be included.

In 1983 the Environmental Protection Agency of the United States (EPA) asked three CV researchers, Cummings, Brookshire and Schulze, to write a state-of-the-art assessment of CV and to 'reflect on past achievements, remaining problems and future possibilities' (Mitchell & Carson 1989: p.14). Their assessment resulted in the following four Reference Operating Conditions (ROC's) (Cummings Ronald *et al.*, 1986):

- Subjects must understand and be familiar with the to-be-valued good (ROC 1);
- Subjects must have had, or be allowed to obtain, prior valuation and choice experience with consumption levels of the to-be-valued good (ROC 2);
- There must be little uncertainty (ROC 3); and finally,
- WTP and not WTA measures should be elicited (ROC 4).

If these conditions were met, the researchers expected the accuracy of the CV results to approximate the accuracy of estimates from 'normal' market research.

[28] Assumptions in standard economic theory are, for example, transitivity, completeness (particularly of interest to a CV, because in a CV study respondents are confronted with two potential situations, i.e. with/without the environmental improvement and without/with the money). See Anand (1993) for a philosophical discussion of the assumptions in neoclassical economics, and Deaton and Muellbauer (1980) for an extensive discussion of the relevance of these assumptions related to the theory of consumer behaviour. See also section 4.4.

Another major event related to CV research was the huge oil spill due to the grounding of the oil tanker Exxon Valdez in Prince William Sound in the Northern part of the Gulf of Alaska on March 24, 1989. This oil spill was the largest oil spill from a tanker in U.S. history; more than 1000 miles of coast line were affected in an area which was pristine before the oil spill. The total number of dead birds recovered (so it is the lower limit for the actual number of dead birds due to the oil spill) in the area of the spill was almost 23,000 birds, some 75% of which were murres. After the oil spill the State of Alaska undertook various studies to identify the physical damage to natural resources as a result of the oil spill and accompanying economic damage. The studies which measures economic losses also take into account, in addition to the cost of purification, aspects such as the decrease in revenue from recreation and fisheries. Besides this loss of use values, the oil spill also resulted in a loss of non-use values. An interdisciplinary group of experienced CV researchers was commissioned by the state of Alaska to perform a CV study to measure the loss of non-use value to U.S. citizens (excluding people who lived in Alaska, because their value could partly be use value). The loss of non-use values resulting from the Exxon Valdez oil spill was estimated at 2,8 billion US$ (1991 rate) (Carson, 1992).

7.5.1 Criticism on CV analysis in the US and consequent NOAA recommendations

Exxon anticipated the potentially high financial consequences of the Exxon Valdez oil spill and commissioned a number of researchers outside the field of CV who were asked to perform a number of empirical studies to verify whether non-use values could be accurately measured by means of CV. The (predictable) conclusion of this group of researchers was that the CV method is *not* capable of resulting in valid and reliable measures of non-use values and that therefore assessments of lost non-use values by means of the CV method should not be used in court. The main argument of propagators of CV, in response towards their critics, is summarized by Mitchell (in Hausman, 1993: p.211): 'You draw some rather strong conclusions about contingent valuation as a method, based on your analysis of a particular study. And yet when you look at the study, the study does not in any way, shape or form represent the state of the art of contingent valuation..'.

In view of the damage which resulted from the Exxon Valdez oil spill in Alaska, it is interesting to look at the Oil Pollution Act (OPA) of 1990. This Act 'provides for the prevention of, liability for, removal of and compensation for the discharge [...] of oil into or upon the navigable waters of the United States, adjoining shorelines or the Exclusive Economic Zone' (Campbell, 1993).

The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce had to develop regulations and procedures to assess the damages to natural resources covered by the OPA. With this objective in mind the NOAA asked a number of independent researchers to evaluate the accuracy of the Contingent Valuation method for measuring non-use values. This 'Blue Ribbon' CV Panel concluded that provided a number of stringent conditions (mainly survey guidelines) were met, CV studies could convey useful information and that CV estimates were 'reliable enough to be the starting point of a judicial process of damage assessment, including lost non-use values' (Arrow *et al.*, 1993).

The NOAA recommendations can be summarized as follows (See also (Alberini *et al.*, 2005):

1. Apply face to face interviews and allow for pretesting in focus groups
2. Design the survey in a conservative way
3. Elicit WTP instead of WTA
4. Apply a dichotomous choice referendum format
5. Investigate the reasons for No-answer or Would-not-vote
6. Include follow-up questions to investigate Yes or No answers
7. Remind the respondent of their budget constraints
8. Test for the effects of photographs
9. Cross-tabulate WTP with variables such as income, prior knowledge of the site, prior interest in the site (visitation rates), attitudes toward the environment, attitudes towards big business, distance to the site, understanding of the site, belief of the scenarios, ability or willingness to perform the valuation task.

7.6 CV analysis in the EU

In Bateman and Willis (1999) the EU institutional Framework for CV analysis is reviewed by Bonnieuux and Rainelli, (1999). The authors conclude (p. 609) that ‘to date there has been a noticeable absence of guidance regarding the use of valuation techniques within European decision making’. Also on page 601: ‘ We….. have little evidence of CV studies directly influencing regulations and only circumstantial indications of an effect upon wider policy’. In a review for a recent EU project (Alberini *et al.*, 2005) conclude that Contingent Valuation studies have been conducted in many European countries, however only in a few cases have the estimates of WTP from these studies constituted the grounds for policy. As a positive exception, in the UK CV analysis has been applied for a variety of public goods: environmental quality, transportation policies and safety programs.

That is a rather meager result. More seriously, we are not aware of an EU analogy of the US ROC, or NOAA recommendations to do CV analysis. Otherwise stated, CV analysis has not received the same institutional embedding, which was given in the US. This is of course due to differences in legislation between the US and the EU. However, we do think that acceptance of CV analysis within a CBA decision framework requires rules for the application of the technique, analogous to rules regarding discounting.

An interesting example of a major difference in the setting for a CV analysis is given by Polomé, van der Veen and Geurts (2004), where the influence of a referendum format, which is quite uncommon in Europe, is tested. The results indicate that the context does indeed significantly affect the estimated values.

Before we will answer the question whether it is time to formulate recommendations to do CV analysis in a EU institutional setting, we will turn to some recent criticism.

7.7 Recent criticism on the use of CV estimates in CBA

The CV method has been rejected by many researchers as a method for measuring preferences for environmental goods. Early criticism on the use of Contingent Valuation, as already stated above, to assess the non-use value of environmental goods was given by a group of scientists in Hausman (1993). Here it was concluded that the CV method is not suitable for measuring preferences and that therefore its outcomes should not be used in a CBA. Their main argument is that the WTP responses are implausible, and inconsistent with the assumptions of rational choice in neoclassical economics.

More specific Lichtenstein & Slovic (1971) mention ‘preference reversal’ as a major problem. It means that basically equivalent methods result in different orders of preference, which disrupts the procedural invariance. A distinction between methods which is often applied is that of 'choice' (or rating) versus (WTP-)‘payment’ (Tversky, Slovic and Kahneman, 1990). Preference reversal has been demonstrated in many studies. See also (Sugden, 1999) for a review.

Another point of criticism of the CV method is the fact that apparently unimportant changes in the design of the CV survey often result in large changes in the stated WTP. This lack of (convergent) validity (comparable to 'procedural and descriptive invariance' in cognitive psychology) was characterized by Shafer (1986, p.464) as 'the most fundamental result of three decades of empirical investigation' in behavioural decision-making. Despite the fact that cognitive psychological theory does not give a cut-and-dried explanation for the lack of procedural and descriptive invariance, some ideas have been proposed in which direction we should look for an explanation (Payne *et al*. 1992; Krosnick 1991). In general, Gregory *et al*. (1993) are of the opinion that the 'unrealistic cognitive demands upon respondents' (p.178) constitute the main problem of current CV methods.

Furthermore, in the empirical studies on which the critics base their opinions it is usually implicitly assumed that a respondent has 'articulated values' (Fisschoff, 1991); this means that individuals have assigned an ex ante value to all possible goods (including goods unknown to the respondents and goods with which respondents have no experience). The respondents are simply expected to retrieve this value from memory and report it accurately. However, even in the case of market goods this approach is not acceptable: 'it would presumably be implausible to argue that individuals were born with an innate demand schedule for video-recorders' (Green, 2003). In case of public goods, with which respondents do not necessarily have experience, it is even less likely that respondents will have a stable ex ante value for these goods. Less extreme is the thought that individuals will construct stable preferences for goods through experience and possibly through mistakes in market behaviour. Particularly, in the case of relatively unfamiliar goods, respondents should be supplied with sufficient information as to make it clear to them precisely what they are supposed to value. If a respondent is confronted with an interview without having any clear preferences for the good in question, he will have to *construct* a value during the interview (Gregory *et al.* 1993). This causes difficulties in Contingent Valuation, because it makes WTP very dependent on the presented context (Fischhoff & Furby 1988). It is not completely clear how respondents construct a value during the interview; besides, it is doubtful whether the construction of a value during the short time of the interview will lead to stable preferences and stable CV responses.

Finally, to describe a CV scenario knowledge is required on how information is processed. Dependent on the level of complexity of the scenario, there may be a lot of respondents who do not have the mental capacity to assess the impact of the to-be-valued problem and to understand what it means for their own situation (Harris *et al.* 1989; Krosnick 1991).

The criticism as formulated above becomes available more and more in a structured way. In the following we will summarise five articles that constitute, what we call, a new body of knowledge regarding the way economists deal with non-use values in the formation of preferences and perceptions.

1. In Sugden (1999) a thorough review is given on the neo-classical economic basis for CVM analysis. The author confronts Hicksian welfare economic theory with empirical findings of CV surveys. He is puzzled by systematic patterns that are not compatible with Hicksian theory. His conclusion is twofold: either Hicksian theory that models consumer choice is fundamentally flawed, or learning and feedback mechanisms that operate in real markets tend to induce behaviour that is consistent with Hicksian theory. The first conclusion requires new theories of decision making, and the latter asks for more empirical research.
2. In Green and Tunstall (1999) it is argued that a CV survey is a psychological experiment. And psychology does not accept the axiomatic claims made for the assumptions upon which the neo-classical model is built. The psychological model is a process model where the emphasis is on how beliefs and preferences are formed and learnt, and how information is acquired. In an interview the psychologist is worried about whether the task asked of the respondent is one which they can do. Moreover, whilst psychology shares with economics a focus on the behaviour of the individual in isolation, social psychology treats individual behaviour as emerging from the individual’s interaction in a social context. In their conclusion the authors end by stating that any CV survey is an experiment and that it is not an ‘off-the-shelf’ procedure which can be simply used to go out and get some values. It thus is not possible to set out a recipe book and consequently the NOAA guidelines are premature.
3. McFadden (1999) discusses the concept of rationality that underpins economic analysis. His conclusions are the following: Experimental evidence provides no support for preference rationality, although the evidence contradicting preference rationality is mostly circumstantial. More seriously, failures of perception and process rationality may render behaviour so erratic that even if they exist, preferences are largely irrelevant to the explanation of observed behaviour.
4. In Wierstra, Geurts and Van der Veen (2001) empirical evidence is provided for some of the issues mentioned above. First of all, it was tested whether respondents were able to handle complex information in the valuation of an environmental good (reduction in the risk on flooding). Secondly, validity was researched in the valuation of a purely non-use environmental good. The conclusion was that scope validity is ambiguous for goods with high

content of complexity. Moreover, construct validity was not guaranteed for environmental changes with non-use values: Economic factors were not significant, only attitudes were relevant.
5. In a paper in Land Economics Vatn (2004) tries to integrate the theoretical flaws in the application of CV analysis. His conclusion is, in our words, that there are too many anomalies in empirical CV studies that cannot be explained by standard economic theory. Vatn (2004) points to problems related to presumptions about information and information handling, and the characteristics of preferences and preference formation. He believes that a better understanding can be found in expanding the analysis from the individual to the social level.

The five papers suggest that CV analysis is only at the beginning of a long trajectory. It is our belief that current anomalies in empirical analysis should be solved by new theoretical insights. Consequently, building in of CV results in a CBA analysis is a potentially dangerous route to go. We therefore suggest to be careful in applying CV analysis. A distant attitude is recommended. By no means this implies that we like to abandon CV analysis: we like to stress that every CV analysis is a psychological experiment (Green and Tunstall, 1999). Our approach is rather conservative; we like to stay on the safe side.

7.8 EU Recommendations on domain and technique for CV analysis

The distant attitude is translated in recommendations on the domain of environmental goods that can be researched and in the technique of CV analysis.

With respect to the *domain* we propose the following conditions:

1. Market condition: Test whether the national government does accept the rules of the market and thus the outcomes of the CV survey in her public decision-making.
2. Information condition: Test whether respondents understand the valuation task.
3. Scale condition: Do not apply CV analysis to large scale environmental changes
4. Irreversibility condition: Do not apply CV analysis to environmental changes, which are irreversible.

The domain conditions are translated in the following type of goods that can be valued by means of CV analysis: Environmental changes, which are characterized by:

1. Short-term
2. Reversibility
3. Small-scale
4. Easy perceptibility
5. National accountability stance

We do not recommend to perform a CV analysis for environmental changes, which are characterized by:

1. Long-term
2. Irreversibility
3. Large-scale
4. Difficult perceptibility
5. Cross-border accountability stance

With respect to the *technique of CV analysis* we propose to accept the NOAA rules, not as a recipe book (Green and Tunstall, 1999), but as a first recommendation to apply the technique of survey analysis. There is, however, one exception we introduce in relation to the EU institutional context: careful testing is required on the use of the typical US institutional referendum format.

1. Apply face to face interviews and allow for pretesting in focus groups
2. Design the survey in a conservative way
3. Elicit WTP instead of WTA
4. Test for validity in applying a dichotomous choice referendum format in the EU institutional context.
5. Investigate the reasons for No-answer or Would-not-vote
6. Include follow-up questions to investigate Yes or No answers
7. Remind the respondent of their budget constraints
8. Test for the effects of photographs
9. Cross-tabulate WTP with variables such as income, prior knowledge of the site, prior interest in the site (visitation rates), attitudes toward the environment, attitudes towards big business, distance to the site, understanding of the site, belief of the scenarios, ability or willingness to perform the valuation task.

8. Damage reducing effects of flood warnings

Contributed by Sylvia Tunstall and Dennis Parker

8.1 Introduction

8.1.1 Context of flood warning

Recent flood events across Europe and growing evidence of the potential for increased and more extreme flooding due to climate change have highlighted the need to manage flood risks through a range or combination of mechanisms rather than to place reliance upon protecting people and properties through structural flood defences (e.g. in U.K, Defra 2004; Evans et al, 2004, Environment Agency 2003a). As a result, flood warnings systems have come into prominence as a key mechanism for managing flood risk which involves both the probability of flooding occurring and the consequences for the people and property affected. A number of European countries (e.g. Britain, France, Germany and others) are currently expanding their flood forecasting and warning systems.

Flood warnings, it can be argued, are the most fundamental mechanism for flood risk management since even where structural flood defences are provided, residual risks remain. Moreover, long established settlements are likely to remain in flood risk areas even if new development is kept out of the flood plain. Importantly flood warnings can be instrumental in preventing loss of life and injury in floods and this 'public security' aspect provides a key justification for developing flood warning systems. Warning systems also have the potential to reduce flood damages and economic losses. Their economic evaluation and justification can be based on the damages they save and the other economic losses that they prevent. Yet despite the high priority accorded to flood warning in flood risk management by governments, there is a lack of sound data on the benefits (and costs) of these systems.

More generally a flood risk management strategy which uses flood warnings, either solely or in conjunction with other management options, can contribute to making the occupation of floodplains and coastal flood risk zones more sustainable over time.

8.1.2 Rationale for producing this guidance

The aim of this chapter is to summarise what is known from the literature review and data produced by various European and other countries about the potential damage reducing effects of flood warnings. It is also the intention that the chapter should provide indications on the methods that may be used to generate data on the effects of warnings on the impacts of flooding.

8.1.3 Objectives for the use of the information in this chapter.

The overall aim is to produce guidance that will aid in improving the effectiveness of flood warning systems and the social and economic justification for providing such systems.

The information on the damage reducing effects of flood warnings may be used in the following ways.

- To evaluate the benefits of investment in flood warnings (against costs) at national, regional, local or scheme level and to compare the benefits of different flood warning options or levels of investment. For example, in England and Wales, the benefits of various options for national investment in flood warning systems have been appraised as part of the development of the Environment Agency's Flood Warning Investment Strategy Appraisal (Environment Agency 2003b). For the 2003/4 to 2012/13 period the Environment Agency has calculated that, with some 375 million euros of anticipated investments in England and Wales over 10 years, that

the benefits yielded in terms of flood damages saved will be in the order of 1,892 million euros with a ratio of benefits to costs of 4.82.
- To facilitate comparison of the benefits and costs of different flood risk management approaches: structural flood defences as compared with flood warnings schemes.
- To compare and prioritise among possible flood warning schemes for different locations.
- To enable cost benefit analyses for structural flood defences to be adjusted to take account of the benefit reducing effects of flood warnings (where there is a flood warning system in place providing property owners with the opportunity to move or protect their property, flood damages, and thence scheme benefits will be reduced to some extent).

Guidance on ways of generating information on the damage reducing effects of flood warnings provides an important way of ensuring that a consistent approach is adopted when such comparisons are made.

8.1.4 What is included in this chapter

The guidance in this chapter is in draft form for two reasons.

- Guidance on the damage reducing effects of flood warnings need to relate to and to build on other activities in Task 9, chiefly the information on flood damage databases and on estimating economic damages from flooding.
- In the UK, substantial work is in progress to review the methods for estimating the damage reducing benefits of flood warnings developed by FHRC and employed by the Environment Agency in England and Wales. The guidance has been partially amended but may need to be further revised where appropriate to take account of further developments in the research and literature.

This chapter (section 2) outlines very briefly the type of literature available on flood warnings and their damage reducing effects. Section 3 provides an overview of the adverse impacts of flooding and the potential for warnings to reduce them. In section 4, the contextual factors for warning damage reduction are outlined: the types of flood events, warnings systems and the warning recipients and their responses are reviewed based on the literature. Section 5 gives a brief overview on evaluating the damage reducing effects of flood warnings while Section 6 focuses on direct damages to property and Section 7 on the intangible impacts of flooding.

It is assumed that the main aim of this chapter is to produce guidance on evaluating flood warning benefits in economic terms, although the information included could also be used to support an approach based on performance indicators. The Environment Agency uses both approaches in England and Wales.

8.2 Key literature

A review of the literature shows that although there is an extensive body of literature on flood warnings especially from the US, and Australia, there is not much written on evaluating the actual benefits, particularly the economic benefits, of warnings. In particular, there is literature on how people respond to flood warnings (Pfister, 2002; Drabek, 1986, 2000), and for example, evacuation behaviour (e.g.Van Duin and Bezuyen, 2000), effectiveness of flood warnings (Parker and Fordham, 1996; Handmer, 2000; Pfister, 2002), flood warning systems in Europe (Rosenthal and t' Hart, 1998; Handmer, 2000 & 2002;), the UK (Parker, 2000), North America (Handmer, 2002) and Australia (Handmer, 2000), and ways to improve flood warnings (Parker, 2003; Parker, 2000). In the EUROflood project the flood forecasting, warning and response systems of five European countries (Germany, France, The Netherlands, Portugal and the United Kingdom) were evaluated and compared (Parker et al., 1994).

Recent EU funded projects have tended to focus on science and technology issues in flood forecasting rather than the social issues of warning dissemination systems and response. The ACTIF project (Achieving Technological Innovation in Flood Forecasting) was established in February 2003 with a duration of 36 months under FP5 to cluster the results of the many FP5 research projects on flood forecasting. A few of the projects considered under ACTIF, for example, MUSIC, MITCH, FLOODRELIEF and MANTISSA included wider issues of flood warning communication to professional partners and the public. However, a review of recent EU research on flooding has shown the topic of IT and disaster management to be of growing interest within EU research on flooding related topics (Ashton et al., 2003).

8.3 Flood warning system performance

Flood warning systems are one part of a larger system often termed 'flood forecasting, warning and response'. The performance of flood warnings depends greatly upon floods being detected and subsequently forecast with an acceptable degree of accuracy, reliability and timeliness, and warnings systems may under-perform, or indeed fail, if flood detection and/or flood forecasting is flawed in some way. The warning process may also under-perform in a variety of ways. For example, warning messages may be inadequately constructed and/or inadequately communicated to those who require them. A potentially large number of problems can arise at the warning communication stage, particularly if warning communications are not direct between the flood warning issuing agency and those who require flood warnings (e.g. householders). Delays in transmitting or receiving warnings and passing them on may occur. Even if an adequately constructed warning message is received in a timely manner by those who need a warning, an adequate response to warnings can by no means by assured. This latter point is elaborated on below.

Experience demonstrates that all of the main elements of flood forecasting, warning and response systems need to be working well for the overall system to perform adequately, otherwise performance problems will arise. This means that flood warning systems are only likely to perform well if they are constantly maintained and improved, taking advantage of post-warning reviews to diagnose and address insufficiencies. Unfortunately, maintenance of such systems and taking advantage of learning and improvement opportunities sometimes does not take place, especially where floods are relatively infrequent events. In practice, therefore, flood warning systems often display degrees of under-performance or even failure. This problem with hazard warnings in general has led to efforts to evaluate the condition of such systems in order to identify and address problems before they arise (Parker and Budgen 1998).

Unfortunately, therefore, the creation of a sound flood warning system does not guarantee success measured in terms of loss and damage reduction. Sometimes flood warning systems may work well for relatively frequent floods but then fail to perform adequately when confronted by an extreme event. This may happen for a number of reasons. For example, the Environment Agency's flood forecasters did not recognise in advance the severity of the flood event which they detected which led to the Easter 1998 floods in large parts of England and Wales (Bye and Horner, 1998). This was because extreme events of this nature were beyond their experience and the flood forecasting tools were insufficient to compensate for this at that time. Equally, those receiving a flood warning may not grasp the severity of an extreme event, so that their response to the warning is less than is required.

Flash floods pose particular problems for flood forecasters and for flood warning managers, placing a premium on scientific advances which can increase forecast lead times. Most of the methods for estimating flood warning benefits described below assume a two hour or more flood warning lead time, but sometimes the warning lead time is much less. In some parts of Europe, notably the Mediterranean region, flash floods are common. Extreme flash floods are the worst case scenario in this regard, and it is a serious challenge to produce a forecasting and warning system that provides benefits to floodplain users.

Finally, people sometimes refer to previous flood events which they may have experienced when they receive a flood warning. Even if they use a previous event of similar magnitude as their benchmark for warning response, they may be surprised that the flood evolves differently to their benchmarked flood, and floods different areas and at different depths.

8.4 Adverse impacts of flooding

The rationale for, and the benefits of, providing warnings lie in their potential to reduce the adverse impacts of flooding. These impacts, summarised in Table 1.3 above, are complex and wide-ranging. Flooding can, of course, also have positive impacts upon the environment for example. In theory, these potential positive benefits of flooding should be taken into account as well as the negative effects but in practice they are not usually considered in the literature in developed countries at least.

In theory, a flood warning system that is properly planned, operated and maintained can allow many, if not all, of these adverse impacts to be partially reduced or even, in some cases, eliminated. In practice, the difficulty in systematically demonstrating the link between warnings and reduction in many adverse impacts and in measuring that reduction in monetary values, means that only a limited number of effects, chiefly direct damage reduction, have been considered.

Timely, accurate and reliable warnings can provide authorities, communities and individuals with time to respond effectively in two different ways:

To prevent loss of life and injury through:

- evacuating people, animals and property out of the flood zone in advance of flooding to avoid loss of life, injury, some direct damages and possibly health and stress effects.

To reduce damages to property through:

- action to strengthen existing defences, put temporary defences in place or to allow individual home owners or businesses to protect their property with sandbags or flood gates or other devices so that people, properties and other resources are not exposed to flood waters avoiding most of the impacts.
- Raising or moving property out of reach of the flood waters within the flood zone to minimise direct damages.

Recently the range of responses which are made in practice to flood warnings has come under some scrutiny, and an expanded or more holistic model of these responses and their associated benefits is being developed for the warnings component of Floodsite Task 10. For example, a recent research project into flood warning benefits funded by the Scotland and Northern Ireland Forum for Environmental Research (2006) correctly recognises that flood warnings allow:

- the severity of flooding to be reduced through operational activities, such as the closure of structural flood defences and the emergency clearance of culverts and channels which may become blocked during a flood event.

In England there is a growing reliance upon flood defences which need to be closed to make them operational in advance of flooding onset. The outstanding example is the Thames tidal flood exclusion barrier which is a flood barrier which is closed when tide levels and associated weather conditions indicate a storm surge of a defined threshold magnitude. At the same time some twenty or more flood gates and closures must also be made on receipt of a flood warning in the downstream tidal flood defences along the Thames estuary. This is just one example of numerous similar flood defence structures in England and Wales which are reliant upon flood forecasting and warning for their integrity. Very little research has been undertaken to date on the benefits arising from these combined warning and structural defence systems.

The potential for reducing the adverse impacts of flooding through flood warnings and the actions in response to warnings that would be possible and appropriate depends upon three contextual elements:

- the nature and characteristics of the flood events and the catchment within which they occur;
- the characteristics and degree of development of the flood warning systems in place;
- the characteristics, experience, beliefs and attitudes of the public and professional agencies who have to respond appropriately to the warning in a particular event.

8.5 Contexts for flood warning damage reduction

8.5.1 Types of flood event

It is important to be clear as to the types of flooding that are to be considered here: fluvial, tidal, estuarial, tidal surges, dam and dike bursts and groundwater or pluvial flooding because the nature of the flood events, catchment and type of flooding are factors in the potential for reducing adverse flood impacts and in the appropriate response. First, some flood events and flooding, such as extreme rainfall events are much more difficult to predict than others; the flooding in Boscastle, Cornwall, England in August 2004 provides an example of an extremely rare event that it was not possible to forecast with currently available technology in time to issue a warning (Environment Agency 2005). There are cases, particularly in small catchments, where rainfall-run off response times are short, where the principle challenge lies in generating flood forecasts with an acceptable degree of reliability and accuracy, and which provide at least some warning lead time for response. With long, slow rising rivers such as the Thames or Severn in the UK, flood forecasts can provide relatively long warning lead times and allow plenty of time for response. Traditionally, flood risk management has tended to focus on coastal and fluvial events. However, in the UK, policy is moving in the direction of managing all flood risks, coastal, and fluvial but also now flooding from other sources such as pluvial and groundwater flooding, since events often involve different sources of flooding and because it is a matter of indifference to those affected as to where the floodwater comes from.

Second, the characteristics of the flood event: particularly the depth of flooding, but also the velocity of flood waters, speed of onset, and duration of the flooding, will affect the amount of damages incurred and thence the potential for damage reduction through warnings.

Third, the characteristics of the flood event will determine the appropriate and effective response: where a flood is potentially life threatening as with strong coastal or estuarine storm surges, dam and dike bursts and flash floods, evacuation will have priority over other property damage reduction responses.

8.5.2 Flood warning systems

8.5.2.1 Flood warning and warning lead time

It is important to define what we mean by a ‘flood warning’. Usually a ‘flood warning’ is taken to mean a warning message communicated to those at risk (public and professional agencies e.g. emergency services) prior to a flood event by a variety of mechanisms, but emanating from an official, authoritative source. Warning messages, of course, may be received during or after flood waters have entered properties but may still be regarded as ‘warning’. In practice a flood event may be marked by a series of flood warnings, with the level of warning being incrementally raised and then stepped down.

Warnings are usually provided by government agencies, at national, regional or local level. However, there are often unofficial warnings systems drawing on local knowledge and expertise in place where no official ones are provided or operating in parallel with or in competition with the formal system. Such unofficial informal warnings have the advantage of being tailored to the community that receives them and being based on strong local networks and personal observation (Parker and Handmer, 1998). In practice, where both exist, there are often interactions between formal and informal warning, so that the informal system may serve to amplify the official one or may be in conflict with it (Van Duin and Bezuyen, 2000). A key factor in designing successful flood warning systems is to seek to meld together the best aspects of any unofficial warning system which may be in place (thereby hopefully gaining the cooperation and ownership of local flood plain occupants) with an official system (Parker, 2004).

The amount of time a warning gives recipients prior to flooding is considered to be a crucial variable for damage reduction, although empirical evidence to support this view is sometimes difficult to find. Logically, the amount of damage reducing activity that can take place is limited by the amount of time available to take action. Evacuation is similarly constrained by time. Warning lead time is usually defined as the time elapsing between the issue of a warning message and the commencement of flooding in an area; or the time elapsing between the issuing of a warning and its receipt by the person targeted (Parker, 2004). Warning messages sometimes take some time to get to recipients, particularly where intermediary communications are required, and the time that a message is received by a recipient is a critical factor in behavioural response to the warning. In the worst cases documented, a significant proportion of flood warnings were received after flooding has taken place (Parker and Neal, 1990), although at the time the flood forecasting agency believed that the warning system was working relatively well.

8.5.2.2 Complexity of warning systems

Warnings come at the end of a complex set of processes often involving different organisations, professional groups and disciplines: the flood forecasting, warning and response system (FFWRS) comprising the following.

- Flood detection (Weather radar and weather services, rain and flow gauges and telemetry networks).
- Flood forecasting (fluvial and tidal forecasting models and systems, observation and knowledge of catchments) .
- Flood warning message construction and dissemination.
- Response (pre-planning and awareness raising and emergency response to an event).

Developing and maintaining a flood warning system involves political commitment, considerable investment and effort, particularly for environmental modelling and the expertise and hardware required for computer modelling. Achieving the benefits from flood warnings often requires a considerable degree of cooperation and co-ordination between agencies. Many agencies have long struggled to improve their performance and although warning effectiveness has been seen to be improving overall, the literature also documents high profile failures (Bye and Horner, 1998; Handmer, 2000).

All these elements need to be developed and, importantly, co-ordinated to produce what has been called for by a UK Minister ‘a seamless and integrated service’ (Hansard, 1998, 20 October) if the damage reducing benefits of flood warnings are to be realised. Emergency Management Australia (EMA) has developed the integrating concept of ‘the total flood warning system’ to embrace all these processes (EMA, 1999). Yet research interest and investment in the UK and EU has tended to be focussed upon the science and technology of detection and forecasting and only more recently has greater attention been given to the more social issues of flood warning message construction, dissemination and enhancing response.

Emergency Management Australia (1999) has developed a particularly useful guide on flood warnings covering all of the different stages from flood detection through to hindsight review of the way in which flood warning systems have worked in practice. They advocate a 'total flood warning system' view in which all of the stages from flood detection to warning response are recognised, and in which hindsight review (post flood warning review) is recommended. Importantly, a total flood warning system is also characterised by close consultation and liaison with the 'customers' (i.e. those for whom warning are required) and close cooperation with, and full ownership, by the emergency planning community.

8.5.2.3 Message construction and content

The literature on flood warnings highlights the importance of the process of interpreting and translating flood forecasts into warning messages that mean something to their recipients (Handmer 2000; Drabek, 1986, 2000). Warnings need to have a meaning that is shared between those who design them and those who receive them. This may be achieved through consultation and participation of local communities in message design and through the avoidance of technical terms and the use of communications specialists or journalists accustomed to expressing things in simple straightforward language. The Environment Agency, whose earlier colour coded flood warnings were widely misunderstood used such specialists and consultation in developing its new warning codes introduced in 2000. Table 8.1 draws on the literature to summarise the characteristics of effective flood warning message design.

8.5.2.4 Flood warning dissemination methods

Advances in information and communication technologies (ICT) mean that a very wide range of new techniques are becoming available for flood warning message dissemination to augment the more traditional methods that have been deployed in the past e.g. loudhailers, sirens and the knock on the door, as summarised in Table 8.2. Modern direct warning methods such as automatic voice messaging using the telephone are potentially more certain and faster than methods that require the action of intermediaries: delivery of warnings via flood wardens, police or the media. Recent UK research showed that those registered on the Automated Voice Messaging (AVM) system were about twice as likely to have received a warning message as those relying on other methods. The new warning dissemination technologies also have the potential to reduce warning lead times and thence enhance the damage reducing effect of flood warnings.

Such existing and new technologies need to be evaluated not only in terms of their technical performance and costs but also in terms of their social performance as a warning method particularly with vulnerable groups reflecting the facts that groups with different social characteristics have different needs. FHRC has undertaken research and developed a 'social performance matrix' which provides a means of guidance for flood warning managers in the selection, deployment and development of warning technologies to enhance social performance and thence the benefits of flood warning. The matrix yields a social performance rating for each flood warning communications technology based on the recipient characteristics (socio economic group, age, previous flood experience, and special needs), communication barriers and time variables identified through the research taking into account access to, and willingness to use technologies and how well established is the evidence on use of the communications technology (Tapsell et al., 2004).

In England and Wales, the Environment Agency has now launched a multi-media/channel flood warning system called Floodline Warnings Direct: a project that was first established in 2002 with a budget of 15 million euros. This flood warning system employs single data entry but employs a range of warning media and channels, and has absorbed the AVM system referred to above. The new service exploits communications technology to deliver flood warnings simultaneously by telephone, mobile, pager, fax, email and SMS text messaging and is expanded further. Most importantly this system enables the flood forecasting agency, and the agency with lead responsibility for issuing flood warnings (the Environment Agency does both), to communicate directly with individuals requiring flood warnings whether they be at home, at work or in transit. The intermediaries which were a feature of flood warning systems in the 1970s, 1980s and 1990s in England and Wales are now bypassed making warnings more secure and less prone to delayed transmission. The key breakthrough was a decision by central government to give the Environment Agency lead responsibility for issuing flood warnings in 1996 by Ministerial Directive (prior to this there was no lead agency, but simply an informal understanding that the police would relay warning messages from the forecasting agencies to the public and other users).

8.5.3 Warning recipients and their response

8.5.3.1 Warning response as a social process

It is very important to recognise that warnings are received and processed in a social context of household, family, local community, small or large organisations involving a number of individuals (Drabek, 2000). People's behaviour follows a series of complex processes, and for this reason adaptive behaviour that would yield benefits is often delayed, sometimes for substantial periods. A reason for this delay is that the initial response to a warning is usually denial of the threat, especially in areas where flooding is a relatively infrequent event (Drabek, 2000). The literature also shows consistently that on receipt of an initial warning, recipients are likely to seek further information and confirmation of the threat from official or unofficial sources before taking action. Moreover, there is rarely an immediate consensus on what ought to be done, and deliberation and sometimes even arguments may result over what action to take (Drabek, 1999, 2000).

8.5.3.2 Social, psychological and behavioural factors in warning response

In risk communication (i.e. in this case the communication of flood warnings) it is important to recognise that people do not respond to flood warnings in a pseudo-mechanical manner (i.e. using a straightforward stimulus-response model), and that complex social and cognitive processes affect people's evaluation of risk and their behavioural response to it. We cannot rely upon neo-classical economic theories of rational economic behaviour on the part of human agents.

Table 8.1: Characteristics of effective warning message (sources: Emergency Management Australia (1999), Drabek (2000)).

Messages have to be designed to meet needs of general public and professional partners • Importance of understanding recipient community and their needs through: a. research with recipients b. consultation and public/professional partner involvement in the message design process • Heterogeneity of recipient community: same warning message, but variations in what individuals hear and believe • Groups with special needs e.g. those with hearing, sight and other disabilities, minority ethnic groups with limited or no command of the main language of the area
A single, credible, known source • Ideally warning messages should originate from a single, credible, known source and the message should clearly indicate the source • Some sources have more authority than others: e.g. official warning agencies, rather than media, or unofficial sources
Messages need to provide for confirmation • The commonest initial response to a warning message is to seek to confirm the information from other sources, official or unofficial • Messages need to provide a contact through which the warning can be confirmed.
Messages need to provide factual information about the flood • Messages need to describe the current flood and what is expected: its location, timing, depth, duration • Detailed, location specific information is more likely to be believed and acted upon • Using benchmarks: reference to extreme or recent floods and local landmarks
Messages need to advise people on what to do • Messages are more likely to be believed and acted upon if they contain **specific behavioral advice** • e.g. advice on flood proofing, warning others, moving people and possessions to safety, driving, walking in flood waters, contamination, switching off services
Addressing uncertainty • Flood warnings provide information about uncertain events • Warning messages need to reflect this uncertainty and use words such as 'may' 'probably' and' likely' to describe the impacts rather than exclude uncertainties from messages.
Repeated, multiple and consistent messages • There needs to be redundancy in the communications networks • Warning messages should be repeated and be disseminated through multiple mechanisms to maximize the chances that the varied members of a community will receive the message through one mechanism or another • Consistency in messages disseminated by different means is important

The assumption that people base their judgements solely on rational models of expected outcomes, or gains and losses is been shown to be false, and rational decision theory gave way long ago to behavioural decision theory (Drabek, 1986). A common approach to flood warnings is to use an information-deficit model in which the critical gaps between what floodplain occupants know and what they need to know is addressed by the information contained in a warning message (Fischhoff et al., 1998). Like many other flood agencies, the Environment Agency in England and Wales, relies partly upon such an approach. However, even if warnings are delivered in a timely and accurate manner, and contain the 'missing' information that people need, people may still take no action or may not take effective action.

Psychologists and behavioural theorists study the role of cognition and the systematic errors and biases which people introduce into their decisions about hazards and risks. People do not make strictly logical decisions in risk assessment and response (Morgan et al. 2000). Tversky and Kahneman (1973) demonstrate how people use cognitive heuristics, which are akin to mental conveniences or short-cuts, when they process complex information, and these errors and the biases associated with them lead to errors in judgements of risk. These errors are not random but are systematically related to decision processes and are therefore a source of bias. Tversky and Kahnemann (1973) show that people often make judgements in terms of how easily they recall past examples, or how easily they imagine such occurrences, known as the 'availability heuristic'. This explains why and how some of the systematic errors appear in people's quantitative estimates and responses to risk. Others have identified further cognitive factors which affect people's response to risk. For example, Weinsten and Klein (1995) identified the 'optimism bias' when they discovered that people consistently underrate the chance of themselves being adversely affected by in a risk situation. Robertson (2006), an incident manager with the Environment Agency, has contributed a very useful summary and discussion of these and other psychological and behavioural processes which affect how people respond to risk and risk communications such as flood warnings..

Table 8.2: Information and communication methods for flood warnings dissemination. Source Tapsell et al., 2004 – adapted from Parker and Haggett (2001) and Quinetiq(2003)

Well-tried and in use	Comparatively new and in use	Near future, potential and/or advanced
Standard analogue telephone	Press-button digital telephone	Mobile telephone SMS text messaging and SMS Cell Broadcast
Door knocking	Mobile telephone and voice mail	Digital TV and Digital Audio Broadcast
Mobile loudhailer, public address systems	Pagers	Dedicated public address systems
Written communication	Automatic voice messaging (AVM) using telephone	Wireless Application Protocol telephones
Flood wardens	Teletext	Centrally activated local radio alerts
Flood sirens	Dial-and-listen services (e.g. Floodline)	Centrally activated in-home alert systems
Radio telephone/VHF	Television/radio broadcast	Integrated dial-and-listen and AVM services
Radio	Signage e.g. flashing signs	Real time flood data on web; including livecams
Facsimile	Intranet and internet websites with real-time warnings	Third and fourth generation mobile telephones
Automatic water level alerts linked to telephone	Electronic mail	Others including: Crawlers on standard TV

The effectiveness of flood warnings depends upon the response of the public, or more correctly, the many 'publics' affected. People may respond differently to flood warnings because their characteristics, experiences, beliefs and attitudes are different. Drabek has summarised the literature on this topic. Our own review of the literature has also addressed this issue.

Drabek (2000) draws three conclusions from early disaster research.

- There may be considerable variation in what people listening to the same warning message hear.
- People respond to warnings on the basis of how what they hear influences their behaviour.
- People react differently depending on who they are, who they are with, and who and what they see.

Drabek noted that people with a high risk perception, for example, women, will respond more quickly and adaptively to flood warnings and that risk perception is related to, but not the same as, prior disaster experience. For example, some people have previous experience of flooding and if warned may take action (Drabek, 1999). Alternatively, people who live in a community previously affected by flooding but who escaped themselves may have a false sense of security (Drabek, 2000). Drabek reports that generally those of lower socio-economic status and ethnic minorities were less likely to respond adaptively to flood warnings. Lack of trust in the authorities and official warnings, particularly of ethnic minorities and of poorer people and the social isolation of poorer families were contributory factors. Levels of awareness of flood risk, of warning systems and of how to respond, often linked to education and socio-economic group are also important factors.

Community characteristics such as the level and pattern of community development may also be significant to response. For example, Buckland and Rahman (1999) found that social capital can both help and hinder effective decision making and action in an emergency situation.

These are complex issues and the findings are not entirely consistent across disaster and flood studies. Furthermore, much of the valuable research on social factors in warning response reported by Drabek was undertaken in the United States in the 1970s, 1980s and 1990s, and this raises questions as to whether the findings can be transferred across cultures and over time given changes in society and technology that have taken place in the last twenty years (Handmer, 2000). Guidance on evaluating the damage reducing effects of flood warnings in monetary terms inevitably involve a very drastic simplification of the complexities of recipient responses to flood warnings that the research documents.

8.6 Evaluating the damage reducing effects of flood warnings: an overview

The damage reducing effects of flood warnings can be attempted to be calculated at different levels for the nation as a whole, for example, as part of an examination of a national strategy for investing in flood warning systems, for a regional programme or for a particular area or scheme(s). The calculation may serve to facilitate comparison between different flood risk management strategies, or to prioritise between warning schemes for different areas.

What follows reflects our current, imperfect, approach towards estimating flood warning benefits.

The geographical boundaries and thence the estimated number of properties at risk will need to be defined by flood risk maps and models and by the current or potential coverage of the flood warning system(s). For this purpose, it will be necessary to decide what minimum level of flood forecasting and warning dissemination is to be taken as constituting a flood warning.

The Environment Agency categorises and provides for warning dissemination at three levels of service (Andryszewski et al., 2005).

- Maximum (Individual warnings) direct warning to each property by telephone, fax, e-mail etc using a computerised warning system.
- Intermediate (Community warning) using loudhailers, sirens, public address systems etc in each community.
- Minimum (Broadcast warning) use of media and other agencies to broadcast warnings e.g. a dial and listen services such as ‘floodline’, internet, ceefax, teletext, TV and radio.

The Agency’s minimum level: some form of broadcast warning applying to a particular area emanating from an official source and based on some level of technical provision and staffing offering a detection and forecasting capability, can be taken as the least that must be available for an area to be said to be provided with a flood warning service.

Having defined the objectives and scope of an assessment, the damage reducing effects of flood warnings can be considered under two broad headings:

- direct tangible damage to property; and
- human intangible impacts.

It must be recognised that this represents a simplified and partial approach to estimating the damage reducing effects of flood warnings, because current research has focused mainly on residential property only and has largely ignored the value of flood warnings to commerce, industry, offices and infrastructure operators where loss avoidance can be direct and indirect loss avoidance. The approach is also partial in only tracing the impacts of raising property in buildings to save them from flood damage.

8.7 Direct damages to property

8.7.1 Literature on reducing direct damages to property

Van der Veen et al. (2003) in their literature review on methodology quoted in 'Draft guidelines for estimating economic damages' (May 2005) concluded that there was no agreed methodology, let alone a settled definition of damage. However, these tangible and direct damages have been the main focus of research on flood impacts and such definitions and methods necessarily provide the basis for assessing the damage reducing effects of flood warnings in monetary terms. In contrast to research on flood damages, there has only been a limited amount of research on the benefits of FFWRS.

Carsell et al. (2004) reviewed the evolution of methods for evaluating effects of flood warnings in reducing direct property damages. Day in 1970 proposed that the tangible benefit of a flood warning system could be estimated as a function of the flood warning time due to the system with reductions in damage as warning time increased. Day suggested a maximum possible reduction of 35% of total damage due to the flood. This work has been further extended by the US Army Corps of Engineers (1994).

FHRC research evidence on the damage reducing effects of flood warnings in Britain began to be accumulated in the 1970s (e.g. Penning-Rowsell et al., 1978). The main focus of this research has been on private households rather than businesses. Particularly important have been social surveys of households affected by flooding to whom flood warnings were issued designed to determine: whether households received warning, the actions they were able to take, the damages thereby averted, and the factors that affect this (including flood warning lead time) and the availability of assistance with moving household goods etc. A total of over 1,200 interviews were undertaken in this research (Parker and Tunstall, 1991). Since 1997, the Environment Agency has commissioned a series of post-event surveys for flood events in England and Wales which provide further evidence on the receipt of warnings by households and businesses, warning lead times and actions taken to protect people and property (BMRB Post Event surveys). Recent FHRC research for the Department for the Environment, Food and Rural Affairs (Defra) and the Environment Agency has provided more detailed information on actions taken to save property and property damage (Tunstall et al. 2005).

These methods of evaluating the damage reducing effects of flood warnings appear to have focussed on the benefits resulting from actions to move or raise property out of the reach of flood waters. They might also be extended to cover households' attempts to prevent flood waters entering the property. However, the Potential Flood Damages Avoided term (PFA) is based on the assumptions about what property could be moved in a given time and could thus underestimate damage reduction through wholly successful actions to exclude flood waters from entering the property (e.g. through installing efficient flood boards) and thus avoiding or minimising contents damage and some internal structural damages.

8.7.2 FHRC's data and methods for calculating the damage reducing effects of flood warnings

FHRC's 'Blue', 'Red' and 'Yellow' and now 'Multi-coloured' Manuals include data and methods for assessing damages to property. Depth-damage data of this kind provide the starting point for estimating flood warning benefits.

The section below on the estimation of the damage reducing effects of flood warnings has been brought up-to-date to the beginning of 2007. It therefore incorporates some of the latest survey results from England and Wales which have been synthesised as part of our Floodsite Task 10 research into flood warnings.

On the basis of FHRC research, the following equation for assessing the economic benefits of flood warnings has been developed and calibrated, and has become known as the 'Parker model' (see Parker, 1991):

FDA = PFA x R x PRA x PHR x PHE

Where:

FDA =	**Actual flood damage avoided**
PFA =	**Potential flood damage avoided** (property plus road vehicle damage avoided)
R =	**Reliability** of the flood warning process (i.e. the proportion of the population at risk which is warned with sufficient lead time to take action)
PRA =	**Availability -** the proportion of residents/households available to respond to a warning
PHR =	**Ability -** the proportion of households able to respond to a warning
PHE =	**Effective response** - the proportion of households who respond effectively

Although the original formulation of the model above included cars and motorbikes, these are not included in the household inventory items and have subsequently been excluded from the calculations. FHRC's formula for estimating the damage reducing effects of flood warnings was developed mainly on the basis of research on private households. In the UK, it has been applied – as a proxy method of warning benefit estimation - to property generally and specifically to Non-Residential Property (NRPs): retail, distribution, manufacturing and public sector enterprises in warning benefit assessments but this application needs very careful consideration. It is usual to calculate the damage reducing effects of flood warnings using the formula separately for private households and NRPs because somewhat different values are usually given to the components in the formula for residential property and NRPs.

What little research there is available on businesses' responses to flood warnings (Penning-Rowsell et al., 2003, 2005) indicates that flood warnings can make substantial differences to the damages for certain types of NRPs under certain conditions. However, the recent research carried out by FHRC shows that the potential response to warnings and the direct damage savings that can be achieved by moving moveable equipment and stock vary markedly across business sectors and sizes of enterprises making it particularly difficult to generalise about the direct damage reductions associated with warnings for NRPs.

The formula inevitably involves a simplification of the complex social processes of flood warning response. It is also imprecise and involves many assumptions. These are examined in the following subsections.

In adapting the model for its performance factors and targets (Environment Agency, 2003b) the EA introduced an additional variable – the coverage of the flood warning service which it currently defines as follows:

% coverage = No. of properties serviced by warning service X 100 / No. of properties at risk

where the number of properties serviced is the number that have been offered an appropriate flood warning service. Thus the EA's formula is

FDA = (AAD x DR x C) x (R x RA x PR x PE)

where :

AAD = **Annual average damage**
DR = **Damage Reduction** – the % amount of pre-flooding action that can be taken to reduce the cost of the flooding event

8.7.2.1 Potential Flood Damage Avoided (PFA)

PFA is the maximum (i.e. total potential) of flood damages that could reasonably be expected to be avoided if all the other components in the formula were 100%: i.e. assuming that there was 100% success in forecasting and warning dissemination and in response by warning recipients. As discussed in earlier FHRC benefit assessment manuals and presented in the Manual of data and techniques for 2003 (Penning-Rowsell et al. 2003), PFA took into account and was calculated for both of the following:

- A particular flood warning lead time: 2, 4, 6, 8 hours and
- The depth-damage relationship: what would be damaged at 5 levels of depth of flooding O.1m, 0.3m, 0.6m, 0.9m and 1.2m

In the 1970s, a theoretical exercise, backed by survey research of residents, was carried out (Chatterton and Farrell, 1977; Penning-Rowsell et al. 1978) to establish what could be moved of the items damaged at a particular level of flooding in a given time and the value of these items. Clearly, structural damage could not be avoided and a judgement was made on the Household Inventory items that could be moved or raised in the time. The values were then expressed as a percentage of Total Potential Damage (structural and contents damage) for each warning lead time and depth of flooding. Thus, this component in the formula is based on expert judgement and assumptions.

Table 8.3 shows the approach presented in earlier FHRC manuals and the calculation of PFA (% of Total Damage) for households according to flood depth and flood warning lead time for a short duration flood (<12 hours duration) in England and Wales using updated Household Inventory Data and 2004/5 £ Sterling values. Details on the definitions and calculation of the Total Flood Damage and Household Inventory Damage are given in Penning-Rowsell et al., (2005). Similar data are available on PFA for a long duration flood (>12 hours) and for an average of the two durations. Total Potential Damage and Total Household Inventory Damage are somewhat higher for a long duration event at each level of flooding. Therefore, PFA £ values are higher although the PFA % of Total Damage figures used are the same for the long and short duration floods. Once PFA has been calculated the rest of the formula is applied to the PFA £ value(s).

Applying the PFA percentages presented in Table 8.3 to Total Potential Non-residential Damage is to assume that the constraints on the maximum amount of property that can be moved operate in the same way for non-residential property and private households and this may not be the case.

Table 8.3: Calculation of Potential Flood Damages Avoided (PFA) for a short duration flood (<12 hour) for residential property

Depth of Flooding (m)	Total Potential Damage £	Total Potential Household Inventory Damage £	Flood warning lead times							
			Up to 2hours		2-4 hours		6 hours		8 hours	
			PFA £	PFA % of Total Damage	PFA £	PFA % of Total Damage	PFA £	PFA % of Total Damage	PFA £	PFA % of Total Damage
1.2	33,040	20,423	8,359	25.3	11,795	35.7	12,786	38.7	13,447	40.7
0.9	31,265	20,237	8,254	26.4	11,756	37.6	12,694	40.6	13,319	42.6
0.6	29,268	19,051	7,463	25.5	10,888	37.2	11,766	40.2	12,351	42.2
0.3	26,105	18,046	7,832	30.0	10,990	42.1	11,774	45.1	12,296	47.1
0.1	13,507	9,977	3,309	24.5	4,430	32.8	4,835	35.8	5,105	37.8

In recent research for the latest FHRC manual of benefit assessment techniques, the Multicoloured Manual (Penning-Rowsell 2005), the calculation of PFA was reconsidered in the light of changes to household contents and a new simpler approach to calculating PFA was developed. The FHRC data base includes updated information on the £ value of property structures and on the £ value of the contents, the Household Inventory items for different house types, building periods and social classes and flood depths. The value of inventory items can be calculated as a % of the value of total potential damages for each of these categories. Averaged across all of these, the household inventory items were calculated as 52% of the total potential damage (structure and contents damage together). This percentage will vary according to the flood depth, house type etc. and where data is available can be calculated for the specific flood depth, house type etc. Of the household inventory items, our assessment, informed by our most recent surveys and thus part of our current on-going research which is part of the Floodsite warnings research (Parker et al., 2007), is that only 41% could be moved or their damage otherwise avoided with warnings. Because Moveable Inventory Damage (MID) is 41%, and Potential Inventory Damage (PID) is 52% of Total Potential Damage, only 21% of TPD can be influenced by the provision of a flood warning.

The 41% value for MID was arrived at by examining the household inventory and adding up the £ value of items judged to be unmoveable e.g. fitted kitchen and bedroom units, built in hobs, ovens and heaters, all high value items and clean up costs. The new approach for estimating PFA described above is simpler, more transparent and better reflects the contents of modern homes than the approach presented in earlier FHRC manuals.

8.7.2.2 The reliability of the warning process i.e. the proportion of the population/NRPs at risk

This component reflects the success of the responsible organisations in detecting, forecasting, and **issuing** a flood warning via dissemination mechanisms to those at risk in a timely manner. The warning referred to here is an official warning emanating from an official agency. The lead time referred to is the time between the **issuing** of the warning by the warning organisations and the commencement of flooding in the area warned. This may be different from the time between the **receipt** of a warning message by householders and flood waters entering their property. Clearly as warning time is increased, the amount of damages saved can be increased. This component raises the question as to what constitutes 'sufficient' warning lead time.

For example, the Environment Agency's Customer Charter for England and Wales specifies that:

> ' A prior warning will be provided (two hours in general) to people living in designated flood risk areas where a flood forecasting facility exists and where lead times enable us to do so'.

This indicates that a warning of no less than two hours is seen as the standard to be aimed for and sufficient by the service providers. However, the Agency recognises that there are types of flood event and 'flashy catchments' where it is not possible given current science and technology to provide a two hour warning, and in Wales where there are many flashy rivers the lead time advertised by the Environment Agency is one hour. The formula does not assume any minimum warning lead time but does assume that a warning is issued some time **prior** to the commencement of flooding.

This component can be assumed to be the same for residential and non-residential property unless there are special arrangements to provide priority or earlier warnings to businesses or vulnerable public or private sector properties such as schools, hospitals or old people's homes. However, recent research indicates that warning lead time is a particularly crucial factor in non-residential property savings and that there would be large differences in the damages that could be mitigated with a two-hour as compared with an eight hour warning. For many companies, particularly large ones, anything less than eight hours would be of little use but given that warning lead time most could save some stock or equipment and for some the savings would be substantial (Penning-Rowsell et al., 2005).

Furthermore, the evidence from the research indicates that businesses are reluctant to suspend trading, services or manufacturing operations and take measures to move stock and equipment unless flooding is almost certain because of the business losses involved in closing down a business even for a day. It is difficult to provide the certainty in forecasts, and specific information on flooding that businesses require with sufficient warning lead time to allow action to be taken.

8.7.2.3 RA Proportion of households (NRPs) available to respond.

In the original specification of the formula, this referred to the proportion of households in which at least one adult was at home and awake to receive a warning. Clearly, the warning dissemination mechanisms used to deliver warning messages have implications for this factor. The assumption at the time the formula was developed was that the warning would need to be delivered to a particular location or the threatened home, through a siren, loud hailer or policeman or other agent calling in person or by telephone to the threatened home and that a household member would need to be available there to receive it. The proportion of people spending time out at work or pursuing household or leisure activities outside the home was therefore highly relevant.

With the development of new warning technologies, the presence of household members at home is becoming less salient. For example, until recently in England and Wales, the Environment Agency's AVM telephone warnings were the main form of direct warning and the Agency was able to issue AVM warnings to work and mobile phone numbers. Furthermore, AVM systems provided evidence of whether or not the message was delivered successfully. The Agency's new Floodline Warnings Direct Service has now been introduced and has absorbed the AVM system which was becoming unreliable and faced capacity limitations. The new system has greater capacity to reach recipients outside the home, at work or on the move by utilising a range of current and emerging technologies such as SMS text messaging and e-mail. However, if a warning is issued to work numbers or to someone on the move and no one is at home, there will be a delay in the householders taking action due to the time needed to reach home.

More serious are those who are absent on holiday or overnight on visits, a factor which may have more impact in flood events occurring at holiday times. Cultural variation in the number of holidays and the length of holiday time taken, and the increasing trend to holiday away from home across Europe may affect this factor. The night time effectiveness of different warning methods and thence the level of availability varies. Radio and TV, internet and e-mail and indeed mobile phones are likely to be switched off at night. Sirens or loud hailers may not be heard by those asleep. Telephone and door knocking may be effective at waking people.

Thus, the availability of householders to receive warning messages and the success of dissemination agencies and mechanisms in reaching those at risk is a key component. The proportion of householders who **receive** a warning message can be taken as reflecting both, R, the agencies' success in issuing a warning and PRA, the availability of householders to receive the warning, and thence the success in delivering a warning.

These components are not necessarily restricted to the receipt of warnings coming directly from an official source. The rationale for not making a distinction here between formal and informal warnings received is that there is so often interaction between the two systems that the distinction between them becomes blurred. There is survey evidence that on receipt of a warning, those at risk warn neighbours and friends and that on hearing about a potential flood event from neighbours, recipients seek confirmation from official sources. Post event surveys can provide evidence on the receipt of warnings and those carried out for the Environment Agency in England and Wales show that generally no more than 40% of those at risk receive any kind of warning, official or unofficial, prior to flooding (Tunstall et al. 2005) although the Agency hopes to improve this through its investment in forecasting and in new dissemination methods (Environment Agency 2003b).

Generally, it is assumed that it is more likely that people will be available at non-residential properties to respond to a warning. Large businesses normally have security staff at least on site at all times and duty staff who can be contacted at all times by telephone. Small businesses where owners or operators live on site or, for example, above the shop, are also likely to be readily available.

8.7.2.4 PHR The proportion of households (NRPs) able to respond

This component reflects an assumption that not all warning recipients will be able to understand and respond to a warning. It is assumed that, without outside assistance, the proportion of the population that is elderly, disabled or pregnant may be unable to undertake the lifting and carrying necessary for raising and moving items out of the reach of flood waters and that these households may give priority to moving their vulnerable members out of the flood risk zone rather than to protecting property from flooding. In addition, countries and localities may have minority ethnic groups or recent immigrants whose command of the language in which flood warnings are issued is limited. These groups with language difficulties may be unable to understand and thus act upon warnings received.

The component is a simplification of the reality. It makes the assumption that none of these vulnerable households will take damage reducing action. However, recent survey data for England and Wales indicates that many such households do respond. Indeed, they were about as likely to make efforts to save property even when they had no outside help as others and the proportion of property value they were able to save was similar to that of others although vulnerability in terms of age, illness and disability did emerge as one factor explaining the £ value and proportion of property at risk saved (Tunstall et al 2005). In the light of these survey findings, the latest FHRC flood warning benefit assessment techniques exclude this component (Penning-Rowsell et al., 2005; Parker et al., 2007).

For businesses, it is usually assumed that there will be no limitations on the ability of staff to respond because those all those employed are unlikely to fall into the categories of those unable to respond.

8.7.2.5 PHE The proportion of households (NRPs) who respond effectively

For able warning recipients to respond effectively on receipt of a warning they need to:

- know about, understand, trust and believe the warning and the warning agency;
- know what actions to take to reduce property damage; and
- elect to take action to minimise property damage rather than to give priority to other actions.

These factors apply as much to staff in businesses as to householders. Action to minimise the monetary value of property damage is not the only course open to warning recipients. They could have different priorities and quite rationally choose to act otherwise. For example, staff in public sector properties such as schools, hospitals and old people's homes would be likely to give priority to evacuating their charges over saving items. Householders too might prefer to take actions that would reduce the disruption to their lives or to minimise damage to items of sentimental value. For example, logic might suggest that on receipt of a warning, recipients should first move survival items: food clothing, torches, radios etc, then irreplaceable items such as photographs and documents, thirdly, bank, insurance and other details; fourthly items that would aid recovery such as tools, cleaning items and then finally try to minimise economic damages, for example by moving low weight /high value items. Evidence suggests that priorities and actions taken on receipt of a warning vary greatly and that seeking to minimise economic damages is only one strategy if an important one among many that recipients may adopt (Tunstall et al. 2005).

Householders and those in NRPs may be constrained making an effective response by the space available to which to move property. This will be particularly the case for residents in single storey or ground level dwellings. Businesses may lack upper floors, or storage space on higher ground on site or alternative sites to which to relocate goods and equipment.

Recent research indicates that the first priority for most businesses on receipt of a flood warning is to ensure the safety of their staff, and where relevant their clients and customers. Many companies would not ask their staff to help move stock or equipment or to take other mitigating action for health and safety reasons. Some machinery and goods may simply be too heavy or bulky to move without special equipment. Some large businesses indicated that they would need to call upon special contractors or staff to operate equipment to raise items or to move items off site. For example, fork lift trucks are subject to regulations concerning their operation and only qualified staff are allowed to operate them. It was more usual for staff in small businesses to take part in efforts to save equipment and stock (Penning-Rowsell et al., 2005).

The formula calculates the proportion of households/NRPs who receive a warning, then are able to act on it and then act effectively. It is then assumed that this proportion are 100% effective in their damage reducing actions i.e. these households/NRPs save the total £ PFA. Recent research on flood victims in England in which detailed data were collected on the household inventory items saved and the items damaged and their £ value shows that very few households, only 15%, saved everything that would have been damaged. Overall, households on average (with those saving nothing included in the calculation of the average) saved 52% of the value of items at risk. Percentages were significantly higher for those warned in some way compared with the not warned (62% compared with 45% respectively) indicating that warnings make a difference but that many property owners respond without a warning on the basis of personal experience and observation and common sense (Tunstall et al. 2005).

8.7.2.6 Calculation of Actual Flood Damages Avoided (FDA)

FDA has been calculated using a conversion factor derived from the formula. FDA equals PFA multiplied by the conversion factor. Table 8.4 gives examples of the values for components of the formula that have been used in arriving at a conversion factor in its earliest formulation and in a recent example of a project to assess the benefits of effective flood forecasting and warning for pluvial flooding. FDA is calculated by multiplication.

Recent research which examined this economic benefits model and its assumptions has lead to the development of a new approach to establishing PFA (an alternative to that outlined in Section 8.6.2.1 above) and to assessing the damage reducing effects of flood warnings overall being recommended by FHRC in its ‘Multi-coloured Manual’ (Penning-Rowsell et al 2005). As the example in Table 8.5 shows, this approach requires only two other factors in addition to PFA:

- the proportion of households/property owners in receipt of a warning (any warning)
- the proportion of property at risk saved by warned households according to receipt of a long or short warning lead time.

Table 8.4: Conversion from Potential (PFA) to Actual Flood Damages Avoided (FDA)

Source of information	**R x Reliability of the flood warning process**	**PRA x Proportion available to respond to a warning**	**PHR x Proportion able to respond to a warning**	**PHE Proportion of households who respond effectively**	**= Conversion factor**
Residential Parker, 1991	(1.00)	.55	.75	.70	.29
NRP Parker 1991	(100)	.45 (.80 for longer warning lead times)	.95	.95	.41
Residential Royal Haskoning/Met Office, 2004	.90	.47	.85	.60	.21
NRP Royal Haskoning/Met Office, 2004	.90	.65	1.00	.60	.35

This simplified approach was developed because it was found that disability/ability was only one factor among a number including experience in the home, help from outside the household, a warning or eight hours or more, flood depth, an informative warning message, number in the household, high social class, long duration flooding that explained the £ value and/or, the proportion of at risk property, saved. Furthermore these factors accounted for only a small proportion of the variance in the £ value and proportion of savings achieved.

This approach requires good survey data to be available or collected on the £ value and proportion of property saved with warnings of a given length. Alternatively the data in Table 8.5 can be used as a guide on the assumption that the percentages shown can be applied to circumstances other than those in which they were collected.

Research for the 'Multi-coloured Manual' also developed and presents an alternative approach to arrive at the potential damage reduction that could be achieved by NRPs on receipt of a warning (Penning-Rowsell et al., 2003, 2005). Scenarios for the receipt of a two to eight hour flood warning were included in discussion meetings with company representatives for the moveable equipment and stock and the representatives were asked to give their expert opinion on the amount of savings they believed could be achieved.

Table 8.5: Flood warning damage reduction in residential property
(Source: Penning-Rowsell et al. 2005)

Item	**Description**	**% (Y)**	**£ (X) Example**	**Calculation**
A	Total Potential damages (TPD)	100	30,000	
B	Potential Inventory damage (as a % of TPD)	52	15,600	BY*AX
C	Moveable Inventory damage (as a % of Potential Inventory damage) (PFA)	41	6,396	CY*BX
D	Households in receipt of a warning	38		
	Effectiveness of response - % of property at risk saved with :			
E	< 8 hour warning	55		
F	> 8 hour warning	71		
	Total Potential damage saved by:			
	< 8 hour warning	4.46	1,337	AY*BY*CY*DY*EY
	> 8 hour warning	5.75	1,726	AY*BY*CY*DY*FY
	Potential Inventory damage saved by:			
	< 8 hour warning	8.57	1,337	CX*DY*EY
	> 8 hour warning	11.06	1,726	CX*DY*FY

Table 8.6 presents selected results from the 'Multi-coloured Manual' research. These illustrate the variation in damage reduction across sectors.

Table 8.6: Expert opinion on percentage damage reduction with warning

	Percentage damage reduction	
	Moveable equipment	Stock (materials, part/finished goods)
NRP code	Mostly assuming warning 8 hours or more	
Super store/hyper store	30	25-50
Garage/Vehicle repair	70-90	20
Café/fast food restaurant	90	90
Bank	40	50
Retail warehouse	20-50	50
	Assuming warning 4 hours or more	
Average across sectors	43	43

The latest refinement of the 'Parker model', Parker et al., (2007), is the result of a complete synthesis of recent advances reflected in the 'Multi-coloured Manual' (Penning-Rowsell et al., 2003) and through analysis and absorption of the latest major social survey results in England and Wales Tunstall et al. 2005). The revised model is as follows:

FDA = (TPD x PID x MID) x RAS x PHE

Where FDA and PHE are defined as above.
TPD = **Total potential damages**
PID = **Potential inventory damage**
MID = **Moveable inventory damage**
RAS= **Reliability of the flood warning process combined with proportion of householders available to response to a warning.**

PHR is now excluded on grounds of the latest research results from England and Wales, but might warrant re-inclusion elsewhere if survey results reveal that this is desirable.

8.7.3 Individual NRP and residential property owners' action to keep flood waters out of their property

In England and Wales, individual property owners are being encouraged to take steps to protect their own property by fitting devices such as flood boards or gates or by sandbagging where structural flood defence schemes are not available or planned. If these actions are fully effective in keeping floodwaters out of property, property owners may avoid damage to the contents that would have been affected altogether as well as some of the internal structural damage that might have been incurred. This damage reduction would be greater than that indicated by PFA which assumes action to raise or move some contents only. Property owners are not recommended to attempt to keep flood waters out of their properties when flood waters are likely to reach depths of 1.2 metres or more because the pressure of the floodwaters held outside the property might cause structural damage.

Where the number of properties known to have effective individual flood protection devices or where the potential for property owners to undertake effective sandbagging can be estimated, the damage reduction that could be achieved in these ways could be calculated separately. This calculation would involve making a judgement on the extent to which the value of damage avoided in these cases exceeds PFA.

8.7.4 Community and individual actions to keep flood waters out of properties

In some circumstances, the planned or likely response to a flood warning would be to take community or agency action to build up existing defences through, for example, sandbagging or to install temporary or demountable defences to keep flood waters away from business and residential properties. For example, in February 2004, a long warning lead time along the River Severn was sufficient to allow the Environment Agency to put in place mobile dams and demountable defences which protected 199 properties from flooding. Flood warning benefits in such cases would be the Total Potential Damages avoided for the properties protected depending on the depth to which properties would have been flooded without the emergency action.

8.7.5 Data and sources for evaluating the direct damage reducing effects of flood warnings

The data and possible sources of information required to evaluate the direct damage reducing effects of flood warnings outlined above are summarised in Table 8.7.

8.8 Human intangible impacts of flooding

A reduction in loss of life caused by flooding is a clear and important potential benefit of flood warnings systems (Ramsbottom et al., 2004). Investment in flood warning systems should not be based upon economic damage savings alone. For example, a warning system which provides 10 minutes of warning for flood plain occupants and just enables them to save their lives, but which does not allow time for property to be moved and flood damage to be saved, will generate zero economic benefits but is clearly of importance in public welfare and security terms.

Flood warnings can not only reduce fatalities by providing enough time for evacuation to a safe place, but also by allowing people to move their belongings to safety in advance since deaths occur when victims enter their homes or the flood waters attempting to rescue possessions or stock (Reimer, 2002 and Coates, 1999 cited by Jonkman & Kelman, 2005). Flood warning services can also reduce fatalities by raising awareness of the dangers so that people do not take risks, for example, walking or driving through floodwaters. However, there is as yet no well researched and tested method for evaluating the effects of flood warnings in reducing the important human intangible impacts of flooding: potential loss of life and injury, the potential health and stress effects of flooding. See Chapter 9 for a more detailed discussion.

8.9 Limitations of this chapter

- In England and Wales, there are well established methods and data for evaluating the direct damage reducing effects of flood warnings. These have been built up and refined over more than 20 years of research and application. Yet despite this experience, the methods and model used are based on assumptions that still need to be tested further.
- The methods have been developed mainly in the context of private households and their application to Non-Residential Property, which may be significant in the potential damages to be avoided, is more questionable. The English research shows different NRP sectors and types of enterprise to be very varied in their damage reducing response to flood warnings.
- The methods presented in this chapter have mainly been developed in an English and Welsh context. The extent to which they are applicable to the flood events, warning systems and social context in other countries needs to be considered carefully.
- The methods suggested in this chapter have very heavy data requirements. In particular, they call for good post event records and post event survey data which may not be available.
- The benefits of flash flood warning systems pose particular issues which are not yet well researched and addressed.

- The approach described above for estimating the benefits of flood warnings, needs to be developed into a more holistic approach which is capable of taking into account the following benefits of flood warnings in addition to those discussed above: a) the benefits arising from flood warnings which are designed to allow static, structural flood defences to be operated (e.g. flood barriers and flood gates); b) the benefits arising from pre-flood operational activities such as culvert clearing and removal of blockages below bridges.

Table 8.7: Data required and sources of information for assessing the benefits of flood warnings

	Data and sources of information	
Data required	**National/Regional level assessment**	**Local/Project level**
Geographical definition of area	National/Regional flood risk zone maps FRM Agency	Local flood risk zone maps FRM Agency at local level
No of properties in the risk are Residential NRP	FRM Agency national/regional databases Regional government agencies	FRM Agency local data bases Site specific surveys Local government agencies
Flood warning service coverage of at risk area	FRM Agency national/regional records	FRM Agency local records
Level of flood forecasting and dissemination service	FRM Agency national/regional records	FRM Agency local records
Total Potential Flood Damage Data Residential NRP	FRM Agency Depth Damage data Annual Average Damage data	FRM Agency/consultancies Site specific depth damage data
Potential Flood Damage Avoided	Derive PFA through research Use FHRC PFA Percentages (Table)	Derive PFA through research Use FHRC PFA Percentages (Table)
Data on FFWRS	FRM Agency	FRM Agency in local area
R Reliability	National/regional FRM Agency records on average flood forecasting and warning dissemination performance and warning lead time	Local FRM Agency records on average flood forecasting and warning dissemination performance and warning lead time
PRA Available to respond Residential NRP	National/regional or available post-event survey data or records on availability and receipt of warnings. Census, administrative or other data on employment rates, holidays.	Local/site specific or comparable post-event survey data or records on availability and receipt of warnings. Local census, administrative or other data on employment rates, holidays
PHR Able to respond Residential	National/regional or other available post event or at risk area survey data on prevalence of disability, limited language ability etc. Census, government or health authority records on disability etc	Local /site specific or comparable post event or at risk area survey data on prevalence of disability, limited language ability etc. Census, local government or health authority records on disability etc
PHE Taking effective action Residential NRP	National/regional or other post event survey data on effective action by residents Expert informants data on NRP action to avoid damages	Local/site specific or comparable post event survey data on effective action by residents Local site surveys on NRP action to avoid damages
Damage avoided through community/agency action to strengthen existing defences or to install temporary defences	National/regional evidence of plans and preparations, availability of temporary defences. Evidence of extent of successful strengthening or deployment of temporary defences in past events from post event records.	Local evidence of plans and preparations, availability of temporary defences. Evidence from post event records of extent of successful strengthening or deployment of temporary defences in past events
Damage avoided through individual property sandbagging and installation of defences	Evidence on number of property owners in possession of protective devices, on arrangements for sandbagging. Post event survey evidence on prevention of flooding through sandbagging and installation of protective devices.	Evidence on number of local property owners in possession of protective devices, on arrangements for sandbagging. Local post event survey evidence on prevention of flooding through sandbagging and installation of protective devices.

9. Other effects of flooding

Contributed by Sue Tapsell, Edmund Penning-Rowsell and Joe Morris

Not all flood effects can be assessed with the methods and techniques described in the previous chapters. Therefore this chapter discusses other effects, which in particular situations can undoubtedly be the dominant impacts that floods can bring. Thus there may be loss of life in floods but no other damage; agricultural production can be the principal loss from certain types of flood, etc.

9.1 Human intangible impacts of flooding

9.1.1 Loss of life

Floods often cause thousands of deaths every year throughout the world. In developed countries people have come to expect to be protected from flooding and have become less aware of the potential risks and likely impacts of living within a floodplain or in a flood risk area, and are subsequently often unprepared when floods strike. In Europe, although the numbers of deaths from floods are not as high as other parts of the world, flooding is the most common natural disaster, and deaths are not uncommon; much flood risk management effort is therefore aimed at reducing these damages. As flood risks cannot be completely eliminated, there is a need for methods to estimate the risks to people, as well as those of economic and environmental damage. To date, very little is known about the likely loss of life in floods, and the various causes. We do not yet have appropriate techniques that predict the incidence of loss of life in floods, or the potential for flood mitigation measures to reduce this loss.

9.1.2 Causes of death or injury

Mortality and morbidity depend on the type of flood. The main health concerns in slow rising and long duration floods are communicable diseases, sanitation, food and nutrition and vectors. In flash floods and other situations where the impact is more immediate, most deaths are due to drowning while injury is usually a result of moving debris and high winds (Legome, *et al*, 1995). Mortality associated with a flood will depend on the flood characteristics, e.g. flood type, but the way people respond to floods is a critical factor. In European floods particularly, deaths are strongly related to risk-taking behaviour (Jonkman, 2003).

Risk to life or serious injury is likely to be greatest when one or more of these following flood conditions exist (HR Wallingford, 2003, p.5)

- flow velocities are high
- flood onset is sudden as in flash floods, for example the Linton/Lynmouth floods in 1952, Big Thompson flood, USA, in 1976 and flash floods in Southeast China in 1996
- flood waters are deep
- extensive low lying densely populated areas are affected, as in Bangladesh, so that escape to high ground is not possible
- no warning (i.e. where there is less than, say, 60 minutes of warning)
- flood victims have pre-existing health/mobility problems
- natural or artificial protective structures fail by overtopping or collapse
- flood alleviation and other artificial structures themselves involve a risk to life because of the possibility of failure, for example dam or dike failure
- poor flood defence assets lead to breaches or flood wall failure, leading to high velocities and flood water loadings on people in the way
- debris in the floodwater that can cause death or injury
- flood duration is long and/or climatic conditions are severe, leading to death from exposure
- dam failure

Certain characteristics of people, their community or property can also increase the risk to life of those affected by flooding. These include, the presence of elderly or ill people, particular types of property (e.g. single storey), no previous experience or awareness of flooding, poor community support, the need to evacuate and live in temporary accommodation, etc. (HR Wallingford, 2003).

Deaths also often occur as a result of undertaking rescues (Jonkman and Kelman, 2005; MMRW, 2000) and disaster clean up (MMRW, 1989). Fast flowing waters rescues in particular present high hazards. Risk of electrocution (Jonkman, 2003; Kelman, *et al*, 2003) and many injuries (Noji, 1993) have a great occurrence during the clean up phase. The meteorological conditions that accompany floods can also cause additional deaths, for example, in car accidents due to more collisions and falling trees (Jonkman, 2003).

Jonkman and Kelman (2005) propose a framework for analysing flood deaths: they suggest that combination of hazard factors (e.g. floodwaters) and vulnerability factors (e.g. elderly person, illness) result in a flood death due to a specific medical cause (e.g. physical trauma, drowning, heart attack, etc.). Flood hazard factors used to calculate how floods impact upon people include depth of water, rise rate, velocity, wave characteristics and debris and pollutants load (Jonkman and Kelman, 2005). Vulnerabilities that can potentially lead to a flood death include age, gender, prior health (physical and mental), swimming ability, experience, clothing, activity and behaviour (e.g. sleeping, attempting a rescue, evacuation), impairment (e.g. due to alcohol or drugs), knowledge of the area, etc. Although the medical cause of death is usually listed, the fundamental cause of death is the flood. The literature reviewed by Jonkman and Kelman rarely makes links between hazard factors, individual vulnerabilities and the medical cause of death.

Three broad sets of flood characteristics were identified in research by HR Wallingford (2003) for Defra and the Environment Agency in England and Wales under the ‘Flood Risks to People’ project. These characteristics are seen to influence the number of fatalities or injuries in the event of a flood, they are:

- Flood characteristics (depth, velocity, etc.)
- Area characteristics (urban/rural,, nature of housing, flood warnings)
- Population characteristics (age, health, etc).

This project developed a methodology for assessing and mapping the risk to life or serious injury caused by flooding. It covered death or serious injury as a direct result of the flood either during the flood or up to a week after the event. The methodology was prepared for the UK and was calibrated using information from several historic flood events. Loss of life is caused by a combination of the above characteristics, e.g. high depth/velocity and vulnerable housing and no warning, etc. Identifying the relationships between the different variables is one of the problems with modelling loss of life (Jonkman, *et al*, 2002).

The ‘Flood risks to people’ methodology is a linear formula that is based on the flood, area and people characteristics and estimates the number of injuries and deaths from a river flood event. Different scores are allocated to each variable in the formula. The formula has been calibrated using several historical and more recent floods in the UK and the numbers of deaths and injuries predicted by the formula were reasonably accurate.

A methodology currently being tested for Floodsite Task 10 is based upon the earlier work of HR Wallingford. The aim of Task 10 is to develop a model that can be used to calculate and map the risk to life from flooding in Europe and to include loss of life in multi-criteria analysis of flood damage evaluation. It should be possible to use the existing UK model and to adapt it, using additional variables, to a range of European flood events and scenarios. The results from the research will potentially be able to be used in a number of ways, including: in project appraisal, to help raise awareness of flood risk and the dangers of flood water, to help improve the targeting of flood warnings, in land use planning and development control, emergency planning and response, and flood mapping across Europe. It is estimated that this model will be available from mid 2007.

9.1.3 The role of flood warning systems in preventing loss of life

There are examples in the literature of the part that warnings play in reducing deaths from flooding. Jonkman and Kelman (2005) who reviewed the causes and circumstances of 247 deaths in 13 recent flood events in Europe and the US, found drowning to be the main cause but note that drowning in vehicles is a much worse problem in the US than in Europe. Better warning systems in Europe combined with better compliance are suggested as one of a number of possible explanations for the difference as well as the type of flooding. Rosenthal and Bezuyen (2000) also noted that in 1997 summer floods across Europe, there were over 100 deaths altogether in Poland and the Czech Republic, but none in Germany where admittedly the area affected was comparatively small and dike breaches in Poland provided some relief but also longer warning lead times, resulted in more time for preparation which appears to have been well used. Gruntfest (1977, 1987) and Gruntfest and Ripps (2000) have documented the frequent occurrence in the US and the particular threat posed by flash floods and the challenge to provide forecasts and warnings given very little warning lead time. Penning-Rowsell et al. (2005) have developed a methodology and an operational framework for assessing and mapping the risk of death and serious harm to people from flooding but have not examined flood warnings as a variable in this process.

In flood events which may pose a substantial risk to life, the main objective of flood warning may be to enable people to evacuate out of the danger zone in advance of flooding. Evacuation to avoid injury and loss of life may then take priority over damage reduction as an appropriate response. Dam burst floods, high velocity and high depth, coastal and fluvial events, coastal storm surges, floods following the breach in defences particularly in low lying areas and in very ‘flashy’ catchments are likely to be life threatening events. In these circumstances, calculating property damage avoided may not be relevant or appropriate. However, in some circumstances, although evacuation may be the appropriate response, there may still be time if there is a long warning to take damage reducing action as well. The Netherlands flood of 1995 exemplifies such an event in which a long warning lead time meant that, in some areas, people had time to move belongings and cattle to a safe place prior to evacuation (Van Duin and Bezuyen, 2000).

Flood warning and warning time have been used to model the number of fatalities that may be caused by a flood. Jonkman et al (2002) reviewed a series of methods available in literature to estimate the loss of life caused by floods. Brown and Graham (1988) propose loss of life as a function of the population and the time available for evacuation (i.e. warning). The procedure is derived from the analysis of 24 major dam failures and the consequential flash floods. For DeKay and McClelland (1991) loss of life is also a function of population and evacuation time, but they distinguish between ‘high lethality’ floods, for example in a canyon and ‘low lethality’ floods, for example, on a floodplain. In both functions, loss of life decreases very quickly when warning time is increased. Graham (1999) presented a framework for estimating loss of life due to dam failures based on the flood severity, the amount of warning and the understanding of the population of the flood severity. Three categories of warnings are given: no warning, some warning (15-60 minutes) and adequate warning (> 60 minutes). According to this model, adequate warning greatly reduces the fatality rate in flood events.

Although systematic evidence is limited, the benefits of flood warnings in reducing flood fatalities are well recognised. However, there has been little research to assess these benefits in monetary terms. An approach that has been suggested is to use the monetary value placed on life in other contexts as a surrogate to evaluate deaths avoided by flood warnings (Taylor et al., 1997).

9.1.4 Stress and trauma

Floods may also result in impacts upon human health, both physical and psychological (Tunstall et al., in press). Methods for assessing the economic benefits of a reduction in the stress and trauma that are associated with flooding were researched and proposed by Taylor et al. (1997). However, Jones-Lee (2001) in reviewing these proposals argued that the methods suggested were seriously flawed. A recent UK Defra and Environment Agency funded research project on the 'Human Intangible Impacts of Flooding' produced measures of the mental health effects of flooding. However, the project was only partially successful in attaching monetary values to these mental health and stress effects (RPA/FHRC et al., 2004). The project produced some evidence that a longer warning lead time was a factor associated with reduced health and stress effects (Tunstall et al., 2005). However, it was not possible to attach a money value to this effect Thus, there is no well researched and tested method that can be proposed in these guidelines for these intangible impacts.

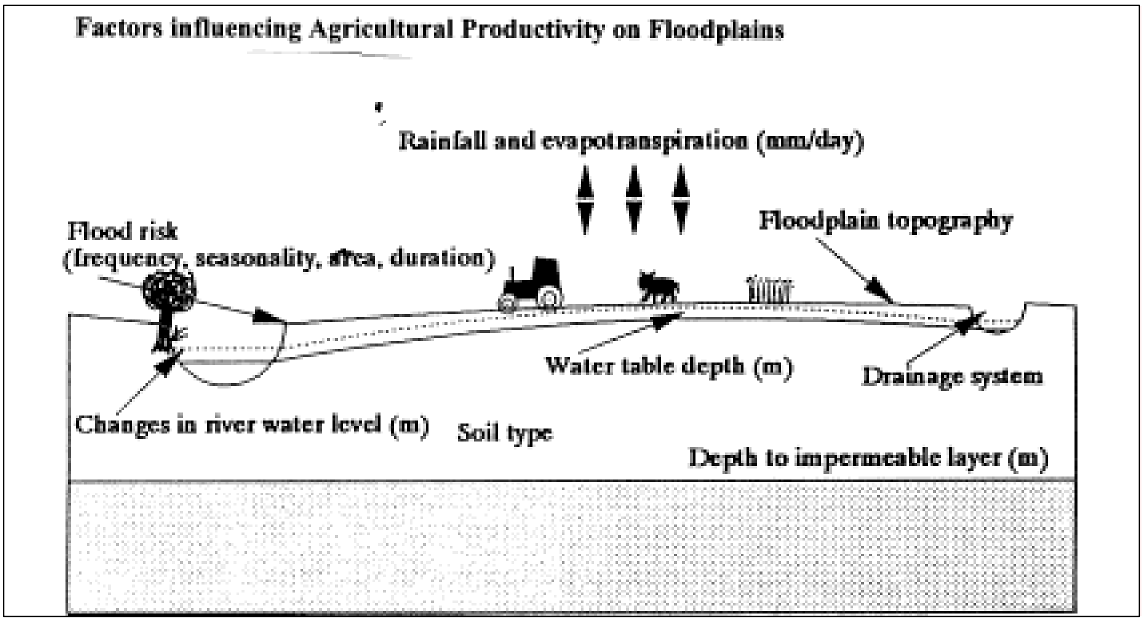
9.2 Appraising flood risk management schemes for agriculture[29]

9.2.1 Introduction

Flood risk management for farmland is an important element of support to the agricultural sector in many EU countries.

However, under current Common Agricultural Policy regimes in most countries (where there are agricultural surpluses) the current role of appraisal (Figure 9.1) is mainly to determine whether it is worthwhile to continue to provide flood defence for agriculture. This may involve comparing some existing flood defence standard with the 'do nothing' option (Table 9.1).

Figure 9.1: Causes and effects of flooding and drainage conditions on farmland



[29] The contribution to this text on agriculture from Professor Morris of Cranfield University is acknowledged.

Table 9.1: 'Tolerance' of flooding according to agricultural land use

Land use type	Whole Year	Summer April-October
	Annual probability	
Horticulture	5%	1%
Intensive arable including sugar beet and potatoes	10%	4%
Extensive arable: cereals, beans, oil seeds	20%	10%
Intensive grass: improved grass, including dairying	50%	20%
Extensive grass: usually cattle and sheep	≥100%	33%

Alternatively some intermediate option may offer better value. The appraisal will require some comparison of the financial and economic performance of land use under relevant flood risk management regimes, and how these compare with the costs of delivering those options.

Where farming is impossible in the absence of flood defence - such as behind flood defences or where land is lower than high tide levels - the advice in the UK is to estimate the economic damages (and therefore the benefits of flood defence) in terms of the likely reduction in the asset value of the agricultural land.

The approaches needed for appraisal are:

- At a broad catchment scale, appraisals will at least require information on categories of land use, and the extent these might be affected by a change in flood risk.
- At a detailed scheme appraisal level, however, there is likely to be a need to collect primary data and undertake detailed farm-by-farm analysis.

9.2.2 Methods for assessing agricultural benefits

Three main steps are required to derive a monetary value of agricultural benefits under different flood risk management conditions:

- Step 1: Defining agricultural productivity
- Step 2: Defining the impact of flooding
- Step 3: Expressing any difference in monetary values

The greatest detail will be required to assess reductions in flood defence or flood risk management standards for specific schemes on relatively intensively cropped land, including intensive grassland. Less detail is justified for broad scale or reconnaissance level assessment at the catchment scale.

9.2.3 Step 1: Defining agricultural productivity

For the area in question we need, first, to estimate the level of the water table during the critical periods of the farming calendar. This can be expressed as a drainage 'condition' and an agricultural productivity class (Table 9.2).

*Table 9.2: Field water table levels, drainage conditions and freeboard**

Depth to water table from surface	Agricultural drainage condition	Agricultural productivity Class	Spring time Freeboards in watercourses (natural drainage)	Spring time Freeboards in watercourse (field drains)
0.5m or more	Good	Normal, no impediment imposed by drainage	1m (sands), 1.3m (peats) 2.1m (clays)	1.2m (clays) to 1.6m sands (0.2m below pipe outfall)
0.3m to 0.49m	Bad	Low, reduced yields, reduced field access	0.7m (sands) 1m (peats) 1.9m (clays)	Temporarily submerged pipe outfalls
Less than 0.3m	Very Bad	Very Low, severe constraints on land use, reduced yields, reduced field access, mainly wet grassland	0.4m (sands) 0.6m (peats) 1m (clays)	Permanently submerged pipe outfalls

*Freeboard here is the height difference between water in the ditch and the adjacent field surface level.

Information on land use, classified into major crop and grassland types (Table 9.1), is then used to determine the likely consequences for the physical and financial performance of arable and grassland.

- For **arable land**, estimates of crop yields can be obtained from farm surveys or from data on regional yields adjusted according to local drainage condition based on research findings (Table 9.3). Farmers are usually able to report the degree to which yields on poorly drained parts of their farm are lower than elsewhere.

- Assessing **grassland** productivity requires data not available on most farms (i.e. livestock numbers; ages and weights at grass; number of livestock grazing days; liveweight or milk yields; weight and nutrient value of conserved grass).

- Using data from secondary sources and from farm surveys in the study area, it is possible to estimate the productivity of grass in terms of energy (Mj/ha) based on drainage condition, grass suitability class, fertiliser use, and grass conservation and grazing methods.

9.2.4 Step 2: Defining the impacts of flooding

These can be distinguished in terms of:

- Frequency of occurrence (including the chance of multiple floods per year)
- Seasonality (especially the distinction between winter and summer floods)
- Duration (from one or two days in some cases, to two or three months in washland areas)
- Depth (as this affects damage to crops and livestock)
- Soil compaction; erosion risk; chance of crop recovery.

Flood damage costs include:

- The loss of output due to inundation, plus
- The cost of remedial work.

A similar approach is adopted for grassland. The impact of a flood occurring in a given month is assessed in terms of energy lost from grass valued at substitute feed prices, less any savings in hay/silage making costs if relevant, plus stock relocation costs and clean up.

Table 9.3: Common farming performance by field drainage conditions (England and Wales)

	Field Drainage Conditions		
Land Use	Good	Bad	Very Bad
Grassland			
Typical nitrogen use on grass kgN/ha	150 - 200	50 – 75	0 - 25
Grass conservation	2 cut silage	1 cut silage or graze	1 cut hay or graze
Typical stocking rates; Livestock units/ha	1.7 – 2.0	1.2 - 1.4	0.7 - 1.0
Typical livestock type	Dairy, intensive beef and sheep	Beef cows, 24 month beef, sheep	Store cattle and sheep
Typical financial gross margins £/ha (after forage costs)	£1200-1400 (dairy) £600 (intensive beef/sheep)	£300-£400	£200
Days reduction in grazing season compared to 'good' category			
Spring	0	14 to 21	28 to 42
Autumn	0	14 to 21	28 , no stock out in winter
Arable			
Yield as % of 'good' category			
Winter wheat and barley	100	80	50
Spring wheat and barley	100	90	80
Oil seed rape	100	90	80
Potatoes, Peas, Sugar Beet	100	60	40*
Typical wheat financial gross margin £/ha	550	440	270

Livestock units: dairy cow, 1 Lu; beef cow, 0.8 Lu; 24 month beef, 0.7 Lu; sheep plus lamb, 0.14 Lu.

A grazing day is worth about £1.12/lu in spring, £0.8/lu in autumn, and £0.38/lu in winter in terms of savings in housing costs and feed conservation costs.

*not grown if persistently ‘very bad’.

9.2.5 Step 3: Expressing any difference in monetary values

1. Gross and net margins

The financial impacts of changes in flood risk management standards can be determined using the accounting conventions of gross margins, fixed costs and net margins, expressed either per hectare (ha) or for a farm as a whole.

The level of detail required depends on the purpose and context of the appraisal. Where the 'do-nothing' option involves write-off of agricultural assets, the appraisal can use the estimated reduction in land values (suitably adjusted: see Table 9.4) as a basis for assessment. In many cases, however, it will be necessary to estimate the financial and economic performance of agriculture under different flood regimes.

Table 9.4: Different assumptions for assessing a range of agricultural flood risk management scenarios (UK government advice)

	Scenario I	**Scenario II**	**Scenario III**
	Land lost to agriculture	Temporary, one-off loss of agricultural output	Permanent reduction in the value of agricultural output
All agricultural land use	Loss assumed equivalent to 65% of prevailing land values		
Crops: Cereals; oil seeds; beans/ peas. **Grassland:** Beef and sheep		Loss of Gross Margins per ha (adjusted for possible savings in costs), plus clean-up costs	Reductions in Net Margins associated with change in flood and land drainage conditions
Other: Dairy; sugar beet, potatoes; high value fruit/ vegetables		As above, treated as though the area is occupied by wheat	As above, treated as though the area is occupied by wheat

For arable crops, gross margins per hectare measure the value of output, including any remaining direct subsidies, less variable costs such as seeds and fertiliser. Variable costs are directly related to each unit of activity, and can be avoided if that activity is not pursued.

Gross margins show the monetary gain (or loss) associated with one more (or one less) unit of an activity, assuming other so-called 'fixed' resources available to the business, such as regular labour, machinery, buildings and land (and their associated costs) remain unchanged.

1. Scenarios and their treatment

In 2005 a major change affected the way farmers in the EU receive government financial support. For example, in the UK instead of payments per ha (typically £250/ha) for crops such as cereals, proteins and oils seeds and payments per head of beef or sheep animal, farmers now receive a Single Payment per year under the CAP Agenda 2000 regime, of which the current reforms are part.

Thus in the UK previous government guidance on appraising flood risk management schemes for agriculture (e.g. MAFF 2000) required removal of direct subsidies from crop and livestock gross margins. This no longer applies because, with a number of small exceptions, these direct subsidies no longer exist. Thus the economic analysis of flood risk management investment is more straightforward than before.

To this end UK government guidance identifies three scenarios which reflect the nature of flood risk change, namely:

- Scenario I: Permanent loss of agricultural land;
- Scenario II: One-off damages arising from infrequent flood events;
- Scenario III: A permanent deterioration in flood management standards.

These scenarios justify different approaches and methods for the assessment of flood management benefits; these are detailed in Table 9.4.

9.2.6 Data needs, sources and collection methods

It is advisable to start any assessment with an exploratory survey of the study area to define the geographical boundary of influence, that is the benefit area, and to determine current flood risk management standards and issues arising.

The exploratory survey will also identify broad categories of land use, dominant farm types and systems, possible flood risk management options, the likely impact of these and the likely attitudes of key stakeholders, especially farmers.

Key informants will include:

- Government officials with flood risk management interests in regional offices ;
- Representatives of farmer organisations;
- Local agricultural advisors and land agents;
- Environmental groups.

In most cases some form of farm survey will also be needed. In most cases it will be appropriate to select a quota of representative farmers that cover the major variations in farm circumstance (e.g. size, tenure, land type, flood risk), farm practices (e.g. enterprise mix, drainage improvements), and farmer characteristics (e.g. age; family circumstances and motivation).

For agricultural enhancement schemes, for which controlling floods is an important part, the extent to which flooding and drainage currently constrain farming will be a focus of enquiry, together with the factors that are likely to encourage farmer take-up of potential benefits. Conversely, the scope for, and attitudes towards, reconciling flood storage, wildlife and farming interests will be a focus for wetland and washland development schemes where the focus of attention is the prevention of the deterioration of farming as a result of flooding (probably associated with a deterioration of existing flood defences).

10. Glossary

Accuracy - The ability to measure differences when there are differences.

Assets at risk - assets are entities functioning as stores of value and over which ownership rights are enforced by institutional units, individually or collectively, and from which economic benefits may be derived by their owners by holding them, or using them, over a period of time (Eurostat 2005). Assets at risk are e.g. houses, cars, inventories etc. which could be affected by a flood.

Catchment area - the area from which water runs off to a river

Consequence - An impact such as economic, social or environmental damage/improvement that may result from a flood. May be expressed quantitatively (e.g. monetary value), by category (e.g. High, Medium, Low) or descriptively.

Contingent valuation – A social survey method for the monetary evaluation of goods that are not traded in markets which involves asking people their "willingness to pay for" or their "willingness to accept" changes in the supply of such a good.

Cost-benefit analysis – Assessment of measures comparing the benefits of a possible course of action against their costs. In context of flood risk management measures: Relating the benefits, i.e. the damages avoided by a measure to its costs.

Damage function (damage curve) – the functional relation between inundation characteristics (mostly depth) and damage for a certain category of elements at risk. *Relative* damage functions show the damaged share of the total value of the element at risk. *Absolute* damage functions show the amount of damage for an element of risk or an unit of area of this element in absolute terms.

Direct damage - covers all varieties of harm which relate to the immediate physical contact of flood water to humans, property and the environment. This includes, for example, damage to buildings, economic assets, loss of standing crops and livestock in agriculture, loss of human life, immediate health impacts, and loss of ecological goods.

Discounting – A means of comparing the desirability of income and expenditure occurring at different times in the future.

Efficiency - In everyday language, the ratio of outputs to inputs; in economics, optimality.

Event (in context) . In **FLOODsite**, these are the conditions which may lead to flooding. An event is, for example, the occurrence in *Source* terms of one or more variables such as a particular wave height threshold being exceeded at the same time a specific sea level, or in *Receptor* terms a particular flood depth**.** When defining an event it can be important to define the spatial extent and the associated duration.

Exposure - Quantification of the receptors that may be influenced by a hazard (flood), for example, number of people and their demographics, number and type of properties etc.

Expressed preferences - techniques for the economic evaluation of goods which rely upon the use of interview or questionnaire surveys of those populations who may value those goods.

Flood - A temporary covering of land by water outside its normal confines. From a more social science point of view it is water in a place where we don't want it, at a time we don't want it, in a quantity we don't want.

Flood damage - loss of life, loss of value of elements at risk (buildings, inventories, infrastructure, goods, cultural and ecological assets) compared to pre-flood conditions and loss of production caused by a flood.

Flood risk management - Continuous and holistic societal analysis, assessment and mitigation of flood risk.

Flood risk management measure - An action that is taken to reduce either the probability of flooding or the consequences of flooding or some combination of the two

Flow value – value of a good measured by the flow of income or consumption generated by a good in a certain time period.

Hazard - A physical event, phenomenon or human activity with the *potential* to result in harm. A hazard does not necessarily lead to harm.

Indirect damage - loss 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 of their suppliers and customers, the costs of traffic disruption or the costs of emergency services.

Intangible damage – damages on goods which are not or not easily assessable in monetary terms. E.g. harm to people or damages to the environment.

Inundation - Flooding of land with water.

Inundation depth – Height of flood water above ground level at a certain location.

Inventories (stocks) - list of household contents or, for businesses, stocks of outputs that are still held by the units that produced them prior to their being further processed, sold, delivered to other units or used in other ways, and stocks of products acquired from other units that are intended to be used for intermediate consumption or for resale without further processing (Eurostat 2005)

Land use data – in this context: any information about number, location and type of properties or activities at risk.

Probability - A measure of our strength of belief that an event will occur or that some statement is true. For events that occur repeatedly the probability of an event is estimated from the relative frequency of occurrence of that event, out of all possible events. In all cases the event in question has to be precisely defined, so, for example, for events that occur through time reference has to be made to the time period, for example, annual exceedance probability. Probability can be expressed as a fraction, % or decimal. For example the probability of obtaining a six with a shake of four dice is 1/6, 16.7% or 0.167.

Project Appraisal - The comparison of the identified courses of action in terms of their performance against some desired ends.

Receptor - Receptor refers to the entity that may be harmed (a person, property, habitat etc.). For example, in the event of heavy rainfall *(the source)* flood water may propagate across the flood plain *(the pathway)* and inundate housing *(the receptor)* that may suffer material damage *(the harm or consequence).* The vulnerability of a receptor can be modified by increasing its resilience to flooding.

Resilience - The ability of a system/community/society/defence to react to and recover from the damaging effect of realised hazards.

Return period - The expected (mean) time (usually in years) between the exceedence of a particular extreme threshold. Return period is traditionally used to express the frequency of occurrence of an event, although it is often misunderstood as being a probability of occurrence.

Risk - Risk is a function of probability, exposure and vulnerability. Often, in practice, exposure is incorporated in the assessment of consequences, therefore risk can be considered as having two components: the probability that an event will occur and the impact (or *consequence)* associated with that event.

Risk = Probability multiplied by consequence

Risk analysis - A methodology to determine risk by analysing and combining probabilities and consequences.

Risk reduction - The reduction of the likelihood of harm, by either reduction in the probability of a flood occurring or a reduction in the exposure or vulnerability of the receptors.

Stock value – value of a good at a certain point in time. In a market which is not distorted and is at equilibrium the stock value of a good is its opportunity cost.

Susceptibility - The propensity of a particular receptor to experience harm.

Tangible damage - damage which can be easily specified in monetary terms, such as damages on assets, loss of production etc.

Uncertainty - A general concept that reflects our lack of sureness about someone or something, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome.

Value - In economics, the extent to which an individual desires some good or service, and is consequently willing to pay to obtain access to a specific quantity of that good or service.

Vulnerability - Characteristic of a system that describes its potential to be harmed. This can be considered as a combination of susceptibility and value.

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