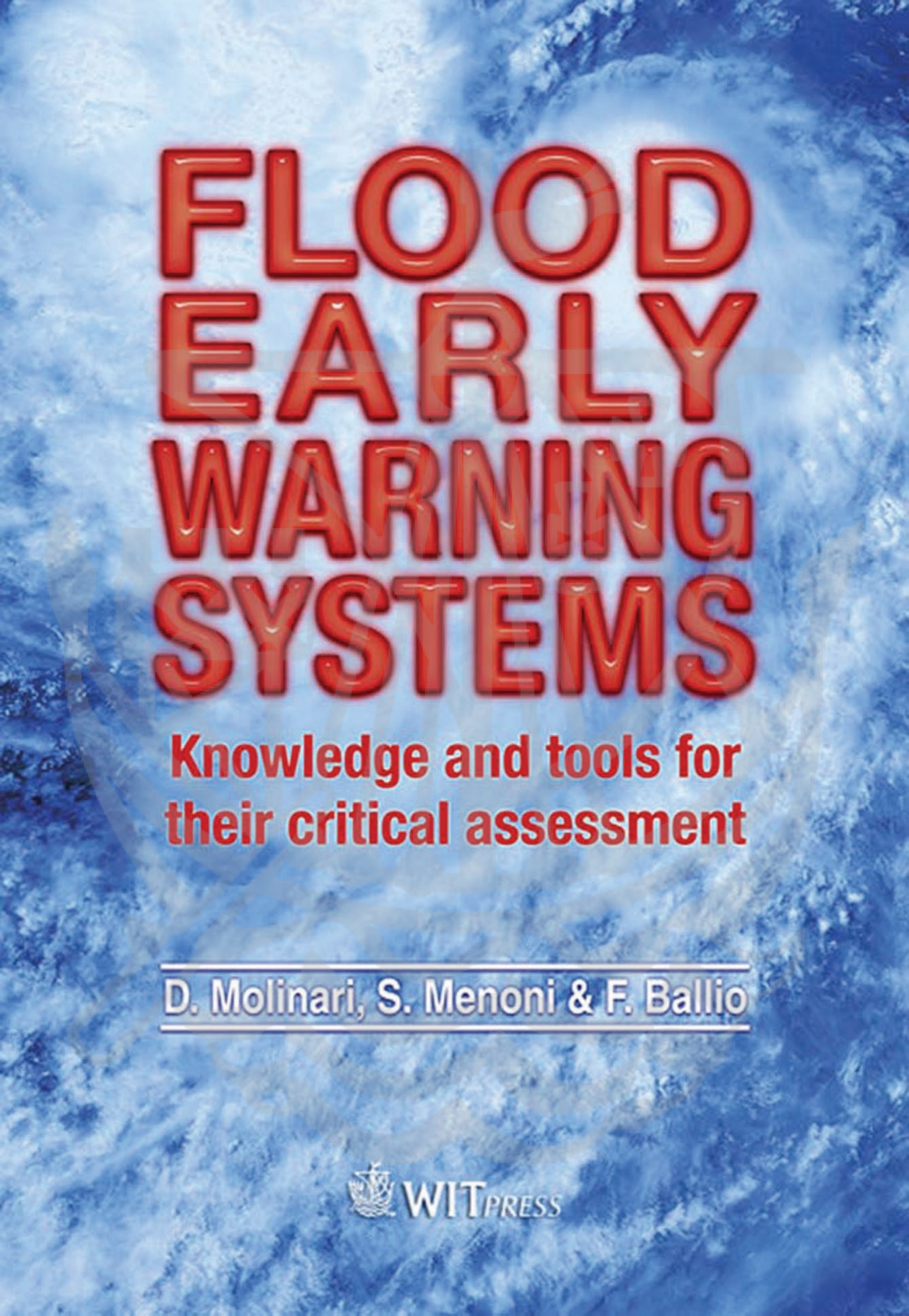

FLOOD EARLY WARNING SYSTEMS

Knowledge and tools for their critical assessment

D. Molinari, S. Menoni & F. Ballio

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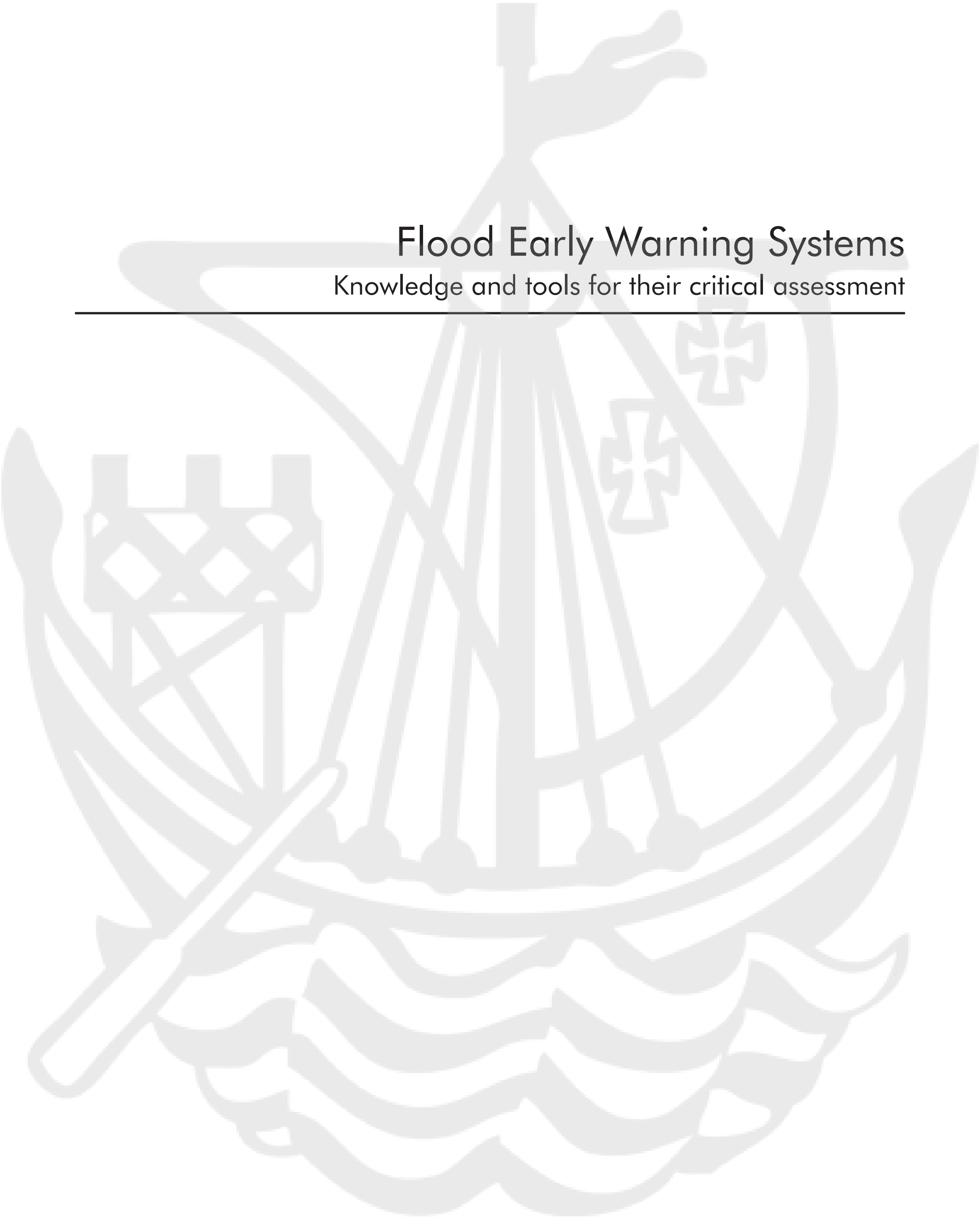

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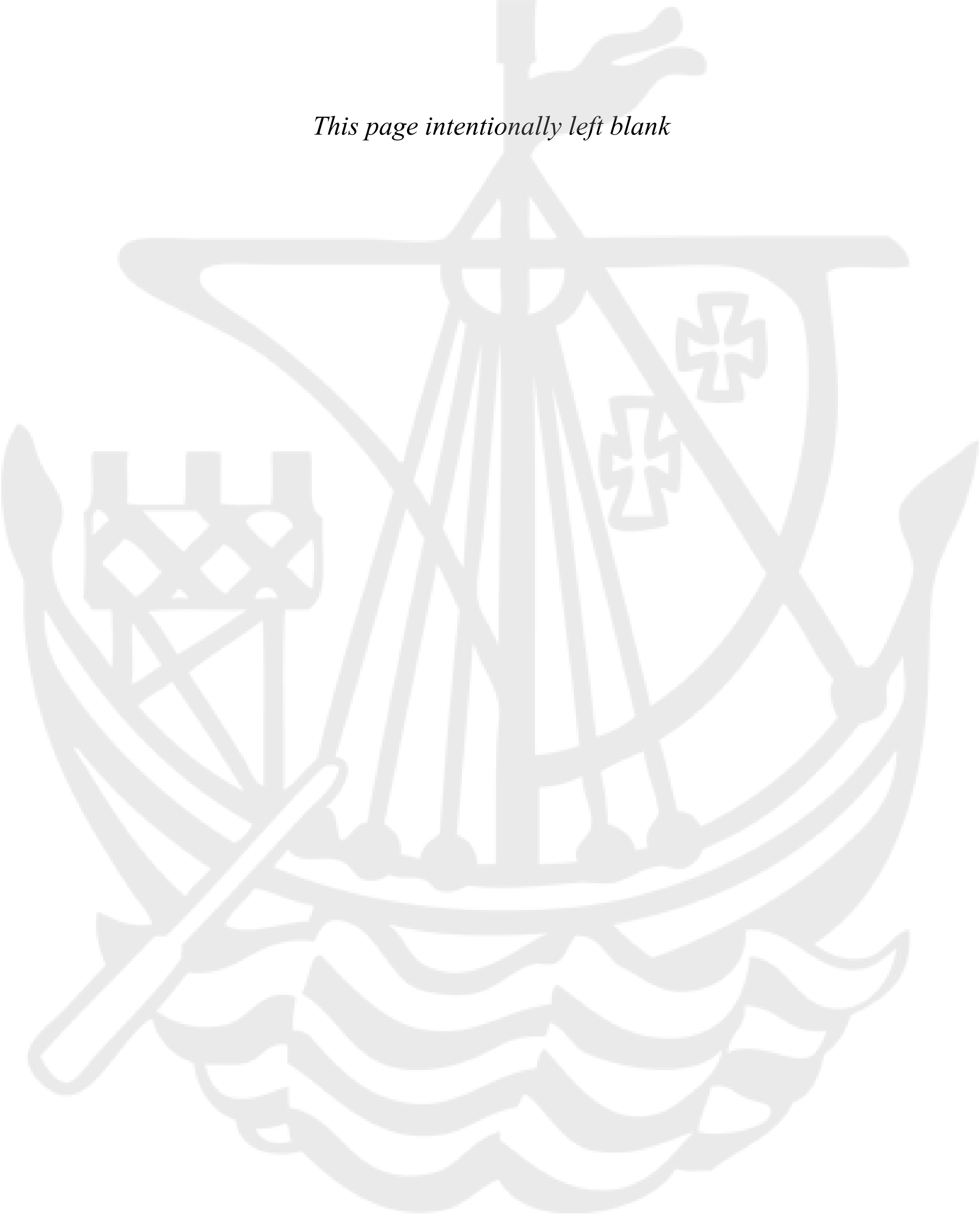

Introduction

The idea and the structure of the book

The last decades experienced a rapid increase of flood occurrence and related impacts[1]; as a consequence, the traditional approach of "flood protection" (which is mainly aimed at controlling flood hazard factors as far as possible by means of structural measures) was put into question.

Evidence from the past suggested in fact that the conventional practice was insufficient to deal with flood risk leading, in some cases, even to the opposite effect to the desired one: the unexpected increase of the flood risk. On the one hand, one of the main reasons for the increasing number of people affected by floods and flood damages was the increasing growth of urban populations in flood-prone areas; the massive construction of river dikes in the past (and, more in general, of hazard control measures) brought into people a "false sense" of security, encouraging such wrong behaviour. On the other hand, river dikes did not eliminate the hazard but simply shifted the problem downstream (where dikes were not present) where floods could then occur even with much more intensity, mainly because of systematic artificialising of natural water courses and floodplains.

The direct consequence of this awareness was that the need for a "new" holistic approach of **flood risk management** (FRM) arose. The risk is now viewed from a wider perspective where not only hazard but also exposure and vulnerability factors must be carefully taken into account and handled, with the general aim of reducing risk (not controlling hazard).

The FRM process is described in detail in Figure I.1. In brief, three steps are required (Pilon, 2002):

1. The identification of the risk; it includes assessing the potential for hazard to occur and a vulnerability analysis to provide an understanding of the consequence should an event of a certain magnitude and frequency occur. Results are supplied in different forms, usually maps.
2. The development of strategies (i.e. mitigation strategies) to reduce the risk estimated during the previous stage.
3. Finally, the creation of policies and programmes to put these strategies into practice.

The figure puts into evidence that the three steps are not independent but strictly interconnected to each other (e.g. the knowledge of risk assessment is a prerequisite for risk reduction).

This book focuses on the second step required by risk management, being risk mitigation. Also within this narrower perspective, a shift occurred from the traditional implementation of

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[1] See for example EM-DAT, NatCat and Munich Re disaster databases.

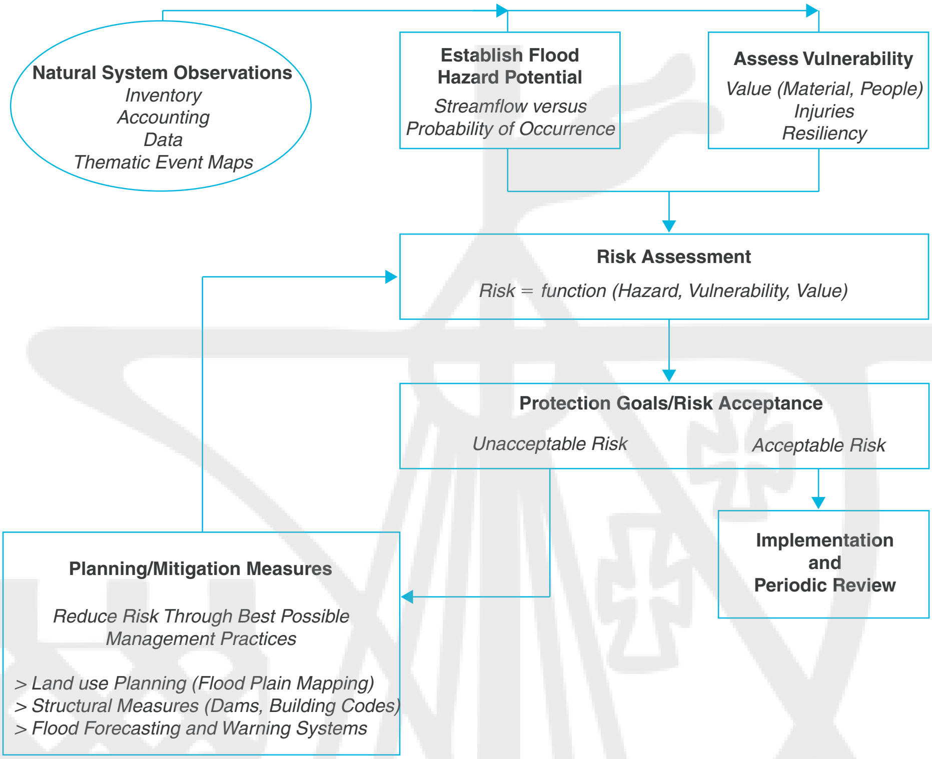

Fig. 1.1
Framework for FRM (Source: Pilon, 2002)

structural measures only to the adoption of more comprehensive strategies where both structural and non-structural measures must be considered. The recent European Floods Directive[2] is explicative of this new paradigm. The Directive asks Member States to accomplish three tasks: (i) conduct a preliminary flood risk assessment by 2011, (ii) prepare flood hazard maps and flood risk maps by 2013 and (iii) define flood risk management plans (FRMPs) by 2015. FRMPs, in particular, “shall address all aspects of flood risk management focusing on prevention, protection, preparedness (. . .)”.

This book focuses in detail on one crucial aspect of FRM, being flood early warning systems (FEWSs); the latter are one of several mitigation tools that can be put into practice in a holistic risk management strategy. For this reason, before going straight to the point under investigation, a brief discussion of flood mitigation tools is herewith supplied, the aim being to stress the role of FEWSs for mitigation. The last part of the chapter introduces instead the main contents of the book.

1.1 Flood mitigation tools and FEWSs

Mitigation is defined by UNISDR (2009)[3] as “the lessening or limitation of the adverse impacts of hazards and related disasters”. Flood mitigation tools can be defined, as a consequence,

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[2] EU: Directive 2007/60/EU of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, Official Journal of the European Union, 2007.

[3] United Nations International Strategy for Disaster Reduction Secretariat, see Chpater 1.

as those measures aimed at reducing flood damage to the built and natural environment and potential harm to people.

The FP6 Scenario[4] project (Menoni et al., 2011) classifies mitigation measures as reported in Table I.1.

In detail, tree criteria have been used to classify mitigation measures:

1. The risk component they are designed to reduce
2. The use or not of structural works
3. The time needed to see first positive results in terms of risk reduction.

According to the first criterion, mitigation measures aim at reducing the hazard (e.g. levees), the exposure (e.g. evacuation, relocation) or the vulnerability (e.g. building flood proofing, education) component of risk.

The second criterion makes instead a distinction between structural and non-structural measures. The former consist mostly in engineering works that are designed (i) to modify the physical phenomena representing a hazard for a given community (e.g. levee) or (ii) to strengthen exposed buildings and infrastructures. Non-structural measures consist instead in social, economic and managerial adjustments, aimed at making communities and settlements more resilient to floods (like emergency planning, educational campaigns, etc.). Finally, there is a distinction between short- and long-term measures. Long-term measures have a longer time horizon and require time to develop their efficacy. An example is land use planning. Short-term measures address instead preparation for a potential emergency, building the coping capacity of a given community and territory. Examples are educational programmes, house retrofitting and emergency planning.

The wider perspective of FRM is clearly evident in Table I.1. Having disposal of a number of tools which allow (i) to work on the various components of risk, (ii) through different strategies and (iii) at the different stages (physical, social, economic, etc.) of processes leading to the creation of risk, widens analysts spectrum of intervention (with respect to the traditional flood protection approach). As a consequence, our capacity of reducing risk ideally arises.

FEWSs can be seen as a non-structural short-term measure, their aim being the treatment of the so-called unmanaged risk. In fact, where a risk is present, it is impossible totally to protect communities from the likelihood of a disastrous event even in the few cases where appropriate preventative measures have been implemented. Consequently, there is always a residual risk for exposed systems. FEWSs make it possible to handle the ineliminable residual risk, by reducing its potential negative impacts in the many cases where significant hazard, exposure and vulnerability reduction measures have not been satisfactorily implemented. As a consequence, their importance in the last decades has been progressively remarked (see Chapter 1).

As suggested by Maskrey (1997), however, "FEWSs should be seen as a "last line of defence" within a much wider (longer) flood risk management strategy; if developed as a 'stand alone' system, FEWSs may even create a false sense of security, leading communities to increase rather than mitigate their risk". This is true, in general, not only for FEWSs but any time mitigation is considered (i.e. hazard, exposure and vulnerability features); as a general rule, mitigation tools need to be combined to be effective, in the best possible way in order to fit with the specific context investigated.

FEWSs are complex tools, as discussed in detail in Chapter 1. As a consequence, they allow tackling with all the different components of risk: the hazard, by means of monitoring and

---

[4] Support on Common European Strategy for sustainable natural and induced technological hazards mitigation.

Tab. I.1
Mitigation measures for natural risks (Source: Menoni et al., 2011)

	Structural		**Non-structural**			
			Reducing vulnerablity			
	Decreasing hazards	**Reducing exposure**	**Physical**	**Social and economic**	**Built environment**	**Natural environment**
Long-term mitigation measures	Buildings consolidation	Land use planning to avoid the most hazardous zones	Buildings codes	Preparedness programmes	Land use planning	Preserving diversity in agricultural activities
	Levees, outlets, etc.	Relocation from the most critical areas	Buildings retrofit codes	Education, training of various public sectors	Locational decisions regarding public services and infrastructures	Tailoring agricultural practices to the type of soil/terrain
	Avalanches defence Landslide consolidation	Insurance integrated to land use planning	Norms to secure public facilities, factories etc.	Development of programmes with the media		Protection of marsh areas, humid zones, shoreline dunes
	Reduction of gas emissions			Adaptation to reduce the impact of climate change		
Short-term mitigation measures	Lava flows diversion	Evacuation	Buildings usability checks	Improvement of civil protection organisational capabilities	Accessibility to services and to potentially damaged areas	Sustainable practices in lava, water flows diversion
	Sandbags and barriers to inundating waters		Temporary repairs particularly for lifelines	Business continuity plans also for the public sector		
	Fires control			Use of the media to dispatch emergency messages		

forecasting, and the exposure and vulnerability, by means of warning and related responses. It is going without saying that FEWSs design and evaluation requires the analysis of each of these components.

I.2 The objective and the structure of the book

The research this book is grounded on started with the ambitious intent to understand why FEWSs may fail. However, from the beginning, the objective turned out to be challenging; first, because, so far, there is not a shared opinion on what an EWS is (among both communities of researchers and practitioners); second, as a consequence, because it is equally not clear when an EWS can be considered successful or not.

The direct consequence of this is that "open questions" needed primarily to be faced about the identification of the subject of the analysis (i.e. what is a EWS?), its components and functions, and its peculiarities (weak points); then, causes of EWSs' failure could be analysed.

This book is organised accordingly to the conceptual steps required by the research. In Chapter 1 preliminary "open questions" about the definition and the role of FEWSs are handled (the aim being the identification of how to evaluate EWSs effectiveness/performance). Chapters 2–4 focus on the real aim of the research, providing concepts and practical tools to assess FEWSs performance.

According to the philosophy adopted by the book, FEWSs should be evaluated from three different perspectives which are all crucial for their effectiveness:

1. First, from the forecasting point of view, meaning looking at the goodness of flood forecasts in terms of their capability to predict the features of incoming floods; this is the objective of **Chapter 2**.
2. Second, from the perspective of risk scenarios, that is considering the capacity of the system to properly figure out expected damages in case of flood (on which mitigation actions can be planned); **Chapter 3** deals with this aspect.
3. Finally, from the point of view of damage reduction, that is investigating the ability of the system (and, in particular, of the strategies which it implements to copy with the event) to lessen expected damages; this is discussed in **Chapter 4**.

Each chapter ends with a common case study describing how above evaluations can be carried out in practice. Lot of attention is put on the case study, the aim being to (i) explain concepts and tools directly by means of a real application and (ii) highlight problems that analysts can face once such concepts and tools are really implemented. The idea of a common case study originates from the necessity to stress and compare the potential of each perspective in terms of knowledge supplied for emergency managers (i.e. those responsible for warning).

The focus of this book is flood risk, specifically, in mountain regions. However, most of results can be exported to other hazards as well.

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Chapter 1

Basics of early warning

As discussed in Introduction, history teaches us that where a risk is present, even if proper mitigation measures[1] are implemented, it is impossible to totally protect communities at risk from the likelihood of a disastrous event, that is, a “**residual risk**” always exists which affects exposed systems.

This is especially true where exposure and vulnerability are high and/or where the implementation of mitigation measures is not feasible or inadequate; unfortunately, this is just the scenario which characterises the majority of communities worldwide, mostly because of wrong spatial planning and urban development in the past.

Early warning systems (EWSs) allow to manage residual risk and, for this reason, their role has become increasingly important in the last few decades (see Box 1.1). However, as claimed by Maskrey (1997), risk reduction strategies should not rely solely on EWSs which should be seen, instead, as a “last line of defence” for dealing with unmanaged risks within a much wider risk management and reduction policy.

But, what is exactly an EWS?

A shared definition cannot be identified; on the contrary, so far, the problem has been usually handled as fragmented, bringing to the current situation in which conflicting definitions exist.

Actually, unlike the common belief in hydraulics and hydrology, an EWS is more than a forecasting tool. As suggested by the United Nations (UNISDR, 2009), it is a complex system which includes all

> *The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organisations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.*

Accordingly, even if much past EWSs evaluations have focused on the accuracy of hazard predictions, many researchers have recently argued that EWSs success should be seen in terms of the impact of warning on reducing damages.

This is the point of view this book adopts as well, looking for a procedure to analyse FEWSs and their performance.

Nevertheless, in order to evaluate FEWSs capacity to reduce damages, flood forecasting systems performance must be evaluated as well; expected damages vary along with the warning outcomes (i.e. damages are different in case of false warning, missed event, etc., see Chapter 2) which, in turn, depend on the accuracy of predictions.

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[1] All those structural and non-structural tools aimed at reducing damage in case of a disastrous event.

Box 1.1: Milestones and first steps of early warning matters

22 December, 1989

Adoption of the United Nations General Assembly resolution A/Res/44/236 by which the 1990s was proclaimed as the International Decade for Natural Disaster Reduction (IDNDR) in order to increase awareness of the importance of disaster reduction. Special attention was given to the establishment of early warning systems.

1991

The IDNDR's Scientific and Technical Committee declared early warning as a programme target. All countries were encouraged to ensure the ready access to global, regional, national and local warning systems as part of their national development. Targets to be attained by all countries by 2000, as part of their plans to achieve sustainable development, included ready access to global, regional, national and local warning systems and broad dissemination of warnings.

23–27 May 1994

The states members of the United Nations and other states met at the World Conference on Natural Disaster Reduction (UN, 1994), in the city of Yokohama, Japan. Early warnings of impending disasters are included among conference principles as "key factors to successful disaster prevention and preparedness".

9 October 1995

The Secretary General Report A/50/526 (IDNRD Secrtariat, 1995) provides a review on early warning capacities of the United Nations system with regard to natural disasters. It states that early warning is a universally pursued and self-evident objective in determining disaster reduction strategies.

Several expert working groups were created to study different aspects of early warning: (i) geological hazards, (ii) hydrometeorological hazards including drought, (iii) fire and other environmental hazards, (iv) technological hazards, (v) earth observation and (vi) national and local capabilities pertinent to the effective use of early warning.

1997

Publication of "Guiding Principles for effective early warning" (IDNRD Secretariat, 1997), which are accompanied by "Principles for the application of early warning at the national and local community levels" (Maskrey, 1997) and reports by various thematic groups.

7–11 September 1998

The International Conference on Early Warning Systems for the Reduction of Natural Disasters (EWC'98), in Potsdam, Germany, confirmed early warning as a core component of national and international prevention strategies for the 21st century.

July 1999

The strategy "A Safer World in the Twenty-First Century: Risk and Disaster Reduction" and the "Geneva Mandate on Disaster Reduction" (IDNRD, 1999) were adopted at the IDNDR Programme Forum, the closing event of the decade. Relevant elements of the strategy include community participation and increase of partnership activities, improvement of early warning capacities and establishment of early warning systems as integrated processes, with particular attention to emerging hazards such as climate change. Regional and international approaches and collaborative and organisational arrangements were called for, as well as links with the Agenda 21 implementation process for enhanced synergy with environmental and sustainable development issues.

1 January 2000

The International Strategy for Disaster Reduction (ISDR) was launched. As the successor arrangement of the IDNDR, it inherited two mandated tasks relevant to early warning: (i) strengthen disaster reduction capacities through early warning and (ii) continue international cooperation to reduce the impacts of the El Niño phenomenon. It also aimed at managing risk through the integration of risk reduction into sustainable development.

2001

The ISDR Working Group 2 on Early Warning is created. The overall purpose of Working Group 2 was to support the early warning activities of Inter-agency Task Force members, the UN/ISDR Secretariat and other relevant partners, with a view to facilitate a more coordinated approach to improving early warning.

16–18 October 2003

The Bonn Second International Conference on Early Warning (EWC II) was initiated under the ISDR as part of the efforts of the Working Group 2.

2004

The Second International Conference on Early Warning called for an organisational platform to support the establishment of an international programme on early warning. Therefore, the Platform for the Promotion of Early Warning (PPEW) has been established in Bonn, Germany.

18–22 January 2005

The United Nations World Conference on Disaster Reduction (WCDR) took place at Hyogo. A special thematic session on people-centred early warning systems was organised. Results are published within "The Hyogo framework for action 2005–2015" (UN, 2005), supporting risk assessment and EWSs are crucial to save lives. Accordingly, people-centred systems are encouraged.

27–29 March 2006

The Third International Conference on Early Warning (EWC II) was held in Bonn with the slogan "From concept to action". The conference was structured into two streams, a Priorities and Projects Forum, presenting and discussing good practices in early warning, and a Scientific Symposium. The innovative combination allowed the practical demonstration of proposed early warning projects around the world with discussions and debates of key policy issues.

September 2006

Publication of the "Global Survey of Early Warning Systems" (UN, 2006).

On the other hand, the assessment cannot limit to analyse forecasts because expected damages depend also (and mainly) on:

- the features of the exposed elements as well as of the hazardous event (that is on the level of risk);
- the response capability that is the capacity of the affected communities to take actions which reduce expected damages.

Looking at the problem this way, improving FEWSs performance (which means improving their capacity to reduce expected damages) implies better decisions about warnings. In particular:

- better decisions about issuing, or not, a warning (meaning a better capacity to avoid false warnings and missed events);
- better decisions about response (meaning better response strategies).

For this reason, the first point that needs to be faced is the decision-making process which occurs during a flood warning.

1.1 The decision-making process during a flood warning

The answer to the question "What does the decision-making process – during a flood warning – consist of?" is not simple and straightforward. The reason is twofold:

1. On one hand, the evidence that there is not a unique decision maker neither decision makers are a coherent entity.
2. On the other hand, as a direct consequence of the first point, the fact that decisions are numerous and take place at different times along the warning process.

Five stages can be identified in detail along the flood warning process: detection, forecasting, warning, response and reaction (Dham, 2006). For each of these stages, there are different activities to perform and different agencies, institutions and organisations which inform, consult or take decisions. As a consequence, the complex scenario previously described originates.

Of course, the real scenario depends on the specific organisational and institutional context in which the process takes place. For example, in some contexts, forecasters (i.e. scientists) are also decision makers that must choose between issuing, or not, a warning according to the available data. In other situations, local floodplain managers are responsible for warning while forecasters simply provide the prediction. Floodplain mangers, together with emergency services, usually must decide also about how the warning and the emergency will be faced (i.e. decisions are made about which kinds of preventive measures are suitable, according to the available knowledge of the impending risk). Finally, there are citizens, including both private businesses and population at risk. Again, they must decide about how to react to the hazard according to the warning content and to their personal feeling and experience (see Chapter 4).

The situation is even more complicated by the evidence that "each of these categories also contain significant diversity. For example, local floodplain managers (. . .) have a variety of professional training and experience, goals and personalities and serve communities with different constituencies, cultures, histories, regulations, and levels of flood risk" (Morss et al., 2005). Last but not least, each category has different job or personal responsibility and different resources to make use of. For instance, referring again to local floodplain managers, they are constrained by time and money and "must balance flood management goals with the goals of different stakeholders in their communities" (Downton et al., 2006).

In this challenging context, Creutin et al. (2009) carried out one of the few attempts to organise the decision-making problem, in line with the evidences they collected during the analysis of two different case studies.

According to the authors, three types of actions can be distinguished along the warning process; these apply to all the actors, from forecasters to inhabitants, and to all social group sizes (see below).

- The first activity is "information" which covers the collection of data and its crosschecking with other data or actors. Here, decisions regard the quality and the relevance of available knowledge.
- The second activity is "organisation" which synthesises and transforms the above information before initiating a structured response (such as mobilisation of human forces or the implementation of a pre-established defence plans). In this phase, decisions define the chronological and logical organisation of the emergency response.
- Finally, "protection" involves efficient actions in terms of safety (such as decisions about preventive evacuation of people or goods as well as rescue missions).

Human actions (and, as a consequence, decision makers) can then be also classified into three types, according to the size of the groups concerned:

1. "Individual" concerns just one person and/or a small social entity (a family, for instance).
2. "Community" pertains to small groups of people, which may be more or less organised to deal with emergencies (neighbourhood groups, voluntary associations and also the population of a school or a company as well as the population of small geographic entities such as villages are included in this category).
3. "Institution" finally includes the public organisations (such as police or civil protection as well as the national administration, its local representatives and technical operators like meteorological offices and water management departments).

It is quite evident how responsibility increases as the size of social groups widens: if individuals must decide about their personal well-being and those of their family ties, institutions must think about the interest of the community as a whole. This is to say that the variety of decision makers – with their different information needs, responsibilities and responses to risk – suggests that attempts to provide a single "best" description of the problem do not necessarily meet the decision needs of all stakeholders. In other words, in order to analyse and design the decision-making problem in depth, a specific **point of view** must be adopted (i.e. different problem formulations are required for different **stakeholders** perspectives). In the book, the local floodplain manager's standpoint is assumed.

1.1.1 Warning and response: Can the decision-making be futile?

Before going on with the analysis, the previous question needs an answer: "Can the decision-making process be futile?" or, in other words, "are there some **key requirements** that must be satisfied in order to make the warning meaningful?" The answer is, of course, "yes".

Tab. 1.1
Examples of actions noticed by Creutin et al. (2009), according to the classification they proposed

Actor	Action	Type
Residents	Watching for water river	Individual, information
Residents	Local vigilance	Individual, organisation
Residents	Evacuation, furniture elevation, help neighbours, do nothing	Individual, protection
Local fire brigade corps	Control and monitoring of the endangered areas	Community, information
Mayor	Help request	Community, organisation
Mayor	Warning and organisation of population's evacuation	Community, protection
Local fire brigade corps	Rescue of people and protection of endangered areas (sandbags, etc.)	Community, protection
Meteorological service	Meteorological vigilance	Institution, information
Prefecture	Request of heavy means	Institution, organisation
Province	Road close to traffic	Institution, organisation
Army	Rescue of people	Institution, protection

First of all, **the nature of the flood event** must be taken into account: in case of flash floods, even good decisions about warning could be futile; particularly in small catchments, where the rainfall–runoff response time[2] is short, warning is almost useless if there is not enough time to react.

Literature is full of reported evidences. For instance, the British floods in 1998 (Bye and Horner, 1998; Handmer, 2000) can be recalled as well as the flooding in Boscastle, in England, in August 2004 (Parker et al., 2005).

In these cases, even before a good decision, the capacity of generating flood forecasts – with an acceptable degree of reliability and accuracy and which provide at least some warning lead time for response – is decisive.

Deciding about warning could be then futile if warnings do not reach people at risk. This aspect can be analysed from two different perspectives.

On one hand, **dissemination** is crucial. This means that it is essential to guarantee that all people at risk are "physically" reached by warnings during the emergency. For instance, as reported in the British Environment Agency review of 2007 summer floods (EA – UK Environment Agency, 2007), even if the Environment Agency (EA) disseminated proper warnings, routes that vehicle-mounted loudhailers planned to use were flooded (and so impassable) with the consequence that people living in the area were not alerted. This brought to the flooding of most of properties even if floods were predicted and proper warnings were issued. As better discussed in Section 1.1.4, with respect to this problem, redundancy of dissemination means is required.

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[2] The concentration time.

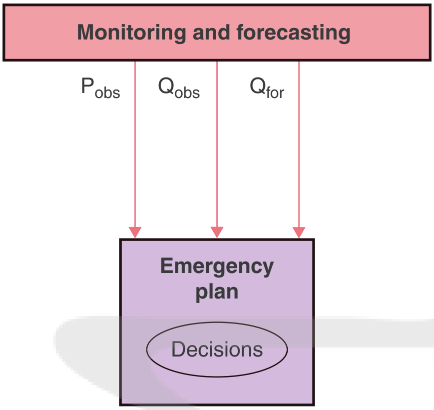

Fig. 1.1
The figure displays the warning decision making process, as historical conceived. Arrow represent variables while rectangles represent processing steps which need to be modelled

On the other hand, as Gilbert White had already noted in 1939, "a forecast is of no value unless those who receive it are prepared to act promptly and efficiently. Further, a forecast that is inadequate (meaning either mistaken, misleading, or misused) may cause more loss than had there been no forecast at all" (Pielke, 1997). With no doubt, Gilbert White thought applies to warning message as well, that is, deciding about warning is futile if people do not know the meaning of the warning and/or how to respond to it. Many evidences support this point; in the review by the EA previously discussed (EA – UK Environment Agency, 2007), the author reports, for example, that people have highlighted the need to be much clearer about the relationship between warnings and the related response (evacuation, distribution of resources). Moreover, they recognised that the language of the EA influenced people response to forecasts and warnings (i.e. the communication of peak flood levels confused people even though it was accurate). Handmer (2000), Parker et al. (2005) and Keys and Cawood (2009) reported other past events that make the point. The conclusion is that decisions are useless if **a proper response capacity** is lacking; for warning decisions to be effective, advanced planning must define prescribed actions linked to the warnings. Likewise, it is important to assure that these actions are taken once the warning is issued. From this perspective, the importance of education arises.

1.2 The decision-making problem: a possible framework

Taking as a standpoint the local floodplain managers, a first simple description of the flood warning process is depicted in Figure 1.1.

According to it, the decision about issuing, or not, a warning is based on the information provided by monitoring and forecasting (mainly the observed rainfall and river discharge and the forecasted discharge). In other words, local floodplain managers should decide about warning according to prescribed rules which link forecasted and monitored data with the likelihood of a flood.

This scheme probably depicts the traditional (historical) view of the problem at stake and, for this reason, the most widespread too. However, it proved to be wrong.

Of course, the importance of a good monitoring and forecasting system is beyond doubt and several examples corroborate the point (Box 1.2).

Box 1.2: The Aston flood, UK, in 2007 (McKnight, 2008)

Aston is a small village in West Oxfordshire passed by the Aston Ditch main river (a Thames tributary) in the western side of the village.

The area is prone to flood; however, the population of Aston can take advantage of the free national flood warning service (i.e. managed by the Environment Agency, EA) which is open to all British business and residents, within flood risky areas, and that involves sending a flood warning via phone, fax, text or email.

The service, however, is standard in the whole country:

(i) The EA issues first a flood watch, when flooding of low lying land is expected.
(ii) Once the Agency is aware that property flooding is going to occur, a flood warning is issued.
(iii) This is elevated to a severe flood warning if the situation worsens and over 100 properties and or major infrastructures would be flooded.

On its side, the EA can take advantage of a variety of forecasting techniques, but this is only possible where the agency is able to monitor rivers levels. Unfortunately, this is not the case of the Aston river where no gauges are placed. That is, currently, the EA offers a full flood warning service to some areas along the length of the River Thames, but this is not possible for the majority of the River Thames tributaries (including the Aston) because no gauges are placed on them. In other words, the agency is unable to forecast accurately for property flooding in areas that these watercourses affect.

The result was that, in July 2007, Aston properties flooded without any warnings were issued. In fact, residents at risk of flooding in Aston were registered to the EA service but to receive warnings for the River Thames (which did not flood in that occasion!).

Of course, the need and the importance of adequate flood forecasts for the Aston community is here maintained and beyond doubt.

On the other hand, evidences from the past show that warnings fail even when flood predictions are accurate (within specified margins). This is because many factors affect decision making and forecasted data are only one of these.

1.2.1 The role of uncertainty

As discussed in the previous section, when a disaster is forecasted to occur, many decisions have to be taken (by various stakeholders) in order to copy with the likely impending event. Such decisions are all characterised by a common peculiarity: they must be grounded on uncertain information about both the characteristics and the consequences of the upcoming event as to say that decision makers must (re)act according to hazard forecasts and damage scenarios which, like every estimate about future, are always affected by errors.

"Decisions made at the beginning of the event do more than just setting the tone of the entire crisis rather they set its entire trajectory" (Weick, 1988). Uncertainty in decision making must so be carefully taken into account, when EWSs are designed or evaluated.

Uncertainty is a multifaceted concept; assessments' results accuracy is limited by a variety of factors like natural variability in the physical environment, limitations in engineering calculations and judgements and uncertainty about future conditions. Nevertheless, a first simplification is possible: trying to simplify the problem to the bone, two uncertainty "sources" can be identified. The former regards the imperfections in the structure of the **models** which are used to describe the system under investigation; the latter is instead related to the uncertainty about the real value of both models input data and parameters (i.e. **variables**).

A second simplification allows then for distinguishing between two forms of uncertainty: **aleatory** and **epistemic** (Apel et al., 2004; Merz and Thieken, 2009). While the former is due to the natural variability in the physical environment, referring to quantities that are inherently variable in time and space (variability exists, for example, in the maximum runoff of a catchment in consecutive years or in the infiltration capacity at different locations of a field), the latter results from incomplete knowledge of the object of investigation and is related to analysts ability to understand, measure and describe the system under study. It derives that if epistemic uncertainty can be reduced by the introduction of additional information, aleatory uncertainty cannot decrease as it is an intrinsic characteristic of the particular problem at stake (e.g. the possibility of distinct flood scenarios in the same basin is a feature that cannot be modified).

On the other hand, model **complexity** cannot be discounted: uncertainty increases with complexity (Ballio and Menoni, 2009), the reason being twofold:

1. On one hand, if complexity increases then the number of variables goes up as well.
2. On the other hand, if a phenomenon (or a process) is the result of many interactions then its modelling requires several components (or sub-models); each variable and each model bring uncertainty into the final results so that their accuracy obviously decreases. In addition, models are usually non-linear; as a consequence, uncertainty is not simply added but it can be also amplified along the "chain".

It is so evident that handling uncertainty is not an easy task; however, a variety of tools have been developed so far.

With respect to uncertainty estimation (Shrestha and Solomatine, 2005):

- A first approach is to evaluate the model outputs **probabilistically** by means, for example, of Bayesian framework (Krzysztofowicz, 2002) or simulation and re-sampling-based techniques like Monte Carlo methods and GLUE methods (Beven and Binley, 1992).
- A second alternative is to estimate uncertainty by analysing the statistical properties of the **model errors** that occur in reproducing the observed historical data.
- Finally, a quite "new" approach is based on **fuzzy theory**–based methods. This approach provides a non-probabilistic tool for modelling the kind of uncertainty associated with vagueness and imprecision.

Of course, no one method is better than others. Each of them presents strengths and weak points and is more suitable in certain contexts than others. For example, the first approach requires the prior distributions of the uncertain input data (to be propagated through the model to the outputs), while the second requires certain assumptions about data and errors. The relevancy and accuracy of every approach then depend on the validity of these assumptions (Shrestha and Solomatine, 2005) for the particular problem at stake.

Regarding, instead, the effects of uncertainty on models results, **sensitivity** and **robustness** analyses are the most common tools. The former tries to identify what source of uncertainty (variables or models structure) weights more on the final result; the latter is someway complementary to it and aims to address the question of how much uncertainty can be tolerated before the model output changes. However, if lot of methods are available to implement sensitivity analysis (see, for example, Cacuci, 1976; Saltelli et al., 2000; Oakley and O'Hagan, 2004; Helton et al., 2006) "info-gap" is probably the most quoted theory of robustness (see Ben-Haim, 2000, 2001, 2004 for the theory and Hine and Hall, 2005, for an application to flood risk).

A common belief (Bernstein, 1998) is that by reducing scientific uncertainty (both in terms of lowering assessment errors and of better characterising them, e.g. by means of probability), better decisions[3] can be taken, supporting, this way, the decision-making process. Yet scholars report circumstances in which additional information distorts decisions as to say that one of the bigger weaknesses in flood warning practice currently lies in the utilisation of data (specifically, forecasting products) rather than in the data themselves (Pielke, 1999a; Victorian flood warning consultative committee, 2005; EA – UK Environment Agency, 2007; Keys and Cawood, 2009).

The point, as stressed by Downtown et al. (2006), is that the selection and implementation of management strategies is not driven only by scientific information, but it is rather "a political process, centred on values issues, often downplaying scientific and technical uncertainties (...). Societies' ability to cope with natural hazards is mediated by many factors, including socio-economic constraints, cultural preferences, demographic patterns, technological and scientific advances and the communication and subjective interpretation of probabilistic information" (Box 1.3).

Box 1.3: The Red River floods, USA, in 1997 (Pielke, 1999b)

The Red River flows north in the USA along the North Dakota–Minnesota border. Since hydrologic floods are commonplace and unavoidable in the flat Red River basin, a flood forecast service is available for the region and local communities are used to rely on it.

Flood forecasts (which are developed by the North Central River Forecast Centre – NCRFC) can differ with respect to the time of prediction. In detail:

(i) A numerical outlook is issued 1 to 2 months prior to the expected peak flooding. This regards the height of the river (stage) and is predicted based on the volume of water (discharge) flowing past a particular point.
(ii) Operational forecasts are instead issued periodically, in the weeks prior to and following peak flooding, and these are the product of a hydrologic modelling system.

Because the risky area is wide, preventive actions are mainly grounded on numerical outlook. Specifically, when the NCRFC issues flood outlooks, two numbers are presented for the expected river stage (of course, for each forecast location). One is

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[3] In terms of rational decision making.

based on a scenario of average temperature and no subsequent precipitation, the other with average temperature and precipitation. In 1997, the numerical outlook issued for the area under investigation was for 47.5 and 49 ft, with respect to the two scenarios.

In interviews conducted after the flood that occurred that year, with various decision makers, it was clear that different people interpreted the flood stages outlooks in different ways, some of which were demonstrably incorrect. These different perspectives clearly influenced the choices made by local officials. For instance, some viewed the two numbers as a range (i.e. that the maximum flood stage would be between 47.5 and 49 ft). Others viewed the higher number as a maximum (i.e. a value that would not be exceeded). Others viewed the flood outlook as exact (i.e. "the crest will be 49 ft"). Still others viewed the 49 ft outlook as somewhat uncertain. Regarding this, examples of the uncertainty ascribed to the outlook by various decision makers ranged from 1 to 6 ft: which decision maker might have been correct is not known as the flood outlooks did not include any quantitative information with respect to the uncertainty in the outlook.

In this case, responsibility for the apparent misuse of the outlooks was so shared. The NCRFC failed to communicate effectively the uncertainty of the predictions, and some local decision makers failed to appreciate the uncertain nature of flood forecasting. The result was, anyway, that actions were taken based on a misinterpretation of what could have been useful information.

A critical question concerns whether or not a more appropriate process would provide decision makers with information about uncertainty?

In the Red River floods (see Box 1.3), local floodplain managers argued that "If someone had told them that flood estimates were not an exact science, or that other countries predict potential river crest heights in probabilities for various levels, they may have been better prepared" (Glassheim, 1997). However, the communication of uncertainty is still an "open question": the point is that the effect of providing information about uncertainty would be a shift in responsibility, from forecaster to local floodplain managers. While some local decision makers want this responsibility, others do not.

Summing up, no matter how it is communicated and managed, it is clear that uncertainty is a key variable in defining warning outcomes (meaning the correctness or not of the decision about warning); for this reason, it is not possible to avoid its counting in the analysis of the decision making during flood warnings.

1.2.2 The role of responsibility

The previous section implicitly introduces a further key aspect in decision-making problem that is individual and social responsibility. Sarewitz and Byerly (1999) argue, for instance, that "if there is no adequate decision environment for dealing with an event or situation, a scientifically successful prediction may be no more useful than an unsuccessful one". Handmer and Ord (1986) make the point even clearer claiming that "the cultural and political factors serve as constraints to the generation and delivering of warning" (Box 1.4).

Box 1.4: The role of responsibility, an example from the past (Keys and Cawood, 2009)

The fact here discussed occurred in Australia and is reported by Keys and Cawood (2009). In that occasion, the Bureau of Meteorology predicted that a rising flood would overtop a town levee protecting 12,000 people. According to the emergency plan, these people would need to be evacuated when such a forecast was received but, as it happened, the senior civil protection officer in the region argued, without evidence, that the Bureau's height forecast was too high. The levee would not be overtopped, he believed, no evacuation operation was necessary and to mount one would be seen in the community as an over-reaction. The officer, in this instance, was prevailed upon by senior management to begin an evacuation (as anticipated by the plan), but time was wasted in negotiating this course of action and the mechanics of the operation were poorly implemented. Not surprisingly, not many evacuated. This example clearly demonstrates the tendency of some emergency managers to act as responders who are not committed to the plans they have devised. In other words, a more clearness about his role and responsibility would facilitate the adoption of the plan by the officer.

Previous observations are surely provocative and contests much current practice where, typically, "policy makers recognize a problem, scientists do research to predict natural behaviour associated with the problem and predictions are finally delivered to decision makers with the expectation that they will be both useful and well-used" (Sarewitz and Byerly, 1999). The authors recognised that this sequence rarely functions well in practice; it is essential to create a decision environment – meaning a sociopolitical context – where roles and responsibility are clear and shared among all the decision makers.

Individual and social responsibility is a subject related to the use of data rather than to the data themselves and belongs to the social science; for this reason it is not handled in this book. On the other hand, the crucial role of responsibility is well recognised by now, both among researchers and practitioners' communities, so it is worthy to remind its importance for the design and evaluation of EWSs.

1.2.3 The role of risk

A last key aspect that influences decision makers is the likely consequence of the forecasted event. Indeed, as Ballio and Menoni (2009) argue, "working in the real word, decision makers could not abstract one aspect (i.e. the forecasting) from its context. This means that they do not limit their consideration to hazard probability of occurrence only, they also take into consideration exposure and vulnerability (that is risk[4])". Once decision makers are supplied with a flood forecast, the choice of issuing or not a warning depends then on the related

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[4] According to UNDR0, 1979, risk (expressed in terms of expected damages) is defined as the result of hazard, exposure and vulnerability. Hazard is related to the potentially damaging phenomenon under investigation and is usually expressed as a measure of its intensity. Exposed elements consist of all the items, in a given area (e.g. population, buildings, economic activities and infrastructure), which could be impacted by the hazard. Vulnerability is finally related to the propensity of exposed elements of suffering loss, or damage, because of their impact with the hazard.

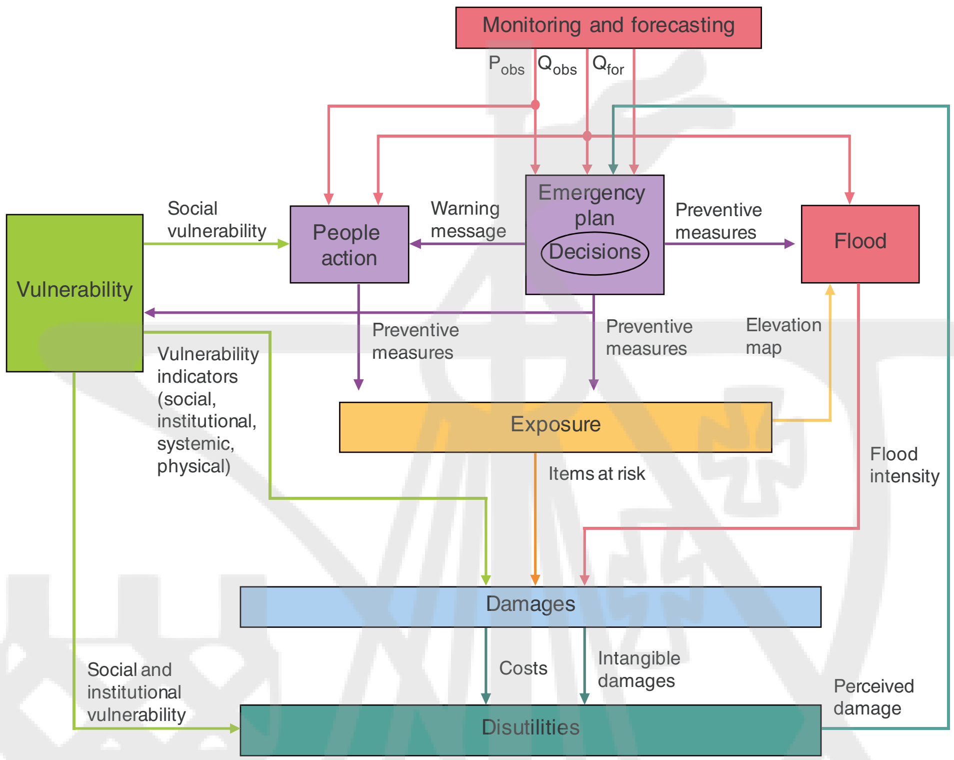

Fig. 1.2
The figure displays the warning decision making process, as conceived in this research. Arrows represent variables while rectangles represent processing steps which need to be modelled

expected **damages** too (in terms of economic costs, affected people, environmental damages, etc.); the lack of information about what the consequences could be as flood rises towards the predicted peak (Australian conceived the explicative term of "flood intelligence") has proved to cause unsuitable warnings several times in the past (Keys and Cawood, 2009). It derives that risk assessment is an unavoidable process in EWSs analysis and design. A new framework for the description of flood warning process is consequently required and the one proposed here is depicted in Figure 1.2. According to the latter, decisions about warning are made by considering not only flood forecasts but also expected damages or, to be more specific, expected disutilities[5].

Specifically, the decision-making process the graph depicts can be explained as follows:

- When a flood forecast is supplied, decision makers make choices, ideally according to what has been previously planned (i.e. in the emergency plan).

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[5] As better explained in Chapter 3, the concept of "disutility" takes into account two evidences from field surveys: on one hand, the fact that diverse stakeholders weigh the same damage in a different way; on the other hand, that perceived/real damage may differ from objective damage because of subjectivity. When flood damage assessment lays the basis for decision making (as in the case of deciding about a warning), the decision maker must carefully consider what "damage" to include in the decision. It then goes without saying that, at this perspective, disutility seems a more suitable indicator than damage.

- These choices regard both warning and preventive measures, aimed at reducing both exposure and flood intensity.
- Once the warning has been issued, people react to it by implementing, in turn, preventive measures, usually aimed at reducing exposure. As better explained in Chapter 4, literature highlights that people reaction depends on both warning features and social vulnerability.
- The extent of items at risk (after preventive measures have been implemented), their vulnerability (from all its perspectives: social, institutional, functional and physical) and flood intensity define expected damages.

However, the flood warning process does not end at this step. The framework points out, by a back-going arrow, how expected damages (in terms of disutilities) affect the initial choice. In other words, the scheme recognises that in developing emergency plans, actions must be linked not only to flood forecasts but also to the "flood intelligence" available for those forecasts.

It must be stressed, however, that, for the sake of simplicity, the warning process here described refers to a non-expert system, meaning to the beginning of a specific warning. Actually, links (i.e. cause/effect relations) other than those discussed could arise, according to the time of the analysis. For example, once a first warning has been issued, decisions about preventive measures (as well as further warnings) usually depend not only on monitoring and forecasting data but also on how the flood is unfolding: thus, a link arises between flood and emergency response. Likewise, it is plausible that when people react their vulnerability decreases, just because of the actions they implement. So, a further link arises between people action and vulnerability.

More in general, it can be stated that whilst the graph refers only to forecasted data (with respect to hazard as well exposure and vulnerability), it is possible that, along the warning and the emergency management process, links arise also among observed data.

The graph shown in Figure 1.2 also allows to identify the variety of **models** (represented by rectangles in the figure) which are required to face the problem under investigation as well as their inputs and outputs (represented by arrows in the graph). In detail:

- Two models are initially necessary to produce flood forecasts and to analyse the development of the real flood, according to observed data. Their outputs are represented, respectively, by forecasted and actual (estimated) flood intensity (e.g. flood peak, flood discharge and flood velocity).
- Another model is required to describe people reaction, according to the social vulnerability of the population at risk as well as the features of the warning. Its output is represented by the extent of preventive actions people would take (e.g. number of evacuated people and percentage of saved items).
- A model is then required to estimate the extent of items at risk (e.g. number of people and number of buildings), taking into account preventive measures implemented after the warning.
- A fifth model is necessary to estimate vulnerability indicators: physical (e.g. buildings features), social (e.g. demographics and economic status of people), institutional (e.g. the degree of civil protection preparedness) and functional (e.g. lifelines systemic behaviour).
- Two models are then required to estimate damages and disutilities: their inputs are vulnerability and exposure features of the affected areas; outputs are respectively objective and perceived damages.
- Finally a last core model is necessary that put together damage data and flood data to define proper warning rules and actions. Its outputs are represented by the features of the warning (mainly in terms of contents and dissemination means) and the extent of preventive

measures (e.g. the height of the flood barriers and the identification of routes that must be closed).

1.3 The "Total Warning System"

The previous discussion highlights the need to rethink the concept of EWS: from a forecasting tool to a more complex system which should be designed to provide communities with all the capacities required to reduce expected damages from a hazardous event or, in other words, a system designed for supporting all the decisions during the warning process.

The idea of "**Total Warning System**", which this book embraces, was first developed by Australian authorities (see Emergency Management Australia (EMA), 1999) just referring to those capacities.

According to it, an EWS should be made up of four sub-systems, strictly interconnected to each other:

1. **A monitoring and forecasting sub-system**, to monitor and forecast hazards to produce information about impending events.
2. **A risk information sub-system**, to develop risk scenarios to figure out the potential impact of an impending event (on specific vulnerable groups and sectors of the society).
3. **A preparedness sub-system**, to develop strategies and actions required to reduce the damage from an impending event.
4. **A communication sub-system**, to communicate timely information on an impending event, potential risk scenarios and preparedness strategies.

Hence, forecasting is only one of the components the whole system relies on.

Figure 1.3 shows how these sub-systems can be mapped on the framework here proposed. In detail:

- The pink box refers to the monitoring and forecasting sub-system.
- The light blue box identifies the risk information sub-system.
- The violet box refers to the preparedness sub-system.

Of course, the communication sub-system cannot be mapped on the scheme as communication occurs everywhere along the "warning chain". Thus, involving functions and actors from different sub-systems, it should be seen as something that is shared between the other components of the chain, rather than a well-defined entity.

To better clarify the concept, one can also consider the typical framework of FEWSs. In this case:

- The monitoring sub-system consists in the networks to observe all those meteorological, hydrological and hydraulic phenomena which are linked to a flood event[6], coming before it or being its cause or best conditions for its occurring (e.g. rainfall amount, soil moisture and river discharge). The forecasting sub-system includes hydraulic models, as well as hydrological or statistical tools, to evaluate the possibility that a flood will occur with certain characteristics (e.g. time, intensity and place), on the basis of observations.

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[6] From now on referred to as "triggers".

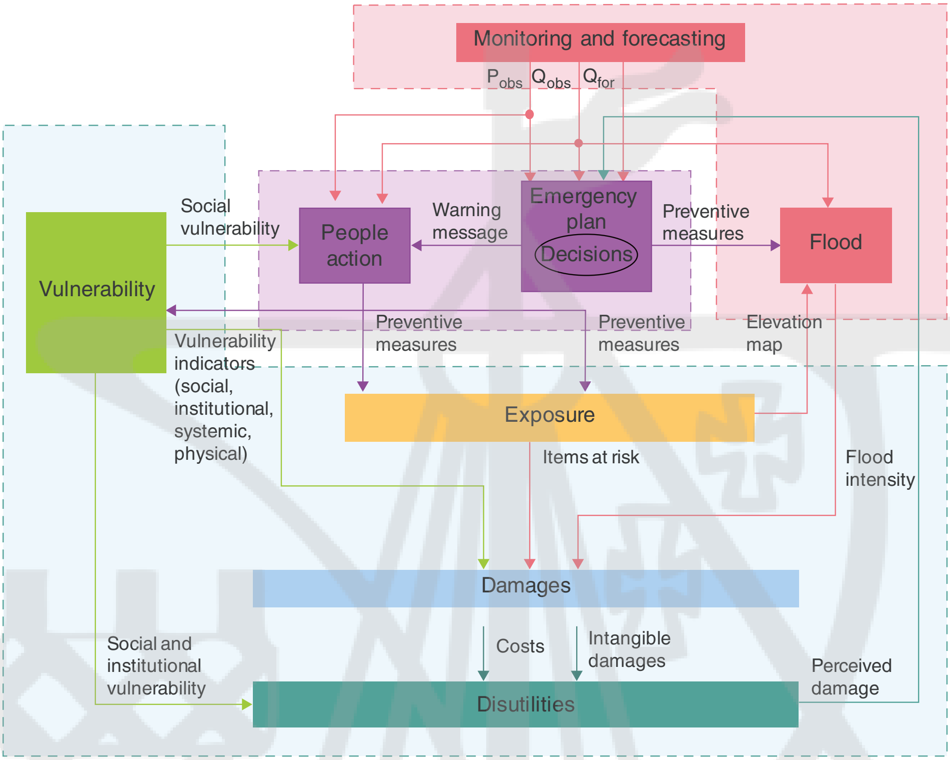

Fig. 1.3
The figure maps Total Warning System components on the framework describing the warning process

- The risk information sub-system is made up of all those damage assessment tools (both qualitative and quantitative) to evaluate the likely impacts of an event. The definition of river (hazard) zones is an example of analytical tools, supporting risk assessment.
- The preparedness sub-system comprises all the strategies which are planned to face the flood. These are usually collected within the so-called emergency plan.
- Finally, the communication sub-system includes all the instruments (e.g. radio, fax and phone) as well as the communications strategies (e.g. roles and timing) and media (e.g. door knocking and collective spread) which are designed to guarantee all the information flows which occur along the warning process.

In such a framework, as partially discussed earlier, evidences from the past show that warnings fail for a variety of reasons: some of them are technical, others are not. For instance, warning can be ineffective because flood forecasts are wrong (forecasted flood actually does not occur or it occurs but with unexpected features), planned flood scenarios differ from reality, contingency plan results inappropriate to face the emergency, warning communication is unsuccessful (because of either wrong contents or wrong time of issuing) or, finally, people at risk are not able to react. Accordingly, non-technical factors cannot be neglected in EWSs appraisals, above all, taking into account the last recommendations by the United Nations (UN, 2006) which stress the importance of social and organisational factors as the weakest point of the warning chain. The analysis which follows adopts this perspective.

The general idea is that of discussing and promoting a **systemic vision** of the warning problem, in which:

- technical and non-technical aspects are combined;
- each EWS component is considered as a link of a chain whose performance affects the performance of the whole warning process.

In other words, a **no-shortsighted attitude** is supported, according to which each actor within the system (being a technician or not) should behave taking into account that their actions affect not only their "component" but the system as a whole.

1.3.1 The monitoring and forecasting sub-system

The function of this sub-system is to generate accurate information on impending hazards. Specifically, **monitoring** consists of the observation of all those trigger phenomena which usually come before a hazardous event, being its cause or best conditions for its occurring. **Forecasting** is the process of predicting the possibility that a hazardous event will occur with certain characteristics (e.g. time, intensity, place), on the basis of observations and by means of suitable models. All these activities (from data monitoring to their processing and interpretation by means of forecasting models) allow to identify potentially hazardous events according to which issuing, or not, a warning.

Figure 1.4 describes, in depth, the framework of a monitoring and forecasting system, highlighting its operational modules. To make the scheme clearer, one can consider, again, the case of a FEWS:

- The first three boxes correspond, respectively, to the monitoring, transmission and processing of all those meteorological, hydrological and hydraulic data which are linked to a flood event (e.g. rainfall amount, soil moisture, and river discharge).
- Forecasting generally aims at predicting river discharge at certain locations, by means of hydraulic models as well as hydrological or statistical tools.
- The last box implies the interpretation of observations and forecasts by scientists, to assess the danger of the impending event, as well as its communication to the authorities in charge of issuing warnings.

The monitoring and forecasting system is so the **technical core** of the warning process. From this perspective, its performance is mainly related to:

- the design of a forecasting model which is appropriate to both the investigated hazard and the available resources (both economic and scientific) for its implementation;
- the presence of monitoring networks which supply the data required by the forecasting model.

Furthermore, also non-technical aspects are important for monitoring and forecasting achievements; first of all, social and organisational factors. In this regard, for example, it is worthy to stress how the operational modules are usually carried out by different organisations (e.g. meteorological bodies, environmental agencies and universities) which, in turn, are made up of different actors with different roles and responsibilities. Consequently, problems

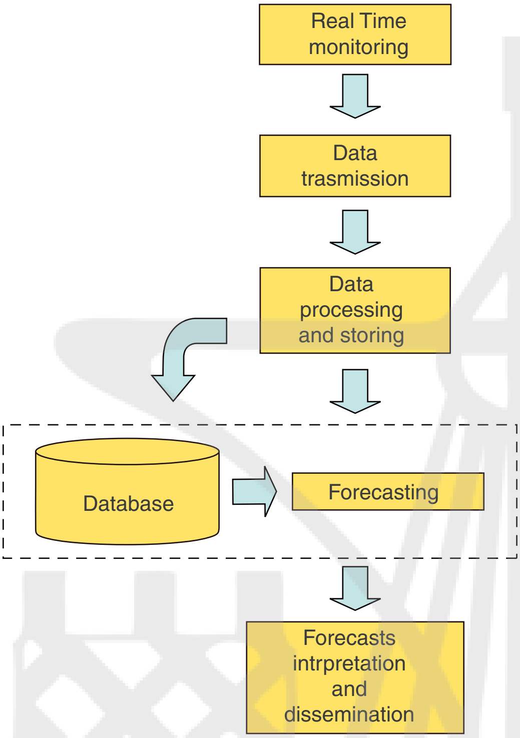

Fig. 1.4
The framework of a monitoring and forecasting system

relating to the time, the contents and the transmission of data can occur both among and within the various agencies. In the FEWS implemented in the town of Crotone (see Appendix 1.A), for instance, the Regional Operational Centre[7] is in charge of monitoring whilst forecasting is implemented by the same centre as well as by the National Civil Protection[8] and the University[9]. Of course, these are institutions with different structures (i.e. public vs. private, local vs. national) and expertise. As a consequence, problems of communication can occur. On the one hand, it is possible that constrains exist on data sharing among different agencies; on the other hand, there could be a problem of communication among experts speaking different languages.

The interaction with the preparedness sub-system is, finally, equally significant. Specifically, the communication of wrong forecasts could imply the adoption of inappropriate flood scenarios (see Section 1.3.2) and, as a consequence, either the occurrence of false warnings/missed events or the implementation of unsuitable mitigation actions.

In this regard, forecasts accuracy, and the ways in which it is communicated and managed, represents a key issue affecting EWS performance.

1.3.2 The risk information sub-system

This component has the role of producing all the information about the risk which is related to the dangerous event under investigation. This process is usually called "risk assessment"

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[7] Centro Funzionale Regionale.

[8] Dipartimento Nazionale di Protezione Civile.

[9] Università della Calabria.

and, as previously discussed, it is crucial for decision making and, so, EWSs performance. Moreover, its importance is stressed by the main international guidelines too (see Box 1.1).

Specifically, risk assessment enables the generation of **risk scenarios** according to which disaster preparedness strategies can be developed. At the same time, risk information subsystem provides information on the vulnerability of the different elements at risk. This knowledge enables specific groups of vulnerable elements (mainly people) to be targeted with appropriate disaster preparedness strategies, grounded on their capacity to absorb and recover from loss.

But what do "risk scenarios" specifically mean?

In general terms, a scenario is a "sketch, outline, or description of an imagined situation or sequence of events (Oxford English Dictionary)". Likewise, in the field of risk assessment, a risk scenario depicts (ex-ante) the expected impacts of a hazardous event in a given area, on the basis of the knowledge of the hazard as well as the exposure and the vulnerability of the area itself.

Risk scenarios can be then more or less comprehensive. Some are merely quantitative and limited to the assessment of direct damages (see Chapter 3) which arise from the physical vulnerability of the exposed elements. In contrast, others are totally descriptive and try to discuss also indirect damages (see Chapter 3) as well as all those phenomena and actions which are triggered by the event and which are typical of a crisis (Menoni, 2005).

According to the point of view of emergency management, the latter are more informative given that they allow for vulnerability from a wide perspective. Maskrey (1997) makes the point: "An early warning system must have the capacity, not only to disseminate warnings of impending hazards, but also to generate risk scenarios of the potential losses and damages to be expected from their impact, including considerations of the vulnerable groups most likely to be affected . . . Vulnerability is much more than the possibility of suffering loss or damage. It refers to the capacity of a household, community, business or organization to absorb losses or damage and then to recover from them. When vulnerability is low it may be possible to absorb losses, without a crisis or disaster occurring. Conversely when vulnerability is high, even a small loss may provoke a disaster for the household or community concerned".

Hence, EWSs effectiveness improves where risk scenarios are based on a full assessment of vulnerability (meaning looking at physical, functional, organisational, systemic as well as social factors) because it allows to foresee not only all the harmful impacts of an event on a given area but also the response by the affected community which allows for better response strategies to be planned.

On the other hand, vulnerability depends, in its turn, on the suitability of the preparedness sub-system; in other words, the way in which people react to an event shapes the extent of damages themselves (i.e. the extent of risk).

Risk assessment is the responsibility of local authorities. However, because of a lack of expertise, they often delegate the analysis to technicians with the result that a first problem of communication could originate between who makes the assessment and who should use the results (as they usually speak "different languages"). As explained before, risk assessment requires then the analysis of various phenomena which are related to different field of expertise (from hydraulics to economics, sociology, etc.) which, so far, have rarely interacted with each other. As a consequence, problems of communication could arise again.

Of course, all these factors add to the technical problems relating to the risk assessment itself (e.g. lack of data and tools), equally affecting the performance of the system.

1.3.3 The preparedness sub-system

Within this sub-system, disaster preparedness strategies are developed. Specifically, the aim is that of identifying which actions are required to reduce the expected damage from an impending hazardous event.

This task is usually handled by means of the so-called **emergency plan** (or "contingency" plan). As Alexander (2005) argues, no standards exist to design a good emergency plan; although some key issues have been identified which allow to assess its goodness and/or effectiveness (see Perry and Lindell, 2003; Alexander, 2005 for an overview).

First, a good plan must be **flexible**. An effective plan is not a static list of procedures, people and actions; rather it must aim at the coordination of all the available resources. Specifically, two main functions must be met:

1. To identify all the available resources of personnel, equipment, vehicles and consumable supplies.
2. To support the crisis management by facilitating (i) the definition of roles and responsibilities, (ii) the identification of priorities for action as well as (iii) the negotiation process which usually arises during a crisis, among various actors involved. Indeed, "while in ordinary situations inter-organisational relationships are stated in a reasonably stable way, during crises criticalities to be faced may require to renegotiate the tasks to be performed and sometime to share information and resources in a way it was not anticipated in official documents and written protocols. An emergency plan should serve then this purpose rather than set a list of detailed actions and responsibilities, that often cannot be fulfilled under crises conditions" (Ballio and Menoni, 2009).

In other words, an emergency plan should not aim to set rules rather to explore possible links between impacts and actions, with the general objective to face an event that usually does not match with the ones previously auspicated (i.e. an emergency plan should be applicable to every event, also the unexpected ones). In this regard, risk scenarios are powerful exploratory tools, allowing to figure out both expected damages and likely response, for certain levels of hazard.

Second, an effective plan must be **feasible**, allowing for the real context in which it is implemented. Several times there are physical, social as well as bureaucratic impediments to the adoption of planned strategies. For example, it is well recognised that Katrina emergency management was influenced and hindered by the physical, functional and systemic vulnerability of the city of New Orleans (Colton, 2005).

On the other hand, emergency plans sometimes exist only on paper. Although local authorities usually have the legal responsibility for disaster management, their actual capacity/efficiency is often extremely weak (but usually in the major cities) and, in a paradoxical way, it is inversely proportional to the vulnerability levels (Maskrey, 1997).

According to Menoni (2005), feasibility is related to:

- contingent factors, that is those conditions that can occur or not in the aftermath of an event;
- organisational factors, which are linked to the capacity of institutions/actors to cooperate to face the event.

Whilst the former can be handled by means of risk scenarios, good communication strategies are required to support cooperation.

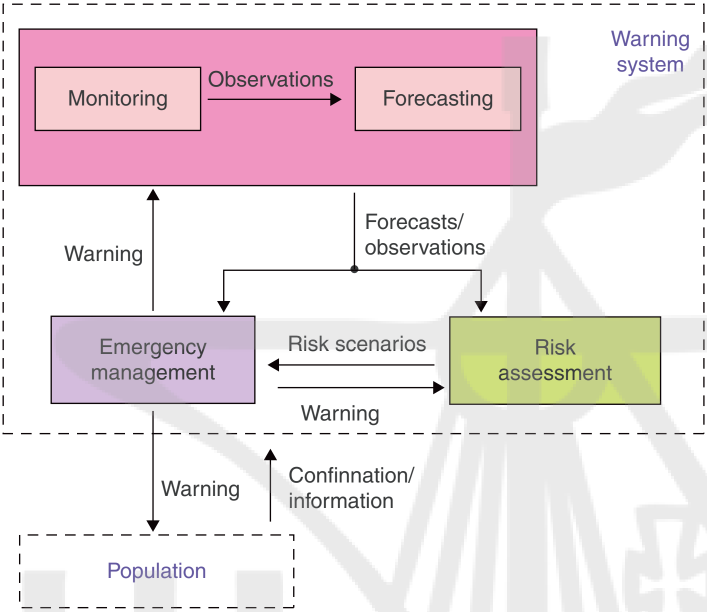

Fig. 1.5 Flows of information along the warning chain

Last but not least, the goodness of a plan requires **community engagement** (Sene, 2008). In other words, to increase the likelihood that warnings lead to effective risk reduction, it is important that emergency plans are tailored to the needs of the different people and sectors of societies. “Effective preparedness strategies are those which are negotiated and developed in consultation with people at risk, taking into account their different perceptions of risk, various needs and coping strategies … if a recommended disaster preparedness strategy contradicts the perceptions of risk and coping strategies of vulnerable groups, then it is likely that the strategy will be ignored or lead to unexpected results” (Maskrey, 1997).

Literature suggests so that the performance of the preparedness sub-systems depends mainly on non-technical factors rather than technical ones. This enforces the importance of the perspective adopted by this book.

1.3.4 The communication sub-system

The communication sub-system allows the dissemination of timely information on impending hazard events, potential risk scenarios and preparedness strategies, in the course of the warning process. Thus, involving functions and actors from different sub-systems, it should be seen as something that is shared between the others components of the chain, rather than a well-defined entity.

To make the point clearer, Figure 1.5 shows the main flows of information that occur along the warning chain.

In particular, Figure 1.5 highlights that:

- A first exchange of knowledge occurs between people in charge of monitoring and forecasters, in order to provide the latter with required data to run forecasting models. Then, forecasts and observations are supplied to the preparedness sub-system, to decide about warning.

- Meanwhile, another flow occurs among the monitoring and forecasting, the preparedness and the risk information sub-systems. Indeed, warning level (and corresponding mitigation actions) will depend on the particular risk scenario which observations and forecasts are linked to.
- Finally, warning is issued and disseminated to both all the emergency actors and population at risk which, in turn, can ask for confirmation or further information on the impending event.

Furthermore, other internal fluxes of information exist, within each component, as warning agencies and organisations are usually organised according to national and local levels of responsibility.

Hence, to synthesise, both vertical and horizontal flows arise along the warning chain.

In line with this, one can define as decisive the role communication issues play, given they actually put the various components of the chain together, to get a unique aim. The communication sub-system must thus be carefully designed to get EWSs effectiveness. Specifically, different aspects must be considered, being:

- warning contents,
- warning trust,
- transmission media,
- warning time.

With respect to **contents**, as stressed by Handmer (2000), there is an important difference between warning messages and individual capacity to understand and act on those messages. Specifically, misunderstandings can occur at two different levels:

- On one hand, within the warning system itself that is among the actors within each component.
- On the other hand, looking at the final users of warning systems that is at the interaction with population.

Regarding the former, it has been already discussed how the warning process involves different actors, with different background and expertise. Accordingly, communication errors can occur everywhere in the warning chain. With respect to population, instead, past flood reviews indicate that if people do not react to warnings this is because they neither understand the meaning nor they know how to react (i.e. which mitigation actions they should adopt). Therefore, warning message should ensure that people at risk are supplied with all the relevant information on the existence of an impending hazard (i.e. its spatial and temporal coordinates and attributes, the pattern of expected loss and damage, the mitigation actions which should be taken and people to contact by necessity).

The quality of this information, however, is not objective but is relative to the perceptions of the people who receive it and are expected to act on it. The key to ensuring the communication content of warning information is to engage the active participation of stakeholders and to incorporate local knowledge. To summarise, quoting Handmer (2000), “to have any chance of success, warnings need to have meaning which is shared between those who draw them up and those for whom they are meant to inform”.

Trust is a further issue which hinders people response. Indeed, experience highlights that people tend to mistrust the source of flood forecasts and warnings when they come from an organisation that is perceived to be distant and bureaucratic (Keys and Cawood, 2009). In this case, personal experience as well as trust in other unofficial sources (like neighbours or local "flood gurus") prevails, especially when official sources supply conflicting messages. In this regard, public participation is, again, the way towards trustworthy and credible early warning systems.

With respect to **transmission media**, a first concern regards technical aspects. Dissemination tools (instruments) should be primary reliable, that is they should work also in case of adverse wheatear or in the post-impact. For example, it is crucial that monitored data are continuously transmitted as the event unfolds. However, if rain gauges rely only on the electric network to broadcast data, they could not work if the line is affected by the event; likewise, discharge gauges can be damaged by the flood wave. Last technologic improvements (like internet or satellite technology) make easier to meet the reliability requirement (Sorensen, 2000). However, a mix of different tools (a sort of redundancy) is always suggested.

A second issue is instead related to the warning coverage, meaning that all people in the "at-risk" area must be warned. On one hand, "spatial" coverage must be guaranteed. However, some dissemination tools can reach only certain areas. For example, some remote places are not covered by Internet services. Likewise, warning people by sirens, megaphones and door knocking cannot be feasible where territorial systems are scattered.

On the other hand, "social" coverage is equally important, that is all sectors of societies must be reached. For instance, Internet is not used by certain categories like children or elderly, phone calls do not reach transient population (e.g. tourists and workers) and radio cannot be listened by deaf persons. Again, redundancy is the suggested tool to face the coverage problem.

Last, the importance of **timely warning** is evident as both individual and community mitigation measures need time to be implemented. Accordingly, if warnings fail to reach people at risk on time to implement proper actions, then EWSs are unsuccessful.

In this regard, a lot of factors (some physical, others not) influence the time of a warning. Actually, warning time is shorter than lead time[10] and depends on:

- the hazard temporal dynamics (i.e. the lead time depends on hazards dynamics as some phenomena develop slowly, others very quickly);
- the monitoring and forecasting skill (i.e. time is spent for data collection and processing, reducing warning time);
- the dissemination tools reliability (i.e. information must be quickly spread to save time);
- people dynamics (i.e. people interactions can take more or less time, affecting warning time);
- the presence of suitable emergency plans (i.e. planning strategies save time);
- uncertainty management skills (i.e. planning strategies to cope with uncertainty can save time).

1.4 A flood warning review

Once the ideal structure of EWSs as well as the scope of their performance evaluation has been identified (i.e. the assessment of its capacity to reduce damages), the analysis of the current

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[10] The time lag between triggers detection and flood impacts. It represents the maximum potential "warning time", that is the maximum available time to implement mitigation actions.

state of the art is the starting point to recognise research needs and priorities. Such an analysis must be carried out according to two different perspectives.

On the one hand, the political and legislative context in which EWSs are implemented influences their level of development (LoD) as well as their effectiveness. Some factors, like the presence of legal duties, good risk management policies as well as risk awareness, are crucial for EWSs accomplishment. Furthermore, economic availability is a further decisive factor, above all for developing countries. On the other hand, looking at their LoD, EWSs must be analysed considering the state of the art of both research and practice as a mismatch can exist between science and its implementation because of, for example, a poor communication between scientists and practitioners (which leads to a lack of knowledge by the latter). This section is focused just on the analysis of these aspects.

1.4.1 The political and legislative perspective

FEWSs have been regulated late with respect to their admission within international policy (see Box 1.1). For example, at the European level, it is the so-called Flood Directive[11] (EC, 2007) that, for the first time, requires Member States to adopt EWSs, maintaining that "Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems".

Nevertheless, a previous step towards FEWSs implementation was already carried out after the disastrous Elbe flood in 2002, when the European Commission communicated the development of the European Flood Alert System – EFAS. Indeed, the extent of damages caused by the event made the Commission to recognise the importance of being able to prepare and manage aid during a flood crisis. Thus, since the beginning of 2003, the European Commission DG Joint Research Centre (JRC) is developing a prototype of EFAS, in close collaboration with relevant institutions in the Member States.

Currently, the system provides medium-range flood simulations across Europe, with a time lag between 3 and 10 days. The real advantage is, of course, for local authorities which can benefit from additional flood information that might contribute to increase preparedness in an upcoming flood event. Indeed, EFAS is aimed at complementing national flood forecasting systems rather than to replace them.

1.4.2 FEWSs implementation in North America and Europe

An exhaustive review of FEWSs in North America and Europe has been recently carried out by Handmer (2002). The analysis led to the identification of current research and practise **shortcomings** which are here summarised:

- First, recently the potential of modern **technology** and the need to apply it with more fervour have been emphasised. Nevertheless, this does not solve the issue of FEWS effectiveness as the main problems and complaints relate to human and institutional failures. Moreover, most of the effort has been directed at improvements to monitoring, modelling and prediction systems; the consequence being that we have better and better ability to monitor, detect and predict hazards while using similar procedures to warn those at risk as were used 30 years ago (with the exception of some web applications). Apart

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[11] The European Directive 2007/60/EC.

from hazard assessment area, much effort has then gone into large-scale ICT (information and communication technology) applications, but it is not clear how this would actually help warning systems performance given that warning and response usually occur at local scale.

- Second, increasing attention has been paid, in the last years, to particularly **vulnerable groups**, having trouble responding to warnings like housebound, mentally ill, elderly and children. However, far less attention was given to less visible at-risk groups that may not be reached easily by common warning communication mechanisms (e.g. motorists, tourists, business travellers, people who are socially isolated such as the homeless). Nevertheless, past events highlight the need to target warning to these people too. For example, Gruntfest and Handmer (2001) found that about half of all flash flood related deaths in the USA regard people in vehicles.
- Then, even if **uncertainty** plagues most aspects (components) of flood warning, it is usually neglected in decision-making process. When uncertainty information is supplied to decision makers, it only relates to forecasts accuracy (without any consideration of other aspects) but, often, all data are managed as deterministic, leading to unsuitable decision. Although an improvement in FEWSs capability of avoiding false warnings and missed events has been recently recognised, this is mainly due to an advance in forecasts accuracy rather than in the implementation of efficient ways of uncertainty management.
- Next, little attention has been devoted, so far, to **FEWSs performance**. In detail, no shared procedures exist to measure FEWSs success. This is a critical issue because without a clear and agreed approach, it is not easy to assess if warnings are improving. Moreover, available tools mainly focus on the accuracy of flood forecasts whilst outcomes in terms of lives saved and property loss avoided should be assessed as well.
- Increasing attention has been then paid to raise **public awareness** and education. However, many programmes fail because they are poorly designed or executed. Specifically, educational programmes are often too generic and/or occasional (discontinuous), meaning they do not target people needs and are usually carried out only in the aftermath of an event.
- Moreover, community needs are often ignored in designing warning systems which are still essentially “top-down or model-based” instead of “bottom-up or people-centred”. Little **community engagement** affects FEWSs performance in two ways: (i) limiting people ability to understand, trust and react against a warning and (ii) ignoring the powerful link between informal and official warning sources.
- Finally, good practice and experience need to be shared on a regular basis. The current lack of **knowledge sharing** among the various actors involved in warning process is representative of all the communication problems (among people with different expertise) discussed in the previous section.

The analysis carried out by Handmer sustains and completes a previous study (Parker and Fordham, 1996), developed within the EUROflood project. Specifically, the problem of addressing research effort mainly on technical aspects has been already recognised by the first review. Conversely, the EUROflood’s analysis highlighted also how FEWSs under performance was more related to unsuitable response by both individual and agencies (e.g. unclear legal responsibilities for disseminating flood warnings, inter-agency difficulties, failure to target flood warnings, failure to provide the kinds of flood warnings needed and failure to elicit appropriate response from the flood prone) rather than to technical deficiencies; the importance of communication and social aspects has thus been recognised since the mid-nineties. Nevertheless, from this perspective, research is still unsatisfactory and fragmented.

1.4.3 FEWSs LoD

Taking into account all the factors listed in the previous subsection, the LoD of a certain FEWS can be evaluated in a systematic way, by means of the **evaluation methodology**, developed within the EUROflood project (Parker and Fordham, 1996) and previously quoted.

The methodology was originally conceived with the aim of defining a uniform evaluation procedure to be applied in the "quiet period" (i.e. the period between disasters):

- To optimise the effectiveness of warning systems, in preparation for a disaster.
- To compare different systems, highlighting common problems, pooling knowledge and transferring best practices.

Here, the methodology has been implemented to evaluate Italian systems effectiveness and their LoD in comparison to each other as well as leader countries. Although the results are strictly valid only for the Italian context, the methodology is general and can be transferred to other context/system as well.

The EUROflood methodology originally employs 14 criteria (Table 1.2) which are based on those factors discovered to be critically important in designing and operating effective flood warning systems. FEWSs may be evaluated by the appraisal of these criteria. In detail, each criterion must be assessed with respect to its LoD that spans from 1, which means "basic", to 5 which means "advanced".

However, the method has been here employed after being adapted to the context of the analysis. Table 1.2 provides a comparison between the original set of criteria and the one here implemented.

Tab. 1.2
Comparison between original and implemented evaluation criteria. In black differences are underlined

EUROflood criteria	Criteria adopted in this work
1. Flood warning philosophy	–
2. Dominance of forecasting vs. warning	1. Dominance of forecasting vs. warning
3. Application of technology	2. Application of technology
–	3. Redundancy
4. Geographical coverage	4. Geographical coverage
5. Laws relating to warning systems	5. Laws relating to warning systems
6. Content of warning messages to public	6. Content of warning messages to public
7. Methods of disseminating warning	7. Methods of disseminating warning
8. Attitudes to freedom of risk information	–
9. Public education about warnings	8. Public education about warnings
10. Knowledge of system effectiveness	–
11. Dissemination of lessons learnt	9. Dissemination of lessons learnt
12. Performance targets and monitoring	10. Performance targets and monitoring
13. National standards	–
14. Organisational culture	11. Organisational culture
–	12. Uncertainty management

Level of development	Meaning
1	Basic/little development
2	Intermediate
3	More advanced performance
1P	No data

Tab. 1.3
LoD values

Specifically, during the adaptation process, the following aspects have been taken into account:

- The regional scale: the original methodology was conceived to be applied at national scale, whilst it is here implemented at regional/local scale. Consequently, some original criteria (e.g. "flood warning philosophy" and "national standards"), which refer to differences among countries, have been here deleted.
- The availability of data: some original criteria have been merged because of a scarce availability of data, that limit the capacity to evaluate each of them in detail (e.g. "performance target and monitoring" and "knowledge of systems effectiveness" became a single criterion).
- The scope of the analysis.
- Further criteria have been added in order to evaluate some aspects which are especially interesting within this research. In detail, a criterion was introduced to assess redundancy in communication, while another one aims at analysing how uncertainty is managed within the decision-making process.

Moreover, again because of little availability of data, the number of development stages has been reduced from 5 to 3 and lack of data has been characterised by means of a counter. Thus, when no data exist, for a certain criterion, an LoD equals to 1 is precautionary assumed; meanwhile a counter is added (see Table 1.3).

This way, confidence in results can be evaluated as well: the higher the counter is, the less reliable results are (LoD values are inferred, for unknown criteria). Table 1.4 summarise the whole procedures, by specifying the meaning of either each criterion or the corresponding development stages.

Once the evaluation procedure has been defined, four case studies have been investigated (see Appendix 1.A):

1. The FEWS and the contingency plan for the town of Crotone, in the Calabria region (Mendicino et al., 1998; Regione Calabria, 2007; Comune di Crotone, 2007).
2. The FEWS implemented in the Arno river basin and the linked emergency plan for the city of Pisa, in the Toscana region (Autorità di Bacino del fiume Arno, 2006; Comune di Pisa, 2006; Regione Toscana, 2006).
3. The FEWS adopted by the Piemonte region and the linked contingency plan for the municipality of La Loggia (Comune di La Loggia, 2002; ARPA Piemonte, 2005; Regione Piemonte, 2007).
4. The FEWS implemented in the Adige river basin and the linked emergency plan for the province of Trento (Provincia autonoma di Trento, 2005, personal interviews).

Tab. 1.4
Evaluation criteria guidlines

Criteria	**Scope/meaning**	**LoD**		
		1	**2**	**3**
1. Dominance of forecasting vs. warning	To evaluate systems capacity to proper design and operate all the warning sub-systems	Systems are monitoring and forecasting dominated	Other cases	All sub-systems are properly designed and operated
2. Application of technology	To evaluate the level of technology implementation within the system	Basic; numerous equipments shortcomings	Other cases	Advanced, state of the art in most areas
3. Redundancy	To evaluate technological reliability; redundancy in communication networks	None to very little; need not recognised	Partially developed	Need extensively recognised and developed
4. Geographical coverage	To evaluate systems ability to warn all "at-risk" areas	Coverage <10%	Coverage <50%	Coverage >50%
5. Laws relating to warning systems	To evaluate organisational aspects; transparency in roles and responsibility setting	No arrangements	Intermediate	Well defined
6. Content of warning messages to public	To evaluate effectiveness of warning contents	Limited; warnings are generic, supplying only the likelihood of an event	Intermediate	Exhaustive; warning supplies likely intensity and impacts as well as actions to be taken
7. Methods of disseminating warning	To evaluate effectiveness of warning dissemination	Dissemination tools are generic, not targeted to people needs	Intermediate	Dissemination tools are different and oriented to people needs
8. Public education about warnings	To evaluate people knowledge of warning and preparedness to react	Non existent	Other cases	Comprehensive, regular awareness and educational programmes
9. Dissemination of lessons learnt	To evaluate whether knowledge and experience are shared among researchers and practitioners	No literature or reports are available	Other cases	Full/wide spread
10. Performance targets and monitoring	To evaluate the presence of suitable performance measures	Non-existent	Performance measures focus on forecasts accuracy	Performance assessment aims at evaluating systems capacity to reduce expected damages
11. Organisational culture	To evaluate how warning management is shared among authorities	Regional authorities are in charge of both forecasting and emergency management	Forecasting is responsibility of regional authorities, whilst local authorities are in charge of emergency management	Local authorities are in charge of both forecasting and emergency management
12. Uncertainty management	To evaluate how uncertainty is managed within the decision-making problem	Problem not recognised	Uncertainty is supplied only with respect to forecasts accuracy	Decisions are taken according to uncertainty too

Tab. 1.5
Results of Italian systems evaluation. Maximum values (in blue) and minimum values (in red) are underlined

Criteria	LoD [–]				
	Crotone	Arno	Piemonte	Adige	Average
1. Dominance of forecasting vs. warning	2	2	2	3	2.25
2. Application of technology	2	2	2	3	2.25
3. Redundancy	3	3	2	3	2.75
4. Geographical coverage	3	3	3	1P	2.50
5. Laws relating to warning systems	3	3	2	3	2.75
6. Content of warning messages to public	3	3	3	1P	2.50
7. Methods of disseminating warning	3	3	2	1	2.25
8. Public education about warnings	2	2	1	1P	1.50
9. Dissemination of lessons learnt	2	2	3	1	2.00
10. Performance targets and monitoring	2	1	2	1	1.50
11. Organisational culture	3	3	2	1	2.25
12. Uncertainty management	2	2	1	2	1.75
Sum	30	29	25	21	26.25
Counter	0	0	0	3	

Results are summarised in Table 1.5.

Looking at Table 1.5, first, it must be stressed that the low number of unknown criteria (marked by the letter "P") should not be interpreted as suggesting adequate available data because, actually, the decision to analyse only four systems was not strategic but due to the fact that enough data were found only for these four systems. On the other hand, this is not to say that no other systems exist in Italy but that no literature is available for them.

Then, it is possible to observe that criteria 10 and 8 are those with the lowest LoD average value, which means that little attention is paid in Italy to both performance evaluation and public education, as generally happens worldwide (see Section 1.4.2). This last evidence is particularly corroborated by the Adige case study, where criteria related to interactions with users (i.e. criteria 4, 6 and 8) are just those for which data are not available, because the problem is simply neglected. However, this is a current limit of national systems that requires to be better tackled by researchers as well as by practitioners (through proper educational programmes).

Likewise, the evaluation highlighted that the systems agree with the global state of the art, at least from two other perspectives. On one hand, almost no performance measures exist that evaluate systems ability to lessen expected damages (criterion 10); on the other hand, uncertainty is usually disregarded in decision making or is simply characterised to evaluate forecasts accuracy (criterion 12). Nevertheless, as discussed before, these are two crucial points for FEWSs effectiveness which this research tries to face (see Section 1.6).

Highest LoD average value corresponds, instead, to criteria related to dissemination redundancy (criterion 3) and roles and responsibilities setting (criterion 5). Unfortunately, this does not imply FEWSs effectiveness which depends also on inter-agencies organisation. This information, however, requires more specific data and cannot be evaluated within this analysis.

Criterion 1 must be carefully analysed. Although it assumes medium to high values, deficiencies have been observed within the risk information sub-systems, meaning that, actually, warning is based only on hazard assessment rather than taking into account also the vulnerability of the area at risk. Nevertheless, a first shift has been recognised towards including exposure and vulnerability in emergency plans. From this point of view, the case of the Adige river is representative where the emergency plan for the province of Trento imposes that warnings should be issued considering not only the most likely hazard intensity but also the most likely degree of exposure and vulnerability because of the time of the impending event (e.g. night or day, high or low tourist season and working day or weekend). As a crucial issue for FEWSs effectiveness, also risk assessment is tackled by this research. In detail, the assessment of expected damages, to support the decision-making process, represents the focus of Chapter 3.

Finally, a last consideration regards criteria 2 and 9. With respect to the former, it is manifest that, also at national level, research efforts have been mainly focused on monitoring and forecasting. Little availability of data has been instead recognised with respect to lessons learnt. However, practitioners turned out to be inclined to share their knowledge and experience.

1.5 Research needs and potential

To conclude the chapter, it is worthy to summarise which are the main gaps in current research on EWSs as well as to identify some potentials for the future.

To synthesise the results of previous sections, four main **directions** for improvement can be defined:

1. First, a shift in thinking is necessary towards the vision (and the design) of EWSs as total systems, including more capacities than forecasts. This implies to pay more attention on questions related to risk assessment as well as emergency planning and communication.
2. Then, according to the previous point, another change is required from hazard-oriented to people-centred systems. That is, more consideration has to be paid on social aspects like increasing people awareness, community engagement, knowledge sharing, communication and trust.
3. Next, there is a need to develop tools to assess EWSs' performance, in terms of their capacity to reduce expected damages (which is in contrast with the current practice of simply evaluating forecasts accuracy). From this perspective, the link with the decision-making process and the point of view of stakeholders must be considered as crucial.
4. Finally, the importance of including uncertainty among the key variables on which decisions are taken.

With respect, instead, to potentials for future research, an analysis of the current state of the art in other fields than floods has been carried out. The scope was that of identifying lessons learnt to be transferred to FEWSs.

1.5.1 The current state of EWSs for seismic, tsunami, landslides and volcanic risk

1.5.1.1 Seismic risk

Unlike other hazards, no triggers come before earthquakes. Thus seismic early warnings must be grounded on real-time event detection rather than on the observation of triggers values.

Considering that earthquakes unfold within a very short time, on the order of seconds, Earthquake early warning systems (EEWSs) are quite modern tools as only recent advances in technology make it possible to build reliable instruments for real-time data acquisition, digital communications and data processing (Kanamori et al., 1997; Wieland, 2001).

The basic elements of an EEWS are a network of seismic instruments, a unit processing the data measured by the sensors and a transmission infrastructure spreading the alarm to the end users, to initiate mitigation measures before the ground motion hits. EEWSs rely on the difference between the velocity of seismic waves and the velocity of analogical/digital signals, the first being slower. Thus, depending on the localisation of seismic instruments, places at risk can be warned few to some seconds before the earthquake strikes. Although it seems a very short time, it is enough to activate different types of both individual and collective mitigation measures (such as shutdown of critical systems and leaving buildings) which can lessen not only direct damages (due to the earthquake impact) but also, above all, indirect damages due to the systemic vulnerability of the area at risk (e.g. fires, explosion and contamination). As a consequence, emergency planning is crucial to guarantee warnings success.

EEWSs may be then further distinguished, by the configuration of the seismic network, as **regional** or **site-specific** (Iervolino et al., 2006). Regional systems consist of wide seismic station networks, monitoring a region which is likely to be the source of a catastrophic earthquake. Such systems are designed to provide data that can be used to estimate the main parameters of the event (as the magnitude and location) and, consequently, to warn areas at risk.

Site-specific systems are instead devoted to critical engineered systems, as nuclear power plants, lifelines or transportation infrastructures. The networks for site-specific EEWSs are smaller than those of the regional type and only cover the surroundings of the system in order to detect arriving seismic waves. Typically, a warning is issued when the ground motion at one or more sensors exceed a given threshold, in order to activate automated mitigation actions. In fact, unlike the regional case, site-specific EEWSs only measure the ground shaking at the network and do not estimate the features of the event, which would require unacceptable computational time. The location of the sensors depends then on the lead time needed to activate the safety procedures before the arrival of the more energetic seismic phase at the site.

Within this research, regional systems are more interesting (see Section 1.4.2). Nevertheless, site-specific systems are the most implemented worldwide because they are cheaper and, most importantly, they do not require public involvement, making their operation easier. On the other hand, they are useless in reducing loss of lives.

Otherwise, regional systems (as those implemented in Mexico City, Taiwan, Istanbul and Bucharest) proved to be effective in saving lives and, more in general, in reducing expected damages, despite the warning time is very short: about 8 seconds in Istanbul and 60 seconds in Mexico City (Erdik, 2006). Recent experimental tools, like the America ElarmS (Allen, 2007) and the Italian SAMS (Iervolino et al., 2006) showed, however, the potential to further increase available warning time.

1.5.1.2 Tsunami risk

A lot of attention has been recently devoted to Tsunami early warning systems (TEWSs) mainly because of the global, massive impact of the event that hit Asian countries in 2004 which actually brought to a significant development of warning tools worldwide.

TEWSs are based on a similar principle than earthquake's, being that tsunami waves move slower than seismic waves. Once the seismic trigger event has been detected, some warning time is so available, depending on the distance between the earthquake source and the coast.

Unlike other risks, TEWSs are globally organised within a set of centres that aim at protecting Pacific, Atlantic and (only recently) Indian Ocean coasts. Specifically, warning centres are structured in hierarchy with (i) **international centres** which cover major events that usually originate far from the coast and have the potential to affect large regions and (ii) **local (national or regional) centres** that focus on those events that originate near the coast, likely affecting limited areas. In any case, it is important that global and local centres cooperate, guaranteeing continues flows of information.

With respect to international centres, if an earthquake has the potential to generate a destructive tsunami, a first warning is issued to warn of an imminent tsunami hazard. Initial warning applies to those areas the tsunami could reach within a few hours and bulletins include a first appraisal of the tsunami arrival times at selected coastal communities within those areas. After that, if a significant tsunami is detected by sea-level monitoring instrumentation, tsunami modelling is carried out in order to get a more detailed estimate of the likely intensity and impacts of the impending event. Consequently, a more exhaustive warning is issued.

Currently, global systems are two:

1. The "Tsunami Warning System" which is made up of two warning centres, respectively, for the Pacific[12] and the Northern[13] coasts.
2. The "Indian Ocean Tsunami Warning System".

In the case of local systems, instead, warning is based only on seismic data because the limited warning time does not allow models implementation. Local systems are more spread. A complete list is available on the website of the "International Tsunami Information Centre" by UNESCO. Some examples are the Russian, Australian, French and Japanese centres.

Both at global and local scale, warning is thus responsibility of warning centres that must alert emergency managers in order to activate mitigation measures. People in charge of emergency, in turn, must communicate with population. With respect to this, different dissemination tools are currently implemented, spanning from private to mass media (see, for example, Schindele et al., 2005).

1.5.1.3 Landslides risk

Landslides early warning is a challenging issue because landslides could be very complex phenomena whose modelling is not always achievable.

Slopes stability depends not only on geotechnical conditions but also on the actions of some trigger phenomena like rainfall, snowmelt, seismic stress, temperature range, erosion at the slope base, river erosion and anthropic factors. Consequently, no accurate models exist that can take into account all these factors as well as their interactions.

Landslides warning is thus currently based on the relationship between triggers and landslide phenomena. In detail, two kinds of tool can be identified:

1. Systems based on **triggers monitoring**
2. Systems based on the **forecasting** of some phenomena (typically rainfall) which influence triggers (and consequently landslides occurring).

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[12] The "Pacific Tsunami Warning Center".

[13] The "West Coasts/Alaska Tsunami Warning Center".

The latter have been, historically, the first to be implemented and are also the most common. The reason is twofold: on one hand, the difficulty, in the past, to get accurate real-time measures; on the other hand, the more warning time available in case of forecasting (against, of course, more uncertainty too).

Nevertheless, last improvements in technology caused a recent shift towards monitoring-based systems. For example, SLEWS (Arnhardt et al., 2007) and LEWIS (Guerriero et al., 2006) projects, grounded respectively on wireless and satellite technology, seem particularly interesting. Of course, these tools present the advantage to be more accurate about the probability of occurrence of landslide events; conversely, warning time decreases.

Landslides warning systems can also be classified as **site-specific** or **local**, according to the spatial scale they focus on. The former analyse single landslides, being characterised by a better knowledge about the physics of the phenomenon and so by less uncertainty. Local systems identify instead homogeneous risky areas, without distinguish among single phenomena, thus, uncertainty increases. Unfortunately, limited skills in landslides modelling have supported the development of mainly local system. Of course, this justifies the limited accuracy of available landslides early warnings.

1.5.1.4 Volcanic risk

Volcanic early warning systems are grounded on both **long-term** and **short-term** predictions. The former imply the evaluation of the most likely eruption type(s) as well as their effects, according to historical evidences. The latter aim, instead, at identifying the likely occurrence of an impending event on the basis of triggers monitoring (like soil deformation, seismic events and temperature anomalies).

Last advancement in technology allows improving short-term prediction skills, with respect to both modelling and monitoring. Although it is now possible to forecast eruptions with a suitable warning time (on the order of months), the prediction of how the event will unfold as well as of their impacts on humans and environment is instead still problematic. The reason is twofold:

1. First, long-term predictions are static, meaning they assume that certain eruptive phenomena will occur in the future likewise they unfolded in the past. However, areas at risk are now significantly different than in the past both from geomorphologic perspective (meaning that it is possible that a certain event will affect different areas than in the past) and from vulnerability and exposure perspective (meaning that damage will be different than in the past).
2. Second, the way in which eruptions unfold (and so their impacts) depends also on meteorological conditions which cannot be long-term predicted.

To summarise, volcanic forecasting is thus characterised by two peculiarities:

1. Uncertainty about how eruptions unfold (catastrophic/fast events vs. continuous/less intense events).
2. Uncertainty about impacts (which depend on the “initial and boundary conditions” that characterise the event occurrence).

As a consequence, emergency planning is crucial for effective warning. Specifically, **scenarios** are quite common tools in volcanic risk management, to investigate how to react to different hazard as well as exposure and vulnerability configuration.

1.5.2 The challenges of flood early warning

In order to define how research on other risks can be applied to floods, first it is required to identify which are the peculiarities and the challenges of the problem at stake, looking for analogies with other risks.

First of all, a common feature to most of hydrogeological hazards is that of being spatial **dispersed** rather than punctual (like avalanches or landslides). Floods can affect large areas, which are the responsibility of different administrations, leading to a first problem of organisation. For example, the Elbe flood in 2002 affected eight countries, involving different regions with different forms of local government. As a consequence, many local as well as national actors have been in charge of emergency management, whose coordination has been crucial to face the crisis. Nevertheless, examples can also be reported at smaller, local scales, for example, when river basins are shared among provinces or regions, within the same country.

Looking particularly at mountain regions, these areas are then usually affected by the so-called **flash floods** which are suddenly and short events (with timescales of the order of few hours), characterised by high intensity, and which usually impact small areas.

Flash floods are mainly caused by intense and short rainfall events, but their intensity depends also on other factors like the topography of the affected area, the soil moisture and the land use (Georgakakos, 1986; APFM, 2007). Specifically, steep terrains and narrow valleys further accelerate and strength the flood wave downstream, as runoff is increased. Likewise, positive flash floods environments are saturated and/or impermeable (e.g. because of dense urbanisation) grounds. Finally, flash floods intensity may increase because of sediment transport which can be relevant in such a conditions like those described above. Of course, the context that has been just described is typical of most of the Alpine territory making flash floods a matter of interest at EU level.

The point, as maintained by Ballio and Menoni (2009), is that the evaluation of flash flood risk is a complex problem, adding some specific elements of complexity to the intrinsic difficulties of any assessment of (flood) risk.

With comparison to the common and established methodology for riverine floods[14], peculiarities of flash flood hazard assessment are the following:

- The **temporal scale** of the analysis. Predictions based on discharge values upstream the location of interest are seldom useful, due to the limited temporal scales of the system (the lead time is short). Accordingly, predictions of flash flood events normally start from rainfall data or rain forecasting data, in order to increase the time available to implement mitigation action. Although hydrological and hydraulic tools do not conceptually differ from those used for long-term evaluations, rain forecasting introduces the need of meteorological models. As **uncertainty** increases with model complexity (see Section 1.2.1), uncertainties are often higher in flash flood modelling than in the case of large river basins.
- The **spatial scale** of the analysis. Flash floods are particularly critical from this perspective. Uncertainty in the prediction can be very high, due to the limited scales of mountain river basins with respect to the scales of meteorological phenomena. Accordingly, relatively small error in the location of the rain event has a large effect on the prediction (Ballio and Menoni, 2009). In more general terms, it is recognised that the atmospheric and hydrological generating mechanisms of flash floods are poorly understood, leading to highly uncertain forecasts of these events. This is not to say that monitoring and forecasting systems are useless, they still provide guidance for decisions.

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[14] Riverine are floods occurring in lowland. In such cases, hazard assessment usually consists of (i) the statistical description of rainfall and discharge, (ii) the evaluation of water levels and (iii) the identification of inundated areas.

- The presence of **sediment transport**. In mountain systems, sediment transport phenomena can be very intense as well as their effects (e.g. significant changes in river geometry can be observed even after a single flood event, river bed aggravation and blockages of bridge openings can occur). A coupled hydraulic and geological–geotechnical model is therefore required. This further increases model uncertainty.
- The effect of **velocity**. Flood damage in low land is basically due to water levels while, in mountain areas, the dynamic and erosive load of high velocities can be prevalent with respect to water depths. As a consequence, some dynamic (complex) modelling of the inundation process may be necessary.

With respect to the **vulnerability**, the most important aspects are the local scale of flash flood phenomena as well as the position of the areas at risk. Flash flood hazard is usually high in small peripheral areas where few resources are available to face the emergency. Specifically, not only material resources (e.g. monitoring and forecasting tools, means and materials and people) but also emergency preparedness is low, meaning that contingency plans may even do not exist at all. Accordingly, vulnerability and risk are high too. Mileti (1999) clearly makes the point, explaining how natural risk management is often neglected in small communities, because of limited economic availability, in favour of more noticeable problems (like criminality and unemployment). Hence, natural hazards paradoxically affect just those areas that are more vulnerable.

Last but not least, the short time for and the high uncertainty of decision making, of course, characterise flash flood emergency management. From this perspective, communications and coordination issues play a crucial role.

1.5.3 Lessons learnt

1.5.3.1 Seismic risk

Current EEWSs present two features which are interesting for FEWSs too. The first is particularly attractive because of the analogies (although with different spatial and temporal scales) between flash floods and earthquakes which are both characterised by (i) limited modelling and forecasting skills as well as (ii) short warning time once triggers have been detected. Just these reasons drove last research on EEWSs to reject warnings which are based on earthquakes real-time modelling. Instead, real-time **probability of occurrence** (which is grounded on the ex-ante analysis of the local seismicity) is often estimated to support warnings.

To make the point clear, the system under experimentation in the Campania region is here briefly explained (for a comprehensive description, see Iervolino et al., 2006).

The system (which is called SAMS – Seismic Alert Management System) is based on the seismic network which covers the most active area of the Campania region. The warning procedure is the following:

- When an earthquake occurs, at any given time t from the origin time t_0, all the real-time information provided by the monitoring network is processed and the probability density functions (PDFs) of the event intensity (i.e. magnitude and source-to-site distance) are estimated;
- In detail, at any time t, PDFs at the time $t - 1$ are revised by means of the Bayes' theorem where PDFs at the origin time t_0 are known thanks to "a priori" analysis, grounded on the seismicity the investigated site is subjected to.
- Instantaneous PDFs represent, then, the information from which the probability of occurrence of an earthquake is inferred and, accordingly, warnings are issued.

Of course, as time increases estimate uncertainty decreases because the amount of data (and, consequently, the knowledge) included in the assessment process increases with time (i.e. more stations trigger as time flows). Thus, to summarise, although the seismic approach allows to save time by avoiding events modelling, a trade-off exists between accurate knowledge and warning time.

However, it is just according to this perspective that research on EEWSs presents the second strength point, suggesting experimental **warning rules** which are based on the real-time comparison between expected damages and their probability of occurrence (see, for example, Iervolino et al., 2007).

Of course, warning rules which are based on probabilistic information instead of deterministic forecasts represent, by themselves, a further advance in the current state of the art on early warnings (see Section 1.4.2).

1.5.3.2 Tsunami risk

The 2004 tsunami in Asia highlighted, above all, a deficiency with respect to social and organisational aspects given that, even when alerted, only those people who lived in historical-prone areas were able to properly react to reduce damages and save their lives (as in the case of the small remote island of Simelueue, see Davis and Izadkhah, 2008).

For this reason, in recent years, a lot of attention has been devoted on the matter through international policies, as well as educational programmes, aimed at promoting the so-called **safety culture**. In brief, the general objective is to create more resilient societies by means of community engagement within both the design and operation of tsunami early warnings. From this perspective, two experiences seem interesting. On one hand, the adoption, within global systems, of ad hoc warning messages (in terms of contents, structure and dissemination media) which are tailored to individual needs. On the other hand, the promotion of educational campaigns aimed at the adoption of mitigation actions by communities at risk.

The so-called TsunamiReady programme, developed by the National Weather Service in the USA, is one of the most successful, from this perspective. Specifically, the programme has been created with the scope of helping communities to reduce their tsunami vulnerability. To join the programme, communities must adopt some mitigation actions (from long term, as spatial planning, to short term, like education and emergency planning, actions) which are supplied as guidelines by the same National Weather Service. The main benefit of being a "TsunamiReady" community is to be better prepared to save lives in a tsunami emergency. Moreover, as tsunamis are highly dangerous but rare events, the programme helps communities keep their tsunami response plans current. Finally, the programme increases communities contact with experts and warning dissemination personnel, helping to overcome the problem of lack of expertise within small communities members. So far, 111 communities have been declared "TsunamiReady" and the trend is positive.

Clearly, questions discussed above are general and should be exported not only to flood warning but also to every warning related to every natural or man made risk.

Conversely, flood and tsunami risks share the peculiarity to be spatial disperse (even if scales are different). From this perspective, the hierarchal organisation of TEWSs could be successful also for floods.

1.5.3.3 Landslide risk

With respect to landslides, an interesting starting point for future research is represented by the evidence that both flood and landslide warnings are usually based on rainfall thresholds. As a consequence, given also the cause–effect relations which can exist between the two phenomena (above all, in mountain regions), further efforts should be devoted to the implementation of **integrated warning systems**. Actually, a partial overlap already exists where the same rainfall forecast is linked to both flood and landslides thresholds. On the other hand, no systems exist which take into account also induced events (e.g. landslides caused by river erosion or floods due to landslides within the river bed), meaning which are able to identify triggers values for both primary and induced phenomena. The main reason is, again, the complexity of the involved processes which limits modeling capacities. Furthermore, a lack of historical data (evidences) is also manifest.

Nevertheless, the problem of integrated systems should deserve more attention, above all, considering that if induced events occur then flood scenarios can be totally different than the ones for which we are prepared to. As a consequence, flood damages can be unexpected too.

1.5.3.4 Volcanic risk

The most interesting aspect related to volcanic early warning systems is represented by the intensive use of scenarios to support emergency planning. Because of the uncertainty which characterises volcanic events unfolding, being prepared to a certain set of likely impacts is, in fact, the best way to plan for emergency. Consequently, a further aspect that has been investigated a lot by researchers within volcanic risk (which is important for floods too) is the problem of **decision making under uncertainty** (see, for instance, Paton et al., 1999; Ronan et al., 2000). Santoianni (2007) makes this point clear. According to him, facing a volcanic warning, the most convenient decision could seem to always evacuate all the population, since the beginning of the warning. Unfortunately, because of high uncertainty in risk assessment, this decision could imply (above all in developed countries) a massive damage (from both economic and social perspectives) in the case, for example, of false warning. This is to say that, if evacuation is the only measure contingency plans adopt than it is likely that warnings are often neglected because no rational decision makers would order an expensive evacuation, facing weak and uncertain evidences. On the other hand, it is possible that if no decisions are taken even when minor events occur (e.g. rumbles and fumaroles) then trust in emergency authorities decreases which affects both the way in which people will react and the crisis will unfold.

Volcanic risk management required then proper rules which take into account, from time to time, (i) the accuracy and reliability of hazard information as well as (ii) costs and benefits in case the warning is issued or not. This is the point on which research on volcanic risk mainly focused in the last years and also the main principle this work is grounded on. Indeed, because of modeling difficulties, uncertainty affects flash floods warning systems too.

1.6 Conclusions

This first chapter supplies all the theoretical/conceptual knowledge which is required to face the problem of EWSs design and evaluation. Main findings are summarised in the framework proposed in Figure 1.2. The latter is intended to describe the flood warning process and will be taken as reference along the whole book.

The framework shown in Figure 1.2 highlights how a variety of aspects actually affect the decision-making process about warning which, in turn, brings to the necessity to rethink the traditional concept of EWSs; from forecasting tools towards the more comprehensive vision of Total Warning Systems, where technical and non-technical tools, about hazard as well as vulnerability aspects, coexist.

Looking at the problem from this perspective, future research needs and potential can be identified. This book focuses on one of them, being the identification of suitable tools to assess FEWSs performance in terms of their effectiveness to reduce expected damages.

By examining the flood warning process in terms of its components, its actors as well as the decisions they perform, the analysis carried out in the chapter suggests that FEWSs should be evaluated at least from three different perspectives, which are all crucial for their effectiveness:

1. First, from the forecasting point of view, meaning looking at the goodness of flood forecasts in terms of their capability to predict the features of incoming floods.
2. Second, from the perspective of risk scenarios, that is considering the capacity of the system to properly figure out expected damages in case of flood (on which mitigation actions can be planned).
3. Finally, from the point of view of damage reduction, that is investigating the ability of the system (and, in particular, of the strategies which it implements to copy with the event) to lessen expected damages.

Referring to the framework shown in Figure 1.2, this is equivalent to analyse the warning process with respect to three different sets of components:

1. First, by considering the models that are required to describe the hazard (which are usually equal to forecasting tools).
2. Second, with respect to the models that are necessary to carry out a risk assessment (i.e. exposure, vulnerability, damage and disutilities models).
3. Third, looking at models to evaluate people and communities response.

The final aim being to define a last core model that put together damage data and flood data to define proper warning rules and actions (i.e. decisions) which maximise FEWSs effectiveness (i.e. damage reduction).

Next chapters are addressed to the implementation of tools which would meet the above requirements. In detail:

- *Chapter 2* focuses on the assessment of the goodness of flood predictions and their value for warning.
- *Chapter 3* supplies all the theoretical knowledge that is necessary/available to carry out damage assessment.
- *Chapter 4* finally focuses on the evaluation of FEWSs capacity of reducing expected damages.

Each chapter ends with a case study which is intended:

- First, to explain concepts and tools directly by means of a real application.
- Second, to highlight problems analysts could face when concepts and tools are implemented in practice.

The case study is the same in all chapters. This choice is in line with the need of stressing and comparing the potential of each perspective in terms of knowledge supplied for emergency managers (i.e. who is responsible for warning).

Although the "Total Warning Systems" approach is strong from the procedural perspective, criticalities exist from the methodological point of view. In fact, while it is only by considering the whole chain (rather than the only forecasting tool) that it is possible to explain why FEWSs fail (overcoming the limits of current FEWSs evaluation tool), few models exist to describe and combine components different than forecasting tools. Thus, practical issues arise.

In such a challenging context, the idea this book is grounded on is not that to be comprehensive, trying to model everything. On the contrary, the objective is that of identifying those critical aspects which significantly affect FEWSs performance. These factors must be evaluated (even if "roughly") as a minimum analysis requirement.

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Appendix

1.A An analysis of four Italian FEWSs

The four Italian FEWSs, on which the analysis in Section 1.4.3 is grounded, are here described in detail. Specifically, FEWSs features are analysed with respect to both the development of the four components a Total Warning System is made up of (see Section 1.3) and the way in which uncertainty is taken into account and managed during the warning process.

Particular attention is given to hydraulic/hydrological aspects, meaning that, for each system, input data, models and output will be identified.

On the contrary, the analysis of other sub-systems than monitoring and forecasting was challenging, because of a limited availability of data and studies on these aspects. Regarding this, the only information gained from legal requirements, as well as from emergency plans, is thus been used as reference.

1.A.1 The FEWS for the Piemonte region

(Source: ARPA Piemonte, 2005; Regione Piemonte, 2007)

The monitoring and forecasting sub-system

In Piemonte, the operating information system, which is called SIPP[15], has been conceived to supply real-time estimates of water levels and discharges for the main rivers of the whole region. This highlights, from the beginning, the **regional** scale of the warning system (see Section 1.4.3).

Actually, SIPP is more than a forecasting tool. Indeed, the core of the system is made up of a software, that is called FLOOD WATCH, to manage information flows, from forecasting models input data to the publication of simulations output.

Predictions are carried out, instead, by means of a set of deterministic and physically based numerical models. In detail, the software MIKE11 by the Danish Hydraulic Institute is implemented which is made up of three modules:

1. A rainfall–runoff module (RR): It describes the rainfall/runoff process by means of an integrated and conceptual hydrological model, which includes a cascade of four linear reservoirs. Specifically, the model can describe the following physical processes: the water storage in ice and the snow melting, the temporal water storage on basin surface, the water absorption by soil, the surface and the ground runoff.
2. A hydrodynamics module (HD): It describes the flood wave by means of the numerical resolution of the De Saint–Venant equations. In the model, river stretches are described

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[15] SIPP – Sistema Informativo di Previsione delle Piene.

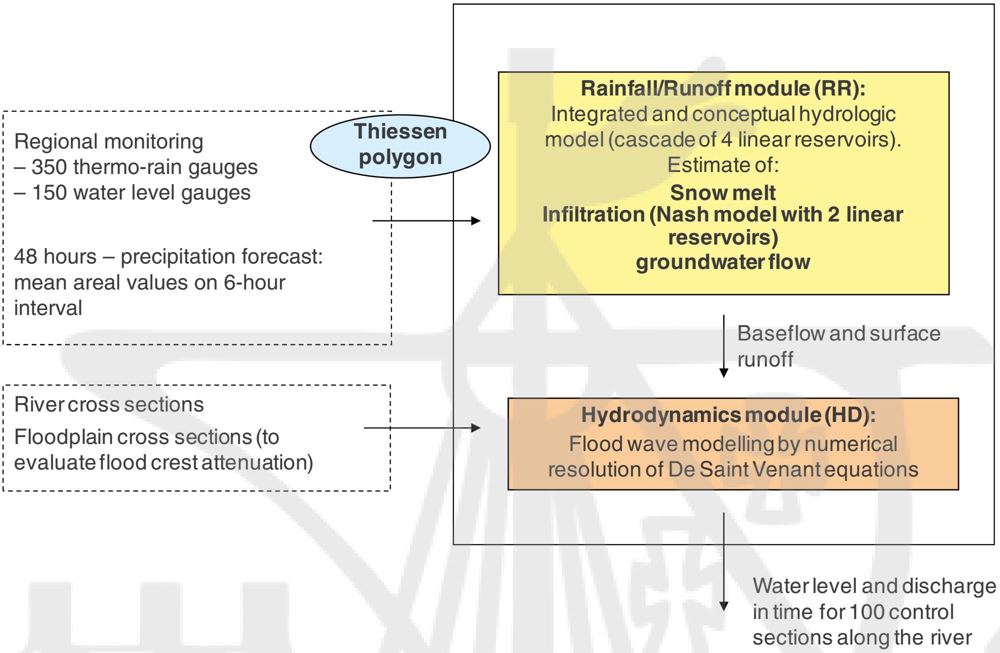

Fig. 1.A.1
The monitoring and forecasting system for the Piemonte region

through a set of river cross sections deriving from both topographic surveys and maps. Moreover, floodplain cross sections are available to evaluate flood crest attenuation.

3. A data assimilation module (DA): It corrects predictions through the real-time estimate of errors, by comparison between observed and forecasted data.

As input, SIPP implements data (observations) coming from the hydrometeorological network of the Piemonte region itself as well as those coming from the networks of the close Valle D’Aosta region, Liguria region and Switzerland[16]; they totally include about 350 rain gauges with thermo sensors and 150 water level gauges. Furthermore, quantitative precipitation forecasts are supplied by the Regional Operational Centre[17]. Specifically, 48-hour average forecasts (on 6-hour intervals) are supplied, for different warning zones[18].

Figure 1.A.1 synthesises the architecture of the whole system. With respect to this, it is important to stress that available documentation does not specify how and when (along the prediction) the DA module works.

The risk information sub-system

The development of the risk information sub-system in Piemonte must be assessed only by analysing legal requirements. Indeed, given the regional “nature” of the FEWS under investigation, there is not a unique emergency plan on which this analysis can be based, but a variety

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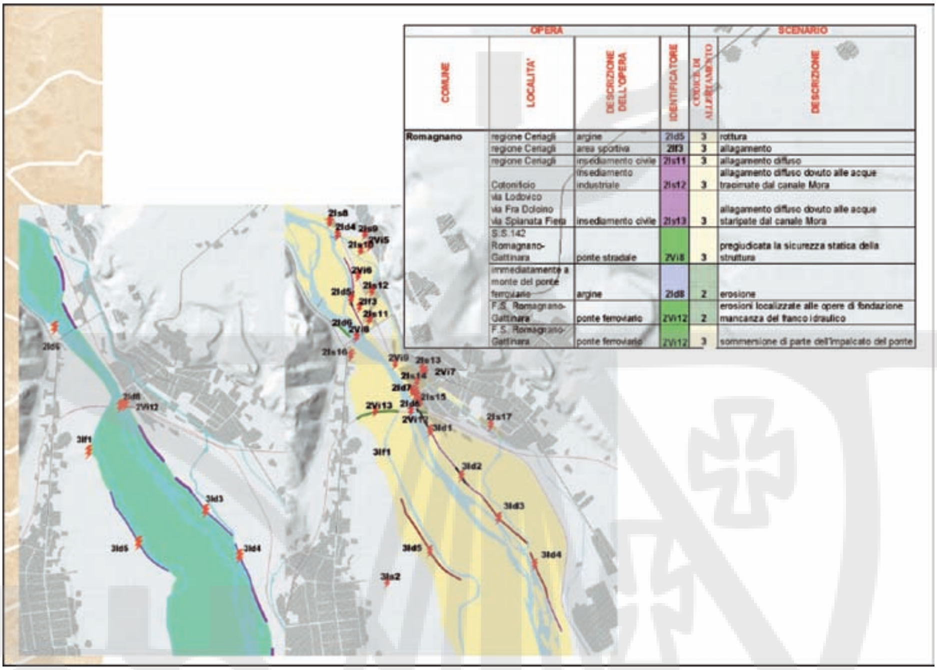
[16] The Ticino network.

[17] Centro Funzionale Regionale.

[18] Zone di Allerta.



OPERA				SCENARIO	
COMUNE	LOCALITA'	DESCRIZIONE DELL'OPERA	IDENTIFICATORE	CODICE DI ALLERTAMENTO	DESCRIZIONE
Romagnano	regione Ceriagli	argine	2Id5	3	rottura
	regione Ceriagli	area sportiva	2If3	3	allagamento
	regione Ceriagli	insediamento civile	2Is11	3	allagamento diffuso
	Cotonificio	insediamento industriale	2Is12	3	allagamento diffuso dovuto alle acque tracimate dal canale Mora
	via Lodovico via Fra Dolcino via Spianata Fiera	insediamento civile	2Is13	3	allagamento diffuso dovuto alle acque staripate dal canale Mora
	S.S.142 Romagnano-Gattinara	ponte stradale	2Vi8	3	pregiudicata la sicurezza statica della struttura
	immediatamente a monte del ponte ferroviario	argine	2Id8	2	erosione
	F.S. Romagnano-Gattinara	ponte ferroviario	2Vi12	2	erosioni localizzate alle opere di fondazione mancanza del franco idraulico
	F.S. Romagnano-Gattinara	ponte ferroviario	2Vi12	3	sommersione di parte dell'impalcato del ponte

Fig. 1.A.2
Risk scenario for the Sesia river

of plans developed at different spatial scales, and, of course, the examination of all available plans is not feasible in this circumstance.

Regional regulations about civil protection activities provide that local emergency plans include flood scenarios to properly evaluate the flood risk. Regarding this, the case of the Sesia river can be taken as an example. Here, two different scenarios have been analysed which are related to the two hazard warning levels (in terms of river discharge) of the regional warning system (highlighting again, the regional nature of the system). The scenarios should represent the starting point for the design of emergency plan.

However, as pointed out in Figure 1.A.2 (that reports an example of available maps), actually current analyses refer to the only hazard components of the risk, without taken into account neither exposure nor vulnerability.

The preparedness sub-system

As for the risk information sub-system, also the preparedness sub-system have been analysed by examining only legal requirements.

Regarding this, warning activities are regulated by a regional decree of 2007[19] which defines the organisation of the warning system as well as its roles and functions (adopting this way the national guidelines described in Section 1.4.1).

In accordance with the national strategy, the Piemonte warning system is based on hazard thresholds which correspond to different critical levels for the occurrence of a flood; in detail,

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[19] Deliberazione della Giunta Regionale n. 46-6578 del 30 luglio 2007.

three levels exist: a “moderate” criticality, a “severe” criticality and an “ordinary” criticality (according to which people can face the likely event without significant discomfort). Hazard thresholds vary then within different warning zones, defined as homogeneous areas in terms of both expected hazard features and effects.

Hazard thresholds refer to river discharges and/or water levels as well as to precipitations; particular attention must be given to the procedure to define precipitations thresholds, which is reported in Box 1.A.1.

With respect to the hydraulic data, in case of a potential hazardous event, the Regional Operational Centre issues a report[20] which indicates the output of the simulation models described above (in terms of water level and river discharge, at specific locations).

Regarding precipitations, instead, the regional weather report[21] (which can be followed by a warning report[22]) indicates always if precipitations are forecasted in the following 60 hours, specifying also a quantitative forecast if warning thresholds are expected to be exceeded.

Box 1.A.1: The procedure to define precipitations thresholds in Piemonte FEWS

Precipitation thresholds are defined by means of a conceptual model according to which the return period (T_R) is the unknown variable. In detail, T_R must be set so that to minimise false warning (FW) and missed event (ME) occurrence, taking into account that an increase in T_R corresponds to an increase in warning thresholds and so an increase in the number of missed events against a reduction in the number of false warnings (and vice versa). The optimal T_R value derives then from the minimisation of the following objective function:

$$\Phi = w_1 \mathrm{FW}_{(T_R)} + w_2 \mathrm{ME}_{(T_R)}$$

where w_1 and w_2 represent outcome weights whose definition is the critical point of the procedure. Indeed, they do not derive from technical aspects but rather from economic and social considerations. Specifically:

- A missed event can imply that mitigation activities are carried out too late, reducing, this way, their effectiveness.
- On the opposite, a false warning does not imply any physical damage but an economic and social cost can occur (because civil protection structures are activated as well as mitigation actions are implemented). Moreover, trust in authorities decreases as the number of false warnings increases.

In the Piemonte region, outcome weights have been set according to damages occurred during past flood events. Of course, this choice presents several limits which are recognised by system designers themselves. The problem of how to set outcomes weight is actually an open question this thesis focuses on.

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[20] Bollettino di previsione delle Piene.

[21] Bollettino di Vigilanza Meteorologica del Centro Funzionale della Regione Piemonte.

[22] Avviso di Criticità Regionale.

In this last case, the report is spread by the regional Civil Protection authority to all the local authorities and civil protection actors that could be affected by the event (e.g. provinces, prefectures, municipalities and private companies).

Criticality levels correspond to different warning levels within emergency plans that, in turn, imply different strategies to face the impending event. In detail, the correspondence is the following:

- Ordinary criticality → alert
- Moderate criticality → alarm
- Severe criticality → warning

Emergency management strategies are defined within the specific emergency plan and cannot be discussed in this circumstance (see previous section).

The communication sub-system

As above, also the communication sub-system is analysed by referring to legal requirement.

With respect to this, only technical aspects are regulated at regional level, that is the way in which warnings must be transmitted among civil protection actors. For example, the decree quoted above provides that warnings must be faxed and that a confirmation message is required back.

Organisational and social aspects (e.g. community engagement) are instead simply ignored by regulations.

Uncertainty management and characterisation

Forecasting models (within the SIPP) supply deterministic data with respect to both the time and the intensity of the event. As a consequence, currently, uncertainty characterisation is a subjective process where forecasters give their opinion about the confidence they put on predictions, in accordance with their experience as well as the historical performance of the forecasting system.

However, some first analysis have been carried out, in order to properly characterise the uncertainty affecting flood forecasts; first results highlight that significant errors can occur, above all, in medium–small river basins. The reason is manifold:

- On one hand, the use of quantitative precipitation forecasts, coming from global models, for medium–small spatial scales.
- Then, the over-simplification of physical processes that occurs at these scales.
- Finally, the uncertainty about initial and boundary conditions that is particularly significant at these scales.

Current research efforts aim thus at improving both numerical models and precipitation forecasts. Regarding, specifically, the last point the use of ensemble precipitation forecasts and wheatear radar is under investigation.

From the operational perspective, it is important instead to assess the role of forecasting errors in defining warning outcomes (i.e. the number of false warnings and missed events). With respect to this, past events analysis shows that warning outcomes mainly depend on the way in which data are interpreted rather than data themselves (i.e. prediction errors). So, organisational and social factors prevail on technical aspects.

1.A.2 The FEWS for the town of Crotone

(Source: Mendicino et al., 1998, Regione Calabria, 2007, Comune di Crotone, 2007, Mendicino)

Introductive remarks: the regional context

Crotone is one of the bigger cities in the Calabria region where warning activities are regulated by a regional decree of 2007[23], adopting national guidelines (see Section 1.4.1). According to it, the region has been divided into six warning zones[24], defined as homogeneous areas in terms of both expected hazard features and effects.

The regional warning system is based on hazard thresholds that can differ from zone to zone. In detail, only precipitations thresholds are implemented; these are linked to specific risk scenarios[25] for which thresholds are defined in terms of both observed and forecasted precipitations.

Specifically, for each scenario, several "kinds" of critical precipitations are considered, in terms of return period–duration pair (e.g. for localised floods in big river basins, critical rainfalls equal precipitations within 6 and 24 hours, relating to a return period of 10 years). For every "critical precipitation", critical values are then identified which correspond to warning thresholds. (e.g. several thresholds are defined for 10 years-1 hour precipitation, corresponding to an equal number of critical levels). Specifically, four critical levels are possible:

1. No criticality
2. Ordinary criticality
3. Moderate criticality
4. Severe criticality.

Threshold values derive:

- from national guidelines[26], if related to forecasted precipitations;
- from the Regional Operational Centre, if related to observed precipitations.

In order to set threshold values, the Regional Operational Centre can take advantage of a set of hydraulic/hydrogeological models, describing the specific reality under investigation (e.g. the model for the Esaro river, described below, is one of the). This highlights the **local** nature of the regional warning system (see Section 1.4.3).

With respect, instead, to the monitoring, the Regional Operational Centre has the use of both regional and local networks, supplying hydraulic, hydrological, climatic and geotechnical data. Regional networks are managed directly by the centre; local networks can be public or private, but they are forced by the law to continuously transmit all their data to the Regional Operational Centre.

To sum up, then, at the local level, the Regional Operation Centre is the authority in charge of monitoring and forecasting. Accordingly, it daily issues weather reports specifying, for each warning zone, if critical levels are or are expected to be exceeded. Indeed, as specified before, different thresholds are defined for observed and forecasted precipitation.

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[23] Delibera della Giunta Regionale n. 172 del 29 Marzo 2007.

[24] Zone di Allerta.

[25] The warning system is for both meteorological and hydrogeological risks. Then scenarios must define the hazard and its likely effects.

[26] Vlaues from the National Civil Protection Department.

On the basis of this information, the regional Civil Protection authority decides about warning. In detail, two different warnings are issued with respect to:

- forecasted precipitations; in this case, warnings refer to warning zones;
- observed precipitations; in this case, warnings refer to municipalities.

In detail, warnings specify both the critical level and the corresponding scenario.

Finally, once get the warning, local authorities implement emergency plans; different actions correspond to different warning levels which, in turn, are related to specific critical levels. In detail, the correspondence is the following:

- Ordinary criticality → alert
- Moderate criticality → alarm
- Severe criticality → warning

It must be remarked, as stressed by the same regional decree, that scenarios supplied with warnings are generic, describing, in general terms, the main features of the hazard and of its effects. Local authorities are in charge of their contextualisation. Indeed, according to regional regulations, vulnerable areas, exposed elements and expected damages, for each scenario, must be properly assessed at local scale and must be included in emergency plans. This further corroborates the **local** nature of the regional warning system.

The monitoring and forecasting sub-system

With respect, in particular, to the town of Crotone, here, the flood risk is due to the presence of the Esaro river for which the Regional Operation Centre has the use of a specific monitoring and forecasting system, designed by the local university[27].

The system is made up of three components: a monitoring network, an acquisition module and a simulation model that, in turn, includes:

- a calibration model,
- a precipitation forecasting model,
- a rainfall–runoff model.

The monitoring network is made up of 5 rain gauges and 2 water level gauges which transmit, every 10 minutes, by radio, observed data to a dedicated database. Monitored data are then automatically acquired by the acquisition module which also carries out a first assessment of the goodness of data, aiming at identifying if data refer to abnormal running of the monitoring network. Moreover, the module verifies if observed data are above critical thresholds. In this case, a visual and an acoustic message are supplied.

The calibration module has two functions: the identification of simulation model input data and the estimate of the simulation model parameters.

The former consists of identifying which gauges can be considered as reliable for the simulation as well as the time period for which monitored data must be taken into account. This operation is manually carried out by forecasters. The latter, instead, is automatic and is based on the minimisation of the errors between observed and forecasted river discharges.

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[27] Università della Calabria.

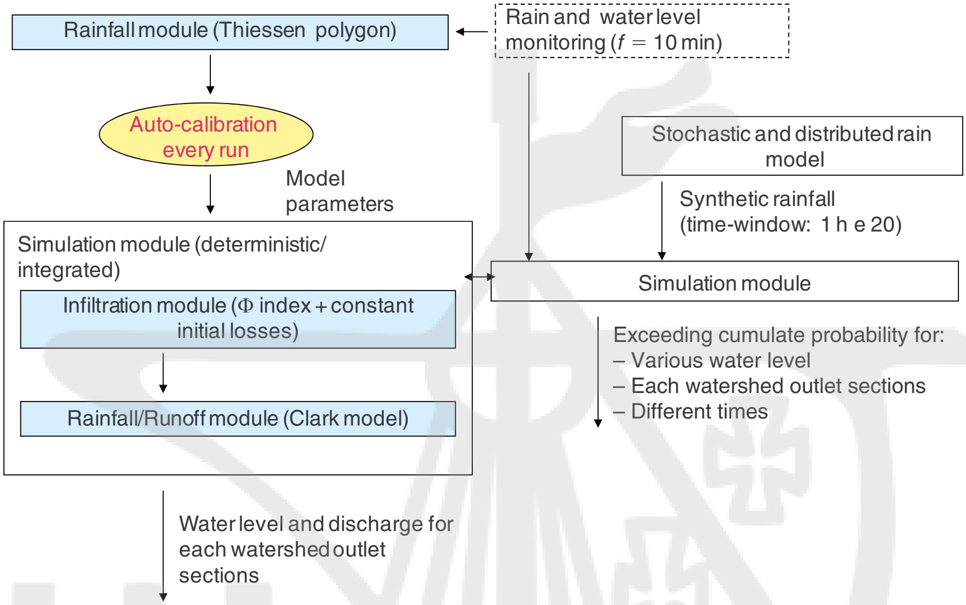

Fig. 1.A.3
The monitoring and forecasting system for the Esaro river basin

The precipitation forecasting model supplies rainfall predictions for the time period between the query and the following 1 hour and 20 minutes. Forecasts are based on a stochastic model, supplying probabilistic predictions.

Finally the rainfall–runoff model consists of a linear, integrated model that supplies probabilistic forecasts in terms of probabilities of exceedance of different water levels, referring to different river cross sections and to different time.

Figure 1.A.3 synthesises the architecture of the whole system.

The risk information sub-system

According to the regional decree, the municipality of Crotone carried a proper assessment to identify likely flooded areas as well as exposed elements. This allowed, on one hand, to estimate available resources to face the emergency (in terms of people, means, etc.); on the other hand, to identify those vulnerable elements (such as schools, hospitals, critical facilities, bridges and vulnerable people) that required priority before and during the crisis.

The preparedness sub-system

According to the regional guidelines, the emergency plan for the town of Crotone provides for three warning levels:

1. Alert, corresponding to a ordinary criticality. In this case, the plan provides a continuous surveillance (in time) of simulation model output, i.e. only instruments are observed.
2. Alarm, consequent to moderate criticality. According to the plan, also field surveillance is activated at this point.

3. Warning, due to severe criticality, when mitigation actions to prevent damage to people and goods are implemented.

As described above, critical thresholds (in terms of observed precipitations) have been set locally by means of the simulation model available for the river basin.

It is important to remark that threshold value for ordinary criticality has been willingly underestimated given that the alert phase does not foresee people involvement. On the other hand, setting threshold value for the alarm and warning phase was more critical because discomforts for the population are possible. For this reason, monitored data must be confirmed by field surveys before issuing a warning.

Even more important is to stress how the presence of a local model allowed setting specific threshold values for the case under investigation. Specifically:

- different thresholds have been set for different gauges;
- a further threshold has been included, in addition to those foreseen by the law, relating to the probability of exceedance of water levels, at river cross sections.

The communication sub-system

A lot of attention has been paid to population. With respect to education, people leaving in risky areas have been informed by informative leaflets describing warning levels and corresponding actions within the emergency plan. On the other hand, with respect to the emergency phase, different ways of communication are planned: door knocking, mobile loudspeakers, sirens and mass media.

Of course, this sort of redundancy positively affects FEWS performance. On the contrary, little attention has been given to communication among civil protection actors.

Uncertainty management and characterisation

Even if the national law (GU, 2004) provides that critical thresholds should include also an assessment of related uncertainty, the regional decree marginally tackles with the point, by simply specifying that foreseen risk scenarios are likely to not happen and, however, cannot always been forecasted. Thus, emergency plans must be carefully take this aspect into account. The emergency plan of Crotone allows for the problem by means of a surveillance service that must be activated during the alarm phase, to timely detect potentially hazardous conditions and/or unexpected event developments.

On the other hand, it must be stressed that the implementation of hydrological models at local scale decreases the uncertainty of the hazard assessment because models are calibrated according to the particular context under investigation. On the contrary, the real benefit of probabilistic forecasts (in terms of reducing the likelihood of false warnings and missed events) must still be assessed.

As stresses by the same system designers, from the operational perspective, model effectiveness will be evaluated after an operational trial period, according to which warning thresholds (in terms of probability of exceedance) will be optimised too.

1.A.3 The FEWS for the Arno river basin

(Source: Regione Toscana, 2000, 2006; Autorità di Bacino del fiume Arno, 2006; Comune di Pisa, 2006)

Introductive remarks: the regional context

The Arno river crosses through the Toscana region. Here, warning systems are currently regulated by a regional decree[28]. However, a further experimental system is now in place for the Arno river basin, after an agreement between the national Civil Protection authority[29] and the Arno river basin authority[30]. In the following, both systems are then analysed.

The monitoring and forecasting sub-system: state of the art

According to the regional decree, the Regional Operational Centre[31] is in charge of monitoring and forecasting.

With respect to monitoring, the centre has the use of three networks (supplying hydraulic, hydrological, climatic, meteorological and geotechnical data) and a weather radar.

Prediction activity, instead, simply consists of weather forecasting. With respect to this, data from global models are acquired and specific forecasts are computed for the Toscana region.

The monitoring and forecasting sub-system: experimental system

The experimental system supplies not only hazard forecasts but also predictions of likely flooded areas and affected goods (in terms of both lists and maps).

Input data consist of quantitative precipitation forecasts and monitored data related to rainfall, wind, temperature, humidity, solar radiation and river water levels. Specifically, predictions derive from four different meteorological models (i.e. Lokal Model DWD, Lami, WRF coarse and WRF fine), while monitored data come from about 900 gauges of the regional network. Starting from them, the simulation model MOBIDIC implements the rainfall–runoff process.

MOBIDIC is a distributed, conceptual model where the surface discretisation is done by means of a rectangular grid whilst the vertical discretisation includes five layers corresponding, respectively, to vegetation, surface water storage, upper soil (where capillarity prevails), deep soil (where gravitation prevails), aquifer. Within each cell coupled energy and mass balance are solved.

The hydrographic network is described instead as a net of prismatic channels whilst specific laws are included to describe the behaviour of big storage systems (natural or artificial). Groundwater flow is finally numerically modelled by means of the discretisation of the Darcy law. A further specific grid is defined for the scope. Of course, the three models are coupled.

MOBIDIC outputs, in terms of runoff discharges along the hydrographic network, represent input data for the hydraulic model (that is called QRF).

Flood wave propagation and inundation are separately modelled. Specifically, flood wave is modelled by the resolution of the De Saint Venant equations, using the Muskingum model with

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[28] D.G.R. 611 del 04/09/2006.

[29] Dipartimento della Protezione Civile.

[30] Autorità di Bacino del fiume Arno.

[31] It includes the regional hydrological service (Servizio Idrologico Regionale), the A.R.S.I.A (Agenzia Regionale per lo Sviluppo e l'Innovazione nel Settore Agricolo-forestale) and the LaMMa (Laboratorio di Monitoraggio e Modellistica Ambientale per lo sviluppo sostenibile).

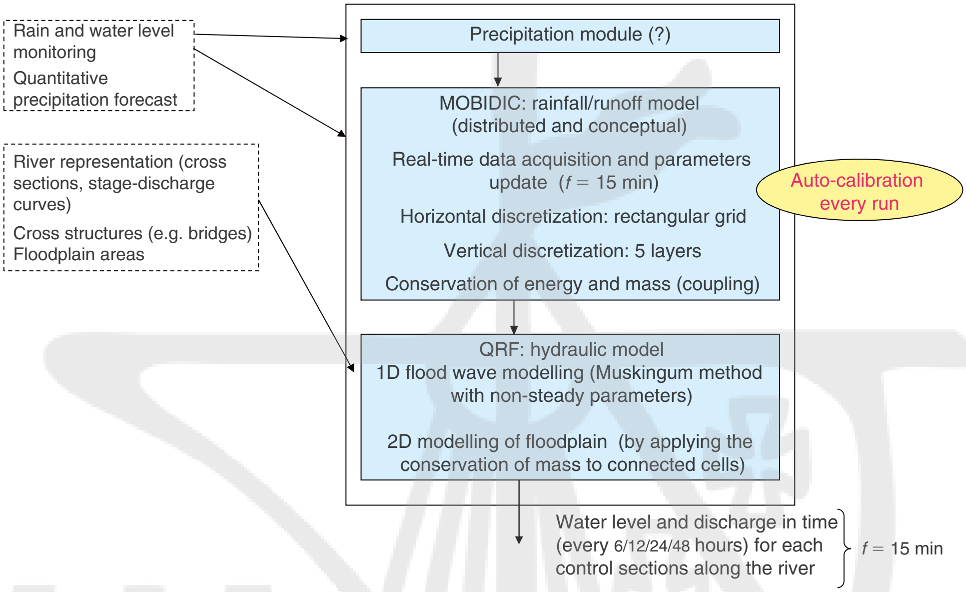

Fig. 1.A.4
The experimental monitoring and forecasting system for the Arno river basin

variable parameters. For the flooding model, instead, the flooded area is divided into storage cells in which water elevation is computed by imposing mass conservation. Potentially flooded areas have been identified by means of available maps, photos and river cross sections.

Eventually, system outputs (which are supplied every 15 minutes) are represented by:

- river discharge and water level hydrographs at each available river cross section;
- flood discharge hydrographs for each likely flooded area;
- water level and water volume hydrographs for each likely flooded area.

Figure 1.A.4 synthesises the architecture of the whole system.

The risk information sub-system

According to the regional guidelines[32], local authorities are in charge of risk analysis which must be included in local emergency plans.

Specifically, guidelines highlight the importance of risk scenarios to support emergency planning, stressing the need of properly evaluating both likely hazard scenarios (in terms of maps of flooded areas) and corresponding risk scenarios (in terms of maps of exposure and vulnerability showing, for example, population density, critical infrastructures and facilities).

At the operational level, however, only hazard scenarios are usually implemented, as for the municipality of Pisa.

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[32] Linee guida per la compilazione del piano comunale di protezione civile" (DGR 26 del 11/01/2000).

The preparedness sub-system

As in previous cases, also in the Toscana region, warning activities are regulated by a regional decree[33], adopting national guidelines (see Section 1.4.1).

According to it, the region has been divided into 25 homogeneous warning zones[34]. For each zone and for each hazard[35], trigger phenomena have been then identified and proper threshold values have been set, corresponding to three different critical levels (ordinary, moderate and severe). With respect to flood risk, critical thresholds vary along with the return period and refer to cumulate observed and forecasted rainfall. Moreover, critical levels depend on further qualitative considerations (by forecasters) about the real conditions of the basin and the likely effects of an event.

When threshold values are exceeded, a warning report[36] is issued and warning levels (and related strategies) are adopted, according to emergency plans. Specifically, the following links exist:

- no warning, if warning report is not issued;
- surveillance, in case of ordinary criticality;
- warning level 1, in case of moderate criticality;
- warning level 2, in case of severe criticality.

Warning report is issued by the Regional Operational Centre whilst it is spread by the Region to all local authorities. These, in turn, adopt warning levels and corresponding mitigation actions.

Mitigation actions are set at the local level. In the case of Pisa, for example, the emergency management system is organised according to “supporting functions[37]” (e.g. mobility, survey, planning, health and media) that must be activated according to the warning level in progress. Likewise, activities performed by the various functions vary with warning level too.

The communication sub-system

Communication aspects are well managed within the system. The regional decree specifically defines transmission modes, data format, roles and responsibilities, guaranteeing a certain redundancy too.

Population is also properly taken into account. The same regional decree defines as strategic the role of people education for FEWSs effectiveness and supports the implementation of educational programmes.

At the operational level, regional guidelines seem well adopted. As an example, the emergency plan for the town of Pisa can be quoted.

Uncertainty management and characterisation

Uncertainty is almost ignored within the current system but for two aspects:

1. On one hand, from warning perspective, critical level assessment makes up for uncertainty by qualitative considerations about how event is unfolding.

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[33] D.G.R. 611 del 04/09/2006.

[34] Zone di Allerta.

[35] The system is for both meteorological and hydrogeological risks.

[36] Avviso di Criticità.

[37] Funzioni di supporto.

2. On the other hand, at the emergency level, uncertainty is faced by figuring out different time scenarios for the same event (e.g. night or day, summer or winter and weekend or working day).

On the contrary, where systems are based on forecasted precipitations only, as in the present case, uncertainty is high and should be properly managed. From this perspective, the implementation of the experimental system could improve the current situation, by reducing uncertainty, for the following two main reasons:

1. First, the new model is at local scale (i.e. the river basin scale) whilst precipitation forecasts are computed, at least, at regional scale.
2. Second, currently, only weather forecasts are considered whilst by applying the experimental tool critical levels, and so warning levels, can be defined according to both hydraulic quantities (the model implements the rainfall–runoff process) and expected damages (even if no information has been found about the risk assessment module of the system, i.e. it is not clear how risk assessment is carried out).

It must be stressed, however, that an increase in uncertainty is also possible. Indeed, as model complexity increases, uncertainty can go up as well. From this perspective, the two models should be properly analysed and compared after an operational trial period.

1.A.4 The FEWS for the Adige river basin

(Source: Provincia autonoma di Trento, 2005; Meteotrentino, interviews with experts)

The monitoring and forecasting sub-system: state of the art

The Adige river crosses through the Trentino Alto Adige region which is a “self-governing” authority within the Italian system. Accordingly, it does not adopt national guidelines.

Here, both the Civil Protection authority[38] and the weather service (that is called Meteotrentino) are in charge of monitoring; the latter being in charge of forecasting as well.

The monitoring network is particularly widespread and allows getting a lot of data, consisting of:

- meteorological and hydraulic data (from 250 gauges of the regional network);
- satellite images (from the Meteosat satellite); images are acquired every 30 minutes;
- weather radar data (from the regional weather radar placed in the closer Alta Val di Non);
- data from radio sounding (from the station placed in Milano Linate, Udine Campoformido and S. Pietro Capofiume).

With respect, instead, to forecasting, the prediction model currently in place is called “Modello Adige” and was originally developed by the local university[39].

Model input data consist of both observed and forecasted precipitation as well as other observed meteorological data like temperature and humidity.

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[38] By the “ufficio previsioni e organizzaioni”.

[39] Università di Trento.

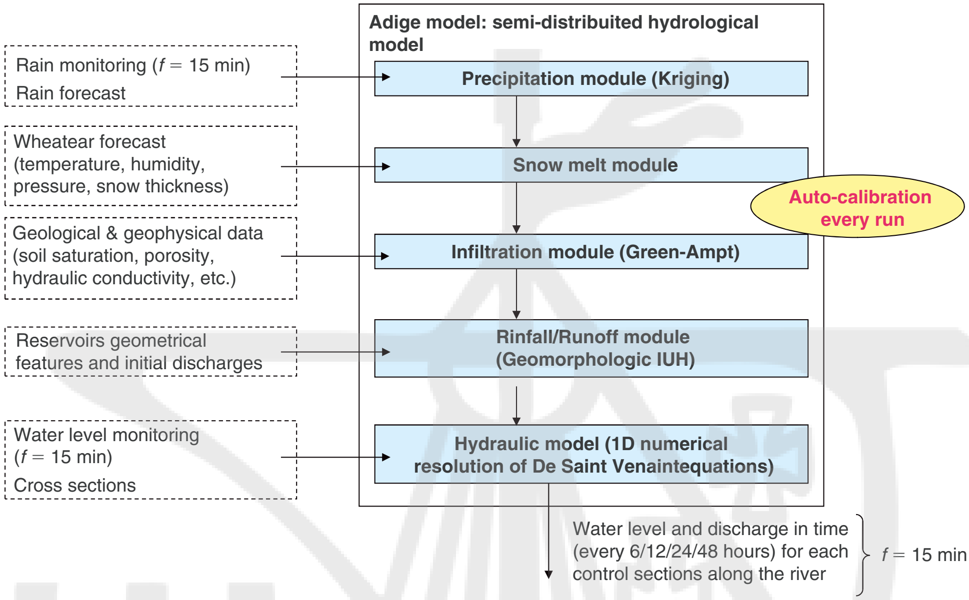

Fig. 1.A.5
The monitoring and forecasting system for the Adige river basin

The hydraulic–hydrogeological model itself is local (i.e. at the river basin scale), deterministic and semi-distributed and is made up of different sub-models:

- a precipitation module, for the spatial conversion of precipitation;
- a module for the estimate of snow melt;
- a conceptual rainfall–runoff model;
- a monodimensional numerical model for the wave propagation.

Model outputs consist of 48-hour forecasts of the maximum river discharge, at different hydrograph network locations. Moreover, water level forecasts are supplied for the main river (i.e. the Adige river). Figure 1.A.5 synthesises the architecture of the whole system.

The risk information sub-system

According to the regional law, the main civil protection actors in Trentino are provinces which, therefore, are in charge of both emergency management and emergency planning. Unlikely, no contingency plans have been found in literature, to evaluate if and how risk assessment is actually carried out.

A general remark comes, however, from the analysis of the provincial decree on warning[40] which provides that warning would be grounded not only on hazard but also on the assessment of possible effects on population, lifelines and, more in general, the whole territory. In other words, damage scenario should be estimated. However, the required assessment is simply qualitative.

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[40] Delibera della Giunta Provinciale n. 972 del 13/05/2005.

The preparedness sub-system

As stated before, warning activities are regulated by a provincial decree which provides for three different temporal phases during the event:

1. A forecasting phase
2. An assessment phase
3. A warning phase.

The forecasting phase is implemented continuously in time by Meteotrentino, regardless of the possibility of an impending hazardous event.

The shift to the following phase (i.e. assessment) happens, instead, only when critical thresholds are exceeded and a weather report[41] is consequently issued. Critical thresholds are in terms of both quantitative and probability values of event triggers, which vary along with the hazard[42] (for flood, for example, thresholds refer to precipitation values).

However, a weather report can be issued by forecasters also when threshold values are not exceeded; specifically:

- after a request by local authorities;
- under especially critical hazard, exposure and/or vulnerability conditions (i.e. intense rainfall in previous days and touristic days).

The latter is a very interesting feature of the system which tries, this way, to link warning not only to hazard but to a more comprehensive assessment of risk.

As discussed before, the assessment phase aims at evaluating all the possible effects of the impending event on population, lifelines and, more in general, the whole territory. However, the assessment is simply qualitative and is carried out by a group of both experts and emergency actors.

The last phase (i.e. warning) occurs if the assessment phase leads to the issue of a “criticality”. In detail, three critical levels are possible which correspond to three different warning levels and strategies within emergency plans. The Civil Protection authority is in charge of warning, by means of a proper warning report[43]. However, it is important to stress that a warning report can be issued also notwithstanding the procedure.

Unfortunately, it is not clear how and when outputs from the “Modello Adige” are implemented within the procedure. This is because the decree is prior to the development of the model for which no “official” documentation is available too.

The communication sub-system

Communications aspects are quite properly considered along the warning chain. Indeed, also in this case, the provincial decree specifically defines transmission modes, data format, roles and responsibilities, guaranteeing a certain redundancy along all the three above phases. On the other hand, aspects related to communication with population are ignored, highlighting a deficiency of the system.

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[41] Avviso Meteo.

[42] The system is for both meteorological and hydrogeological risks.

[43] Avviso di Allerta.

Uncertainty management and characterisation

As described before the “Modello Adige” is a deterministic model that does not supply any kinds of information about predictive uncertainty. However, an offline calibration proved that forecasting errors are mainly due to errors in forecasted precipitations (that represent model inputs) rather than to the model itself. Anyway, without this information uncertainty cannot be properly managed within the warning process.

On the other hand, the provincial decree implicitly allows for uncertainty, for example, by assuming probabilistic value as thresholds and by allowing warning notwithstanding the procedure (in case the event unfolds in an unexpected way). Nevertheless, an optimal characterisation and management of uncertainty is lacking.

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Chapter 2

The role of forecasts

As disclosed in Chapter 1, much past FEWSs assessments have focused on the **goodness of hazard predictions** as unique indicator for system performance (Handmer, 2000). This chapter aims at implementing such an approach. The objective is twofold:

1. First, to identify and discuss which is the information supplied by this kind of analysis as well as its limits;
2. Second, to stress the need to include the whole warning chain (damages, in particular) in FEWSs assessments.

Forecasts verification[1] is a quite investigated field, about which literature is rich. Hence, it is impossible to condense all this knowledge in a single chapter; on the other hand, such a summary would not provide any improvement with respect to the current state of the art.

Accordingly, unlike Chapters 3 and 4, this chapter does not start with a review of all available concepts and tools on the topic but simply supplies a brief discussion of the theory that is implemented in the following case study.

2.1 Theory: from forecasts accuracy to forecasts quality and value

Forecasts verification deals with the evaluation of the goodness of predictions. However, the judgement of what is a "good" forecast can be seen as still tricky.

Murphy (1993) is among the first who faced the point and even if his work comes from meteorology, his concepts can be applied to flood forecasting as well. According to him, the goodness of a forecast must be evaluated against two characteristics:

1. The correspondence between the forecast and observations (i.e. its **quality**)
2. The incremental benefits of the forecast to users (i.e. its **value**).

As a result, forecast verification should not be seen as a universal process, but it should be tailored to the particular context in which forecasts are implemented or, in other words, to the specific standpoint of a stakeholder (Murphy and Winkler, 1987). Indeed, forecasts hold no intrinsic value, but they acquire it through their ability to influence the decisions made by their users. Thus, generally, forecasts value varies from problem to problem and from user to user within a specific problem (Murphy, 1993).

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[1] In the broad sense of evaluating the goodness of a forecast.

On the other hand, forecasts quality is independent from the operational context. However, its assessment is complicated by the evidence that quality is not a simple characteristic, but it is inherently multifaceted in nature (Murphy, 1993). In fact, different aspects (or attributes) can be identified to describe forecast quality (see, for example, Murphy, 1993; Thornes and Stephenson, 2001; WWRP/WGNE, 2009), being:

- *Bias*: The correspondence between the mean forecast and the mean of observations.
- *Association*: The strength of the linear relationship between the forecast and observations (e.g. the correlation coefficient measures this linear relationship).
- *Accuracy*: The level of agreement between the forecast and observations (the difference between the forecast and the observation is the error: the lower the errors, the greater the accuracy).
- *Skill*: The accuracy of forecast of interest relative to the accuracy of a reference forecast (usually "climatology", i.e. the historical observations data set is used as reference forecast).
- *Reliability*: The average agreement between forecast values and observed values. If all forecasts are considered together, then the *overall reliability* is the same as the *bias*. If forecasts are stratified into different ranges or categories, then reliability is the same as the *conditional bias*, i.e. it has a different value for each category.
- *Resolution*: The ability of the forecast to sort or resolve the set of events into subsets with different frequency distributions; this means that the distribution of outcomes when "A" is forecast is different from the distribution of outcomes when "B" is forecast. Even if forecasts are wrong, the forecast system has resolution if it can successfully separate one type of outcome from another.
- *Sharpness*: The tendency of the forecast to predict extreme value. It is a property of the forecast only, and like resolution, a forecast can have this attribute even if it is wrong (in this case it would have poor reliability).
- *Discrimination*: The ability of the forecast to discriminate among observations, that is, to have a higher prediction frequency for an outcome whenever that outcome occurs.
- *Uncertainty*: The variability of the observations. Although this aspect relates to the forecasting situation rather than to the forecasts, the level of uncertainty can have a substantial impact on other aspects of quality (i.e. the greater the uncertainty, the more tricky the forecast will tend to be).

It is easy to recognise that available FEWSs assessment tools, having mainly focused on forecast errors (and, more in general, on the agreement between forecasts and observations), simply allow to assess flood forecast accuracy but not its quality or its value.

On the contrary, Murphy (1993) proved that assessing quality in all its relevant aspects is fundamental, above all, to estimate forecast value. For example, it is clear that an accurate forecast has no value if its skill is low, that is it does not add new information to historical knowledge (i.e. climatology).

In line with this, the procedure implemented in this chapter aims (i) first at evaluating all quality aspects, (ii) then, at carrying out a value assessment, widening, this way, current flood forecast verification tools.

2.1.1 Flood forecasts quality assessment: a proposed methodology

As stressed before, in order to properly characterise forecast uncertainty (meaning the correspondence between forecasts and observations), simple accuracy measures, as used in

Quality attribute	Relevant distributions
Bias	p(f), p(o)
Association	p(f,o)
Accuracy	p(f,o)
Skill	p(f,o)
Reliability	p(o|f), p(f)
Resolution	p(o|f), p(f)
Sharpness	p(f)
Discrimination	p(f|o), p(o)
Uncertainty	p(o)

Tab. 2.1
Links between quality and distributions of forcasts and observations (from Murphy, 1993)

common practice, are not sufficient, but a comprehensive quality assessment is required. Here a methodology is proposed which comes from meteorology (Murphy, 1993).

The basis for the approach is the joint distribution of forecasts and observations as source of all the relevant information for quality assessment. For this reason it is referred to as "**distributions approach**".

More specifically, denoting forecasts by f and observations by o, the approach is based on the notion that the joint distribution of forecasts and observations, $p(f,o)$, contains all of the non-time dependent information relevant to evaluating forecast quality.

This information becomes more accessible when $p(f,o)$ is factored into conditional and marginal distributions, including:

- the conditional distributions of the observations given the forecasts, $p(o|f)$;
- the conditional distributions of the forecasts given the observations, $p(f|o)$;
- the marginal distribution of the forecasts, $p(f)$;
- the marginal distribution of the observations, $p(o)$.

The relation between quality attributes and distributions is summarised in Table 2.1. Specifically:

- By examining the distributions $p(o|f)$ and $p(f)$, reliability and resolution can be assessed. Reliability relates to the correspondence between the mean of the observations associated with a particular forecast ($\overline{o}_f$) and that forecast (f), thus, the evaluation of reliability can provide answer to questions like: does the mean observed discharge on those occasions on which forecast discharge is 200 m^3/s correspond to this forecast? Clearly, small differences between $\overline{o}_f$ and f are preferred to large differences. Resolution relates instead to the difference between this same conditional mean observation ($\overline{o}_f$) and the overall unconditional mean observation ($\overline{o}$). A relevant question here could be as follows: to what extend do the conditional means of the observations corresponding to discharge forecasts of 180 and 200 m^3/s differ from each other and from the overall mean observation? In this case small differences indicate that, on average, different forecasts are followed by different observations.
- The distributions $p(f|o)$ provide insight into discrimination, which relates to the ability of the forecast to discriminate among the observations. For a forecast f, if $p(f|o)$ is very similar for different observations o, the forecast is not very discriminatory. In the extreme, when $p(f|o)$ is the same for all the observations, the forecast is not at all discriminatory

and provides no useful information about observations. When the probabilities are very different for different observations, the forecast is much more discriminatory and hence very informative about observations. The forecast f is perfectly discriminatory if $p(f|o)$ equals zero for all values of o except one.
- The marginal distribution $p(o)$ relates to the uncertainty associated with the forecasting situation. A situation in which the events are approximately equally likely is indicative of relatively high uncertainty, whereas a situation in which one or two events predominate is indicative of relatively low uncertainty.
- Finally, the marginal distribution $p(f)$ provides information about sharpness. If all the forecasted values are equally likely sharpness is low.

The approach, which is proposed in this book, starts then with the analysis of such distributions to focus next on the implementation of various tools to describe forecasts attributes. Specifically, defining **verification methods** as "any mathematical or statistical measure or pictoral or graphical display that provides insight into or summarizes one, or more, of the basic characteristics of a forecast" (Murphy et al., 1989), the approach implements three classes of verification methods:

1. The basic distributions themselves
2. Summary measures of these distributions
3. Traditional performance measures.

2.2 Implementing the methodology: the case of Sondrio

Having briefly supplied all the theoretical knowledge which is required to analyse the case study, the proposed methodology is here applied in practice with the aim of:

- describing, in depth, verification methods and their implementation;
- evaluating the approach feasibility, understanding real problems in its execution;
- discussing its usefulness and shortcomings, in terms of results;
- introducing the need of value assessment and damage estimation to proper evaluate FEWSs performance.

The FEWS under investigation is the one currently implemented in the town of Sondrio, in the Italian Alpine region, to reduce the flood risk induced by the river Mallero. The river is about 24 km long and its basin spreads on an area of about 320 km^2. Because of the reduced extension and the quite high slopes, flash floods are common in the basin, above all, after intense rainfalls. Several past events can be reminded (Ismes-CAE, 1988); only in the last century, four floods interested the city in 1911, 1927, 1951 and 1987 (see Figure 2.1).

As depicted in Figure 2.2, the river Mallero crosses and splits the city centre into two parts. Links are guaranteed by three car bridges (named, from north to south, Matteotti, Eiffel and Marconi), one railway bridge and one pathway bridge. It goes without saying that, in case of flood, all the main activities and properties within the city could be affected.

2.2.1 The flood early warning system

The flood forecasting system for the town of Sondrio is made up of a rainfall–runoff model whose inputs are observed rainfall and river discharge data. Starting from them, model parameters are set and precipitation scenarios are calculated. These, in turn, represent input data to estimate future river discharge.

Fig. 2.1
Sondrio during 1987 flood

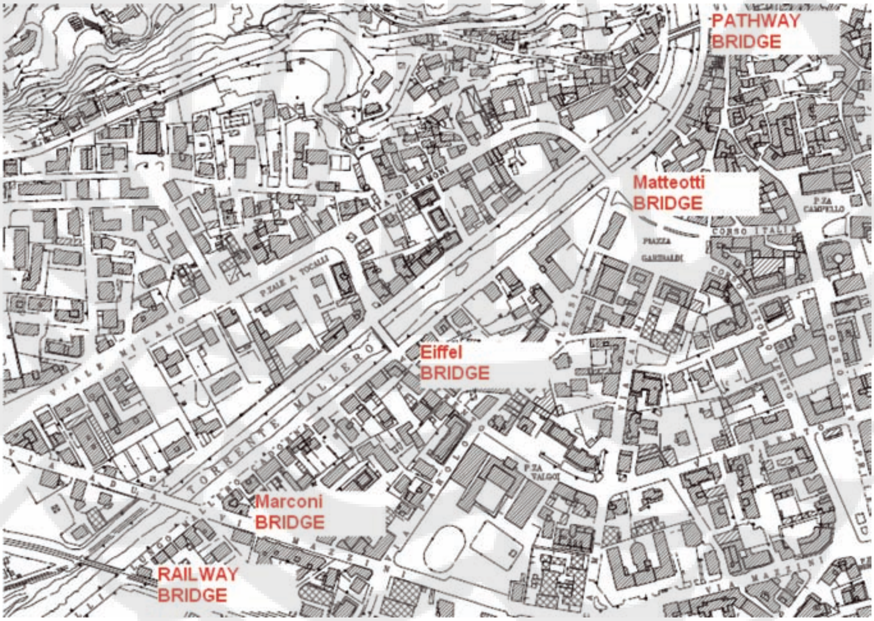

Fig. 2.2
Sondrio city centre: main bridges location

Warning level	Forecasted discharge (m^3/s)
Level 1	Q within 3 hours >400
Level 2	Q within 3 hours >500

Tab. 2.2
Sondrio FEWS thresholds

In particular, three values of future river discharge (within 3 hours) are supplied by the model. They derive from three different hypotheses about the synthetic design ietograph and are identified as follows:

1. *PREVIS 1*: River discharge forecast related to the restarting of the precipitation; it assumes a future precipitation that corresponds to the observation with the maximum return period.
2. *PREVIS 2*: River discharge forecast related to the continuation of the precipitation; it hypothesises a future precipitation that corresponds to the observation with the maximum intensity.
3. *PREVIS 3*: River discharge forecast related to the interruption of the precipitation.

The warning system is based instead on flood hazard thresholds. Different warning levels, which correspond to different actions within the contingency plan for the city, are then related to each threshold. Table 2.2 depicts the situation.

From the analysis of the various reports supplied by the Province of Sondrio, it is possible to state that thresholds refer to flood events without sediments transport. Indeed, in this case, the "flood discharge" (i.e. defined as the minimum river discharge above which river floods) was estimated to be about 700 m^3/s which seems to be coherent with thresholds value.

A flood discharge of 700 m^3/s corresponds to a return period of more than 1000 years (Ismes-CAE, 1988) which would suggest that flood hazard is low in Sondrio. Nevertheless, past events pointed out the opposite: floods occurred even with much lower river discharges. The reason for that is well known, being river bed aggradation due to sediments transport. Indeed, as stressed among others by Franzetti (2005), this phenomenon can be crucial, in the river Mallero during flood events, and can imply a significant rise of the river bed and a consequent reduction in flood discharge (this is just what happened, for example, in 1987). Warning thresholds should then be set taking into account sediments effects.

The current warning system presents a pitfall from this perspective. Hence, an adaptation is required to overcome this limit. On the other hand, sediments transport (and consequent river bed aggradation) is a process characterised by both high uncertainty and modelling difficulty (see, for example, Gomez and Church, 1989; Martin, 2003). For this reason, here, a unique hazard scenario has been considered, according to which warning thresholds have been computed again. Specifically, the river bed aggradation during 1987 event has been assumed. This choice derives from the following considerations:

- The good availability of data and studies regarding the event.
- The evidence that in conditions similar to those of 1987, floods could happen for quite frequent river discharges. Accordingly, some river discharges, which were observed in the past, could be considered as flood discharge in this study (otherwise, without sediments, no floods would have been observed).

The flood discharge in 1987 has been estimated to be about 160 m^3/s (Franzetti, 2005). According to this, keeping constant the threshold/flood discharge ratios of the original system, the adaptation brought to the following results:

$$\text{flood level 1 ratio: } \frac{400\,\mathrm{m^3/s}}{700\,\mathrm{m^3/s}} \cong 0.6 \rightarrow \text{new level 1 threshold: } 160\,\mathrm{m^3/s} \cdot 0.6 \cong 90\,\mathrm{m^3/s}$$

Warning level	Forecasted discharge (m^3/s)
Level 1	Q within 3 hours >90
Level 2	Q within 3 hours >115

Tab. 2.3
Sondrio FEWS adapted thresholds

Warning level	Forecasted discharge (m^3/s)
Level 1	Q within 3 hours >90
Level 2	Q within 3 hours >115
Level 3	Q within 3 hours >160

Tab. 2.4
Sondrio FEWS adapted thresholds: final assumption

$$\text{flood level 2 ratio: } \frac{500\,\mathrm{m^3/s}}{700\,\mathrm{m^3/s}} \cong 0.7 \rightarrow \text{new level 2 threshold: } 160\,\mathrm{m^3/s} \cdot 0.7 \cong 115\,\mathrm{m^3/s}$$

which are summarised in Table 2.3. Clearly, a check has been carried out (by means of numerical simulations) to verify whether flood hydrographs which are consistent with warning thresholds are also characterised by sediment transport (i.e. in terms of volume) that could lead to the river bed aggradation that has been assumed. The test was successful.

At last, in order to better appreciate the flood forecasting system performance, the correspondence between river discharge thresholds and warning levels has been modified as reported in Table 2.4 which portrays the situation finally implemented in this study.

2.2.2 The back analysis

To carry out the flood forecasts verification, a back analysis has been implemented by which both "virtual" flood and no-flood events (according to the reference scenario[2]) have been identified (Table 2.5).

In detail, sample events have been chosen in line with the following criteria:

- Peak river discharge $>90\,\mathrm{m^3/s}$
- Availability of both observed rainfall and river discharge data.

This way, it was possible to limit the analysis to 36 events (related to time period 1987–2008) that actually represent the partial duration series of the significant flow peaks; indeed, numerical simulations highlighted that below the value of $90\,\mathrm{m^3/s}$ the river discharge cannot lead to potentially hazardous events.

However, it must be reminded that, actually, four data are available for each event:

1. Observed river discharge
2. PREVIS 1 forecast
3. PREVIS 2 forecast
4. PREVIS 3 forecast.

At a first glance, data visual examination suggests that forecasts are not able, by themselves, to supply enough information about impending events or, in other words, to be more efficient, the warning system should adopt other indicators as well. For instance, in the extreme example

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[2] Virtual floods mean that actually they did not occur but they would have occured if, during the event, river bed aggradation would have been equal to the one observed in 1987, here assumed as reference scenario.

Tab. 2.5
Back analysis results: observed and forecasted flood peak discharge

Date			Q observed (m^3/s)	Event	Q forecasted (m^3/s)		
Day	Month	Year			PREVIS 1	PREVIS 2	PREVIS 3
17	06	1991	293.05	Flood	146.66	112.79	97.61
30	09	1991	274.41	Flood	241.86	200.67	183.13
14	09	1993	167.82	Flood	233.87	185.76	165.35
13	10	1993	160.41	Flood	85.38	65.03	57.15
14	10	1993	196.89	Flood	131.54	103.18	89.51
08	07	1996	160.41	Flood	191.13	153.47	134.54
22	06	1997	164.10	Flood	209.64	148.87	123.69
28	06	1997	225.76	Flood	212.28	174.74	156.73
29	06	1997	167.82	Flood	164.86	127.61	114.39
07	11	1997	167.82	Flood	243.92	197.18	177.66
20	08	1999	204.97	Flood	231.59	179.70	158.17
20	09	1999	263.01	Flood	331.96	282.56	258.61
04	10	1999	188.94	Flood	88.14	63.77	54.10
25	10	1999	283.67	Flood	125.61	102.04	94.72
25	07	2000	215.26	Flood	254.53	198.98	175.40
13	10	2000	175.38	Flood	196.15	162.64	147.27
24	10	2006	169.70	Flood	124.26	91.60	79.08
06	06	1990	125.54	No flood	106.33	86.87	83.31
26	09	1991	114.22	No flood	61.91	49.97	45.01
12	10	1991	133.91	No flood	113.19	91.85	82.94
23	06	1993	127.19	No flood	101.69	84.35	77.00
11	07	1993	156.76	No flood	331.81	259.75	207.87
10	09	1993	125.54	No flood	173.88	127.35	110.12
02	10	1993	120.63	No flood	162.94	129.12	114.48
09	09	1994	127.19	No flood	145.86	97.06	82.61
14	09	1994	158.58	No flood	192.00	146.70	133.06
26	09	1994	114.22	No flood	111.09	87.70	78.32
12	09	1998	114.22	No flood	146.49	108.84	93.29
27	09	1999	115.81	No flood	142.44	112.51	95.44
16	11	2002	140.77	No flood	284.71	230.52	208.11
29	08	2003	156.76	No flood	379.35	269.73	188.93
09	07	2004	128.86	No flood	190.26	157.98	129.00
18	08	2006	112.64	No flood	128.59	104.84	94.84
15	06	2007	128.86	No flood	87.68	71.39	64.50
04	07	2007	153.14	No flood	145.95	113.12	99.87
18	05	2008	128.86	No flood	196.22	154.54	137.72

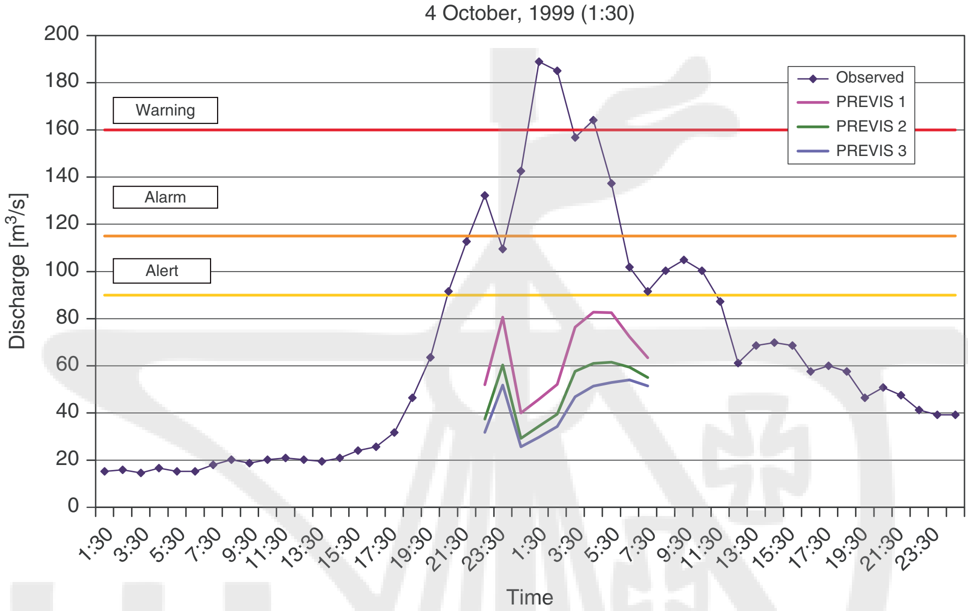

Fig. 2.3
Back analysis results: 4 October, 1999, flood event

of 4 October 1999 (depicted in Figure 2.3), all the forecasts would suggest not to warn (forecasts were all below the warning threshold) but a "virtual" flood occurred. In cases like this, further knowledge regarding the development of the flood (like river depth and sediments transport) could be useful for an effective warning. By considering, for example, data from bridges clearance monitoring, it could have been possible to recognise that a virtual flood was going to happen.

Moreover, it is possible to note how the three forecasts could not imply the same warning level. For example, during the event on 14 September 1994 (reported in Figure 2.4) forecasts at 13.30 implies:

- a warning level 2, according to PREVIS 1;
- a warning level 1, according to PREVIS 2;
- no warning, according to PREVIS 3.

Given that no information is currently available about the probability of occurrence of predicted values (meaning that the three river discharge forecasts are equally likely in probabilistic terms), this could bring to problem in forecasts feasibility: in other words, which forecasts should be trusted? Of course, in such a context, more information about triggering events (i.e. rainfall predictions) could help in choosing one forecast rather than others, but this information is equally not available at the moment. Thus, the three forecasts can be only interpreted as supplying a confidence interval.

According to this, a rational decision maker could choose to take a precautionary approach by always trusting the maximum forecast (which usually corresponds to PREVIS 1). However, this could bring to frequent false warnings. For example, considering again the event on 14 September 1994, at 12.00, PREVIS 1 forecasts a river discharge at 15.00 that is above the

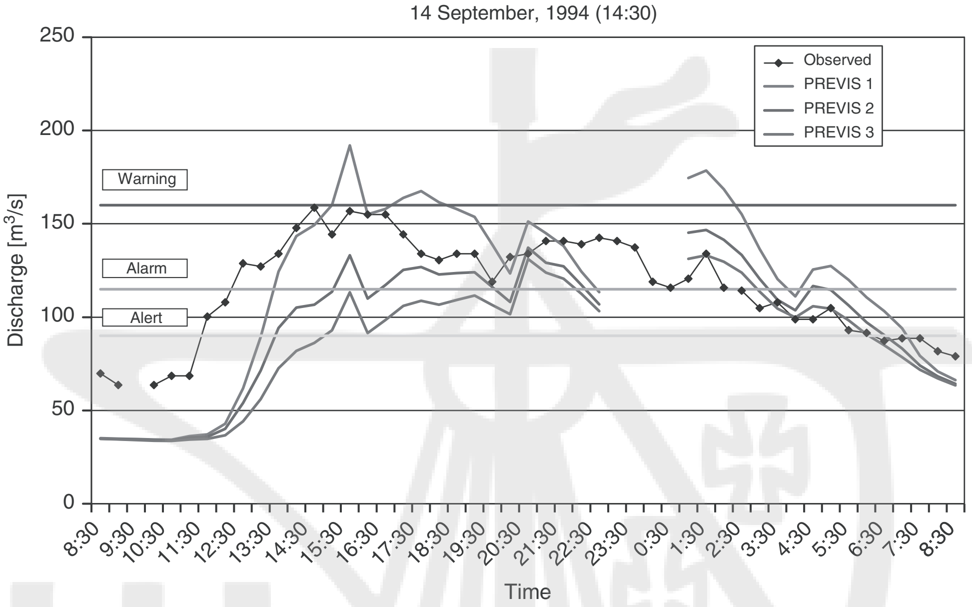

Fig. 2.4
Back analysis results: 14 September, 1994, no flood event

warning threshold and this situation persists until 15.30. However, the observed peak discharge happens at 14.30, without causing a virtual flood. Thus, trusting PREVIS 1 would have meant falling into a false warning.

Otherwise, another decision maker could always trust the middle forecast (usually equalling to PREVIS 2) as representative of the most likely but also this choice could lead to wrong warnings. Indeed, being representative of the medium case, it is likely that PREVIS 2 presents almost an equal tendency to under-forecast and over-forecast.

Anyway, it must be stressed that, with the current level of knowledge, trusting one forecast rather than others is an arbitrary choice. The present case study gives evidence about how quality and value assessments add information which is suitable to support the decision-making process.

2.2.3 The accuracy assessment

The forecasts evaluation for the case study does not start with distributions analysis as suggested in previous section but implements first traditional tools for forecast verification. This is to highlight both the limits of the common practice and the improvement the distributions approach brings into flood forecast verification, in terms of available information for end users.

As already stated in Section 2.1, traditional tools are usually addressed to the analysis of forecast errors, meaning to assess the level of agreement between the forecast and observations. According to Murphy (1993), this is equal to assess forecast accuracy (see Section 2.1). For this reason, from now on, traditional methods are here referred to as accuracy assessment methods.

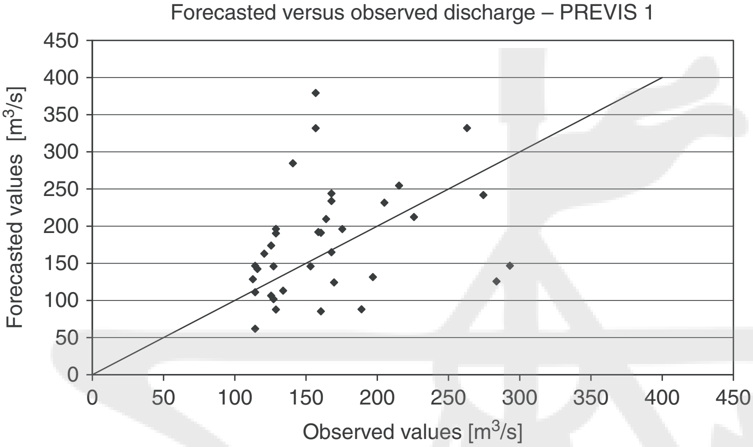

Fig. 2.5
Data plot: PREVIS 1 vs. observations

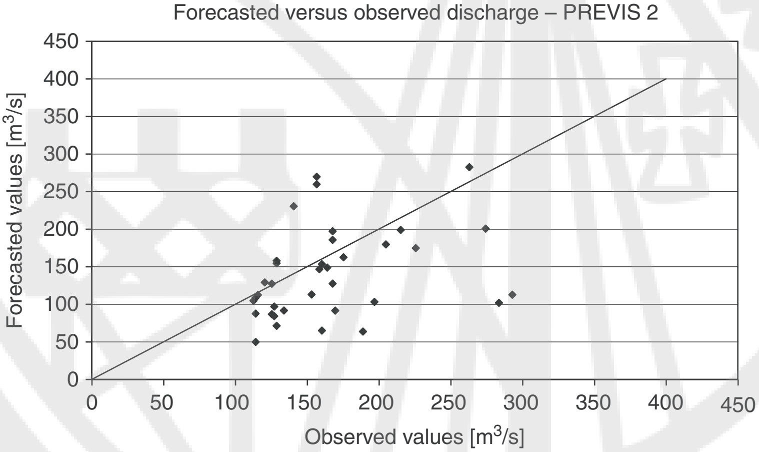

Fig. 2.6
Data plot: PREVIS 2 vs. observations

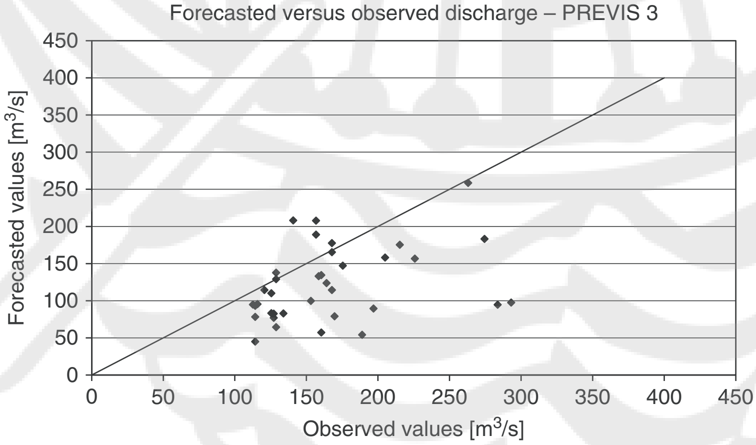

Fig. 2.7
Data plot: PREVIS 3 vs. observations

The accuracy assessment starts here with data and errors scatter plots, for each forecast data set. Then, traditional accuracy measures have been calculated. In detail, Figures 2.5–2.7 plot the forecasted against the observed peak discharge; Figures 2.8–2.10 plot the forecast error against the forecasted peak discharge and, finally, Table 2.6 reports measures values.

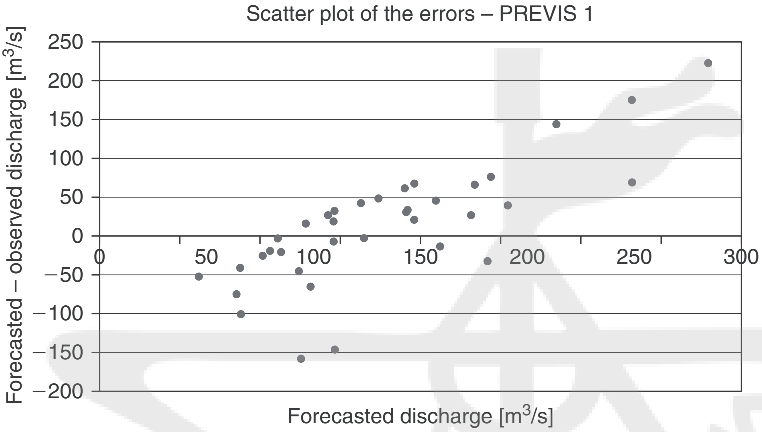

Fig. 2.8
Errors plot:
PREVIS 1

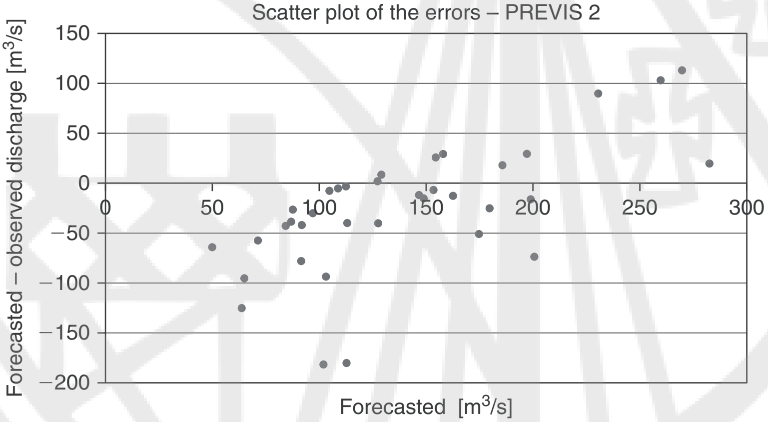

Fig. 2.9
Errors plot:
PREVIS 2

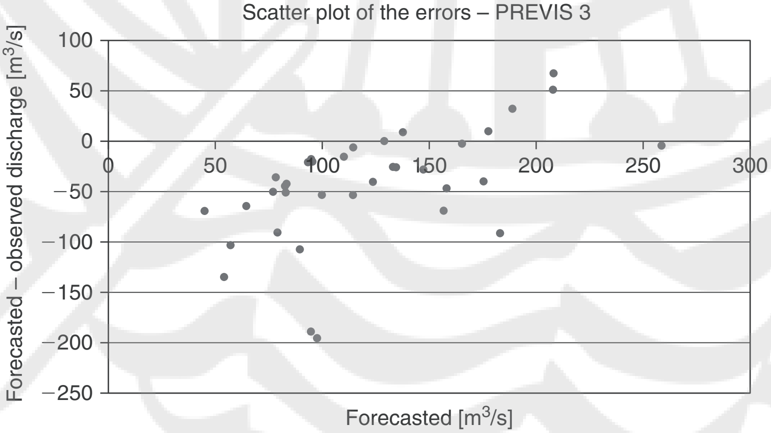

Fig. 2.10
Errors plot:
PREVIS 3

Scatter plots point out, first of all, a poor linear correlation between observations and forecasts, for all the data sets. Moreover, an increasing trend, along with forecasted peak discharge, can be observed in errors. Accordingly, PREVIS 1 tends to under-forecast below the value of 150 m^3/s and to over-forecast above. On the contrary, in spite of the errors trend, both PREVIS 2 and PREVIS 3 tend to under-forecast, for most of discharge values.

Tab. 2.6
Accuracy mesaures

Measure	**Observed**	**Previs 1**	**Previs 2**	**Previs 3**
Mean	165.64	178.22	139.86	122.04
Standard deviation	50.22	74.98	59.38	49.87
Mean error		12.57	–25.79	–43.60
Mean of absolute error		57.54	50.10	53.01
Mean of (absolute error/observed data)		0.35	0.29	0.30
Mean of (absolute error/forecasted data)		0.35	0.46	0.58
Bias		1.08	0.84	0.74
Correlation coefficient		0.29	0.33	0.38

Tab. 2.7
Accuracy mesaures for PREVIS 1

Measure	**Previs 1**	**Previs 1 (data < 150)**	**Previs 1 (data > 150)**
Mean	178.22	55.03	123.34
Mean error	12.57	–39.22	58.92
Mean of (absolute error/observed data)		0.28	0.41
Mean of (absolute error/forecasted data)		0.46	0.25
Bias	1.08	0.75	1.34

Accuracy measures corroborate graphical evidences. In particular:

- the correlation coefficient is low, for every data set;
- mean and bias[3] values suggest that PREVIS 2 and PREVIS 3 have a tendency to under-forecast, otherwise, PREVIS 1 generally over-forecasts; however, if PREVIS 1 data are split into two sets (corresponding to data above and below 150 m^3/s), then accuracy measures (reported in Table 2.7) indicate that PREVIS 1 under-forecast below 150 m^3/s and vice versa.

In addition, further indications can be derived from accuracy measures:

- PREVIS 1 mean error seems to be the lowest. However, this is due to the twofold forecasting behaviour described above. In fact, as errors are both positive and negative, they tend to compensate for each other.
- Mean of absolute errors appears more informative. According to this, PREVIS 2 is the most accurate forecast even if all the forecasts present similar poor accuracy (on average, absolute errors are equal to 30% of observations).

At this point, it is clear how accuracy assessment adds knowledge about forecast uncertainty. In detail, it supplies information about the trustworthiness of forecasted values, potentially

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[3] Bias is here considered as the ratio between forecasts mean value and observations mean value. If this value is >1, then the system tends to over-forecast. On the contary, if the bias is <1, then the tendency is to under forecast.

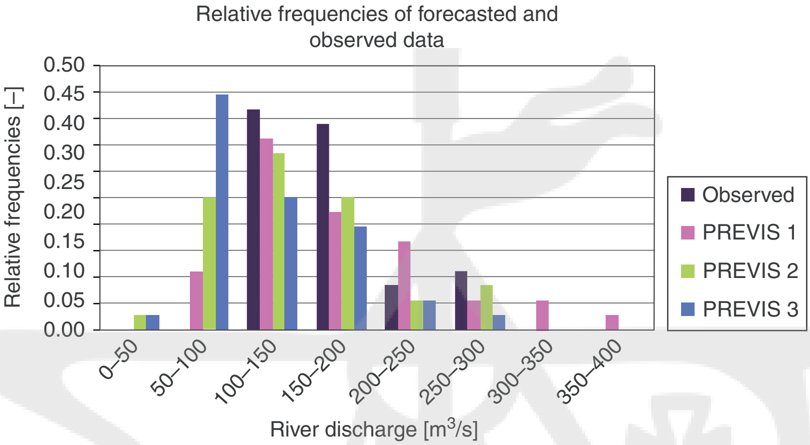

Fig. 2.11
Relative frequencies of forecasted and observed river discharge values

improving the decision-making process. Unfortunately, this is not always the case as for the system under investigation. In fact, accuracy assessment results here suggest that all the forecasts are equally poorly accurate. Thus, no criterion can be identified to trust one forecast rather than others. The following sections, as well as the second part of the case study in Chapters 3 and 4, point out how quality and value assessments are useful from this perspective.

Nevertheless, it must be pointed out that accuracy assessment highlights a very significant weak point of the warning system under investigation. As reported in Table 2.4, current gap among warning thresholds is equal respectively to 25 m^3/s (between level 1 and level 2) and 45 m^3/s (between level 2 and level 3). However, given that the mean of absolute errors is about 50 m^3/s for every forecast data set, this setting is misleading because warning intervals overlap when forecasting errors are taken into account.

2.2.4 The quality assessment

In line with the distributions approach, to evaluate forecasts quality, joint and conditional distributions of forecasts and observations must be analysed. Accordingly, in order to get a first impression, Figure 2.11 reports forecasts and observations histograms.

First, it is important to remind that the lack of observations below the river discharge value of 90 m^3/s is not due to the real features of the phenomenon under investigation but rather to the hypothesis that has been assumed to define the sample (see Section 2.2.2). Second, a question arises about the choice of river discharge intervals (or classes), against which evaluating frequencies.

From the perspective of a local floodplain manager, in order to properly issue a warning, even more important than knowing how forecasted values are distributed along the whole possible range of discharge values is the knowledge of how they are distributed within the "warning classes"[4]. In other words, even before to know whether or not forecasts are accurate, it

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[4] In this case, according to Table 2.4, within the intervals: $Q = 90 \div 115\ m^3/s$ (corresponding to the alert phase), $Q = 115 \div 160\ m^3/s$ (corresponding to the alarm phase) and $Q > 160\ m^3/s$ (corresponding to the warning phase).

Tab. 2.8
Results of probability distributions analysis for PREVIS 1 forecast. In grey cells are identified where a frequency equal to 1 should be present in case of a perfect forecast (with no errors)

Contingency table (joint distribution)						
PREVIS 1		Observed				Marginal
		<90	90–115	115–160	>160	$p(f)$
Forecasted	<90	0.00	0.03	0.03	0.06	0.11
	90–115	0.00	0.03	0.08	0.00	0.11
	115–160	0.00	0.06	0.08	0.08	0.22
	>160	0.00	0.00	0.22	0.33	0.56
Marginal	$p(o)$	0.00	0.11	0.42	0.47	
Conditional distribution of the observations given the forecasts						Mode
$p(o \mid f<90)$		0.00	0.25	0.25	0.5	>160
$p(o \mid f=90–115)$		0.00	0.25	0.75	0.00	115–160
$p(o \mid f=115–160)$		0.00	0.25	0.375	0.375	>115
$p(o \mid f>160)$		0.00	0.00	0.4	0.6	>160
Conditional distribution of the forecasts given the observations						Mode
$p(f \mid o<90)$		Not quantifiable because of the features of the o sample				
$p(f \mid o=90–115)$		0.25	0.25	0.50	0.00	115–160
$p(f \mid o=115–160)$		0.07	0.20	0.20	0.53	>160
$p(f \mid o>160)$		0.12	0.00	0.18	0.71	>160

is more interesting to know if forecasts allow analysts to distinguish between different warning levels and, as a consequence, to properly warn people. Then, of course, once a warning has been issued, the knowledge of the expected river discharge value is equally important, to properly identify preventive measures.

According to this evidence, evaluating forecasts frequencies against warning intervals make more sense than against homogeneous intervals (as for Figure 2.11). This is just the choice that has been adopted in the presented study. Therefore, contingency tables (Tables 2.8–2.10) have been computed which show the relative frequency[5] of occurrence of different *f*–*o* combinations, just against river discharge warning classes.

However, it is important to stress that this choice actually implies to already address the analysis towards the assessment of forecasts value. Indeed, this way, the evaluation of quality is not context-independent but it is focused towards looking for the most informative knowledge for a specific end user (i.e. the warning actor).

Joint probability distributions have been estimated just from contingency tables by assuming relative frequency distributions as being an estimate of the theoretical probability distributions that it would be ideally required to know. Marginal and conditional probability distributions have been then computed by marginalising joint distributions.

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[5] The frequency of occurence over the total number of events.

Tab. 2.9
Results of probability distributions analysis for PREVIS 2 forecast. In Grey cells are identified where a frequency equal to 1 should be present in case of a perfect forecast (with no errors)

Contingency table (joint distribution)						
PREVIS 2		Observed				Marginal
		<90	90–115	115–160	>160	$p(f)$
Forecasted	<90	0.00	0.06	0.08	0.06	0.19
	90–115	0.00	0.06	0.11	0.11	0.28
	115–160	0.00	0.00	0.14	0.08	0.22
	>160	0.00	0.00	0.08	0.22	0.31
Marginal	$p(o)$	0.00	0.11	0.42	0.47	
Conditional distribution of the observations given the forecasts						Mode
$p(o \mid f < 90)$		0.00	0.29	0.43	0.29	115–160
$p(o \mid f = 90–115)$		0.00	0.20	0.40	0.40	>115
$p(o \mid f = 115–160)$		0.00	0.00	0.63	0.38	115–160
$p(o \mid f > 160)$		0.00	0.00	0.27	0.73	>160
Conditional distribution of the forecasts given the observations						Mode
$p(f \mid o < 90)$		Not quantifiable because of the features of the o sample				
$p(f \mid o = 90–115)$		0.50	0.50	0.00	0.00	<115
$p(f \mid o = 115–160)$		0.20	0.27	0.33	0.20	115–160
$p(f \mid o > 160)$		0.12	0.24	0.18	0.47	>160

Hence, to sum up, each table reports:

- the contingency table in terms of relative frequencies; they are assumed to be equal to the joint probabilities $p(f,o)$
- the marginal distributions of the forecasts $p(f)$ and of the observations $p(o)$
- the conditional distributions of the observations given the forecasts $p(o|f)$ and their mode[6]
- the conditional distributions of the forecasts given the observations $p(f|o)$ and their mode.

It must be reminded that actually all these distributions are conditioned to the event $o > 90$.

First of all, it is the knowledge of conditional distributions that provides useful insights into the question about the capacity of forecasts of properly distinguishing among warning levels. With respect to this, in the tables, cells are highlighted (in grey) where a frequency equal to 1 should be present in the ideal case of a perfect forecast (with no errors).

At a first glance, the comparison between the ideal case and results highlights that this capacity is low; not only real frequencies are far from 1 but, in most of cases, the more frequent interval (i.e. the mode of the distribution) is also different than the ideal one, even if it seems that forecasting performance improves for high river discharge values.

In any case, this "rough" analysis can be better formalised by means of quality concepts like reliability, resolution and discrimination (see Section 2.1.1).

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[6] The more frequent warning interval.

Tab. 2.10
Results of probability distributions analysis for PREVIS 3 forecast. In Grey cells are identified where a frequency equal to 1 should be present in case of a perfect forecast (with no errors)

Contingency table (joint distribution)						
PREVIS 3		Observed				Marginal
		<90	90–115	115–160	>160	$p(f)$
Forecasted	<90	0.00	0.06	0.14	0.11	0.31
	90–115	0.00	0.06	0.11	0.08	0.25
	115–160	0.00	0.00	0.08	0.14	0.22
	>160	0.00	0.00	0.08	0.14	0.22
Marginal	$p(o)$	0.00	0.11	0.42	0.47	
Conditional distribution of the observations given the forecasts						**Mode**
$p(o\|f<90)$		0.00	0.18	0.45	0.36	115–160
$p(o\|f=90–115)$		0.00	0.22	0.44	0.33	115–160
$p(o\|f=115–160)$		0.00	0.00	0.38	0.63	>160
$p(o\|f>160)$		0.00	0.00	0.38	0.63	>160
Conditional distribution of the forecasts given the observations						Mode
$p(f\|o<90)$		Not quantifiable because of the features of the o sample				
$p(f\|o=90–115)$		0.50	0.50	0.00	0.00	<115
$p(f\|o=115–160)$		0.33	0.27	0.20	0.20	<90
$p(f\|o>160)$		0.24	0.18	0.29	0.29	>115

With respect to reliability[7], it can be observed that the mode[8] of the conditional distributions $p(o|f)$ is equal or next to the corresponding f class only when $f > 115$; results show (then) that forecasted and observed value agree. This is true for every forecast data set although, from this perspective, PREVIS 2 seems to be the best as reliability is correct for two intervals ($f = 115$–160 and $f > 160$).

Resolution[9], instead, is low for every forecast data set as the mode of the conditional distributions $p(o|f)$ generally corresponds to one of the two highest intervals, whatever the value of f is. In the specific case under investigation, a comparison with the mode of $p(o)$ makes no sense as it is conditioned to the event $o > 90$. However, given the generally constant value of the mode of $p(o|f)$, it is possible to state that the ability of forecasts to sort the set of events into subsets with different frequency distributions is low so that it is not expected that different forecast values are followed by different observations.

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[7] The average agreement between forecast values and observed values, it relates to the correspondence between the mean of the observations associated with a particular forecast and that forecast (see Section 5.1.1).

[8] In the analysis, the mode has been used (instead of the mean value) to evaluate reliability and resolution. This is because, for the problem under investigation (i.e. the capacity to distinguish among classes), the knolwedge of the more frequent class is more informative than the mean value of forecasts.

[9] The ability of the forecast to sort or resolve the set of events into subsets with different frequency distributions, relates to the difference between the mean of the observations associated with a particular forecast and the overall unconditional mean observation (see Section 5.1.1).

Conditional probabilities	Observed value			
	<90	90–115	115–160	>160
PREVIS 1				
$p(o\|f<90)$	0.00	0.25	0.25	0.50
$p(o\|f>90)$	0.00	0.09	0.44	0.47
$p(o\|f>115)$	0.00	0.07	0.39	0.54
$p(o\|f>160)$	0.00	0.00	0.40	0.60
PREVIS 2				
$p(o\|f<90)$	0.00	0.29	0.43	0.29
$p(o\|f>90)$	0.00	0.07	0.41	0.52
$p(o\|f>115)$	0.00	0.00	0.42	0.58
$p(o\|f>160)$	0.00	0.00	0.27	0.73
PREVIS 3				
$p(o\|f<90)$	0.00	0.18	0.45	0.36
$p(o\|f>90)$	0.00	0.08	0.40	0.52
$p(o\|f>115)$	0.00	0.00	0.38	0.63
$p(o\|f>160)$	0.00	0.00	0.38	0.63
Climatological				
$p(o)$	0.00	0.11	0.42	0.47

Tab. 2.11
Probability of observations conditional to forecasts

Finally, discrimination[10] varies with respect to forecast data set. PREVIS 1 well discriminates when $f > 160$, meaning that when $f > 160$ the most likely following observation is well identified. On the contrary, discrimination is poor for other f classes. PREVIS 2 has a good/medium discrimination for $f < 90$ and $f > 160$. Finally PREVIS 3 has a good/medium discrimination only for $f < 90$.

On the other hand, useful information can be derived also looking at marginal distributions $p(f)$. In detail, it can be observed that, for all the three forecasts, there is no clear tendency to predict extreme values ($f > 160$), that is sharpness is low (see Section 2.1.1). However, from this perspective, PREVIS 1 has the best performance.

At this point, one might ask what general conditions must be satisfied to ensure that a forecast data set has better quality than others. According to Murphy (1993), these conditions are embodied in a statistical relationship referred to as the "sufficiency relation". According to this, a forecast is "sufficient for others when exhibits better scores in all quality aspects".

It is clear that this does not happen in the case under investigation, for any forecast data set. Thus, it is possible to state that no one forecast is better than others in terms of quality meaning, once again, that it is not possible to define a warning criterion that always guarantees the best performance of the system. Clearly, this result is specific for the case under investigation; generally speaking, it is however evident how quality assessment adds useful information in comparison with accuracy assessment about both forecasts uncertainty and forecasts feasibility in the warning process.

Looking at the problem at stake, conditional distributions in Table 2.11 seem even more informative than the ones previously computed according to the standard procedure. This

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[10] The ability of the forecast to discriminate among observations, that is to have a higher prediction frequency for an outcome whenever that outcome occurs (see Section 5.1.1).

Tab. 2.12
Warning outcomes definition

Warning outcome	**Definition**
False warning (FW)	A warning is issued but no floodoccurs
Missed event (ME)	A flood occurs but no warning is issued
Forecasted event (H)	Forecasted flood occurs
Calm (N)	No flood is forecasted and occurs

		Observed	
		>160	**<160**
Forecasted	>160	H	FW
	<160	ME	N

is because they have been conceived to supply data of interest for specific forecasts users (i.e. information about warning effectiveness), that is they further more focus the analysis towards the assessment of forecast value.

Specifically, besides climatological distribution[11], Table 2.11 supplies the probability distributions of observations conditional to the evidence that forecast is above a certain warning threshold. Hence, from them, the probability of a flood ($o > 160$) conditional to a warning level can be assessed. Of course, this datum is especially interesting for warning actors.

For the case study, Table 2.11 points out that forecasts are not much more informative than climatology (i.e. forecast skill[12] is low). In fact, even if a forecast is above the level 1 threshold (115 m^3/s), the probability of flood occurrence ($o > 160$) does not change very much with respect to the same probability when $o > 90$ (i.e. supplied by climatology). This is true for every forecast data set, and forecasts performance are even worse if one considers the probability of a peak discharge between 115 and 160; in this case, because of forecasting errors, the information supplied by climatology ($o > 90$) is more informative than forecasts ($f > 115$). Looking then at PREVIS 1 and PREVIS 3, the probability of flood occurrence does not noticeably increase (with respect to that supplied by climatology) neither if forecasts exceed the warning level 3 (160 m^3/s) whilst it happens considering PREVIS 2. In this case, the probability of flood occurrence rises from 0.47 to 0.73.

Of course, this discussion is valid only if the advantage of time prediction is not taken into account. Indeed, every forecast presents the benefit of supplying analysts not only with information about peak river discharges but also on their time of occurrence. This information is not available looking only at climatology. From this perspective, forecasts skill improve.

To conclude, it is evident that results corroborate the improvement the distributions approach brings into flood forecast verification, in terms of useful information for end users. However, this improvement is significant only if distributions approach is oriented towards forecast value assessment. The next section tackles with this point.

2.2.5 The value assessment

Value assessment aims at evaluating the utility of forecasted data, or better, the incremental benefit of forecasted data to users (i.e. their value). Hence, before going on with the assessment, it is first necessary to define what forecast "benefit" is.

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[11] Distribution which derives from observations; in the case under investigation climatology is conditioned to $o > 90$.

[12] The accuracy of forecast of interest relative to the accuracy of climatology.

Tab. 2.13
Flood contingency tables: absolute frequencies are reported on the left, relative frequencies on the right

PREVIS 1		Observed	
		>160	<160
Forecasted	>160	11	8
	<160	6	11

PREVIS 1		Observed	
		>160	<160
Forecasted	>160	0.31	0.22
	<160	0.17	0.31

PREVIS 2		Observed	
		>160	<160
Forecasted	>160	8	3
	<160	9	16

PREVIS 2		Observed	
		>160	<160
Forecasted	>160	0.22	0.08
	<160	0.25	0.44

PREVIS 3		Observed	
		>160	<160
Forecasted	>160	5	3
	<160	12	16

PREVIS 3		Observed	
		>160	<160
Forecasted	>160	0.14	0.08
	<160	0.33	0.44

Looking at the problem at stake, one might instinctively identify forecast benefit with the ability of the system to distinguishing between flood and no-flood events. Indeed, as already argued in previous section, this ability seems more important than the capacity of correctly predicting river discharge, at least from the perspective of warning effectiveness.

Contingency tables (Table 2.13) has then been computed accordingly; they show, for each forecast data set, the frequency of occurrence[13] of all the possible warning outcomes as defined in Table 2.12. Starting from them, some performance measures have then been computed. Their definition (see, for example, Thornes and Stephenson, 2001, WWRP/WGNE, 2009) and computation results are reported in Table 2.14.

Results point out the following evidences:

- PREVIS 2 is the best forecast in terms of PC. However, looking at contingency table (Table 2.13), it is clear how this is due to the high frequency of N events. Indeed, PC does not allow distinguishing between flood and no-flood events. On the other hand, PREVIS 1 is similar to PREVIS 2, in terms of PC, but frequencies of flood and no-flood events are the same;
- According to the respective tendency to over- and under-forecast, PREVIS 1 tends to false warnings more than missed events; otherwise PREVIS 2 and PREVIS 3 have a tendency to produce missed events, but the performance of PREVIS 3 is worst;
- PREVIS 2 is the most informative against the chance.

At last, some performance measures have been implemented considering also joint distributions previously reported in Tables 2.8–2.10. These actually represent indicators of the aptitude of correctly forecasting river discharge within certain classes.

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[13] Both absolute and relative frequencies are supplied. The latter have been considered as an estimate of joint probabilities.

Tab. 2.14
Measures of performance

Measure	Definition	Value		
		PREVIS 1	PREVIS 2	PREVIS 3
Percent correct	Percentage of right forecasts $PC = \frac{H+N}{H+N+FW+ME} \cdot 100$ Range: 0–100 Perfect score: 1	61.11	66.67	58.33
Bias	Number of forecasted floods over the number of observed floods $B = \frac{H+FW}{H+ME}$ Range: 0 to infinity Perfect score: 1	1.12	0.65	0.47
Miss rate	Percentage of observed floods that were not forecasted $M = \frac{ME}{ME+H}$ Range: 0–1 Perfect score: 0	0.35	0.53	0.71
Probability of false detection (false alarm ratio)	Percentage of forecasted floods that did not occur $POD = \frac{FW}{FW+H}$ Range: 0–1 Perfect score: 0	0.42	0.27	0.38
False alarm rate	The percentage of no-flood events that were forecasted as floods $F = \frac{FW}{FW+N}$ Range: 0–1 Perfect score: 0	0.42	0.16	0.16
ORSS	It is a measure of the improvement of the forecast over random chance $ORSS = \frac{H \cdot N - ME \cdot FW}{H \cdot N + ME \cdot FW}$ Range: -1 to 1, 0 indicates no skill Perfect score: 1	0.43	0.65	0.38

Unfortunately, literature is poor from this perspective; something has been done in the USA (see, for example, Welles, 2002; U.S. Department of Commerce, 2006) just referring to flood forecasting. However, some indicators had been created hereby to better suit the problem at stake (see Table 2.15). In other words, new measures have been created to highlight the information of most interest for the case study. Results are reported in Table 2.16.

Table 2.16 points out that:

- Within the forecast range $Q = 90$–$115\ \mathrm{m}^3/\mathrm{s}$, the capacity of correctly forecasting (PFR) is low, for every data set. The general tendency is to fall into missed event (high MR values) whatever forecast data set is considered.
- Within the forecast range $Q = 115$–$160\ \mathrm{m}^3/\mathrm{s}$, the capacity of correctly forecasting is again low, except for PREVIS 2 which presents a medium to high PFR value. However, the tendency to produce missed event decreases, even if it is still high for PREVIS 3.

Tab. 2.15
Measures of performance related to discahrge classes

Measure	Definition	Source
Probability of detention (POD)	The percentage of observations within a class that were forecasted also in that class	Literature
Traditional false alarm rate (TFAR)	The percentage of times a forecast is within an interval but the observation is not	
Under forecast rate (UFR)	The percentage of times an observation is within an interval but the forecast is below	
Over-forecast rate (OFR)	The percentage of times an observation is within an interval but the forecast is above	
Perfect forecast rate (PFR)	The percentage of forecasts within a class that were observed in that class	New
Hit rate (HR)	The percentage of forecasts that fall within an interval that have been observed within or below that interval	
Miss rate (MR)	The percentage of forecasts that fall within an interval that have been observed above that interval	

Tab. 2.16
Performance assessment results

	PREVIS 1		PREVIS 2		PREVIS 3	
Index	Q=90–115	Q=115–160	Q=90–115	Q=115–160	Q=90–115	Q=115–160
POD	0.25	0.20	0.5	0.33	0.5	0.20
TFAR	0.75	0.63	0.8	0.38	0.8	0.63
UFR	0.25	0.27	0.5	0.47	0.5	0.60
OFR	0.5	0.53	0	0.20	0	0.20
PFR	0.25	0.375	0.2	0.625	0.2	0.375
HR	0.25	0.625	0.2	0.625	0.2	0.375
MR	0.75	0.375	0.8	0.375	0.8	0.625

2.3 Results: critical analysis and generalisation

Looking at the above results, the first impression a reader can infer is that the implemented approach is inadequate for the problem at stake because even analysing forecasts with respect to their value, it is impossible to identify a forecast that is "absolutely" better than others (i.e. which should always be trusted to get successful warning). Actually, this is not the reality.

The point is that the problem, as conceived by now, is ill-posed. It is impossible to identify a forecast that is absolutely better than others because, as stated at the beginning of the chapter, the goodness of a forecast is context-specific, meaning that each user can be interested in one forecast aspects, or another, according to their specific application context.

Of course, the implementation in the case study highlighted how the assessments of quality and value allow adding useful information for decision making. Specifically, the implementation pointed out that, by applying the proposed procedure, step by step, it is possible to evaluate

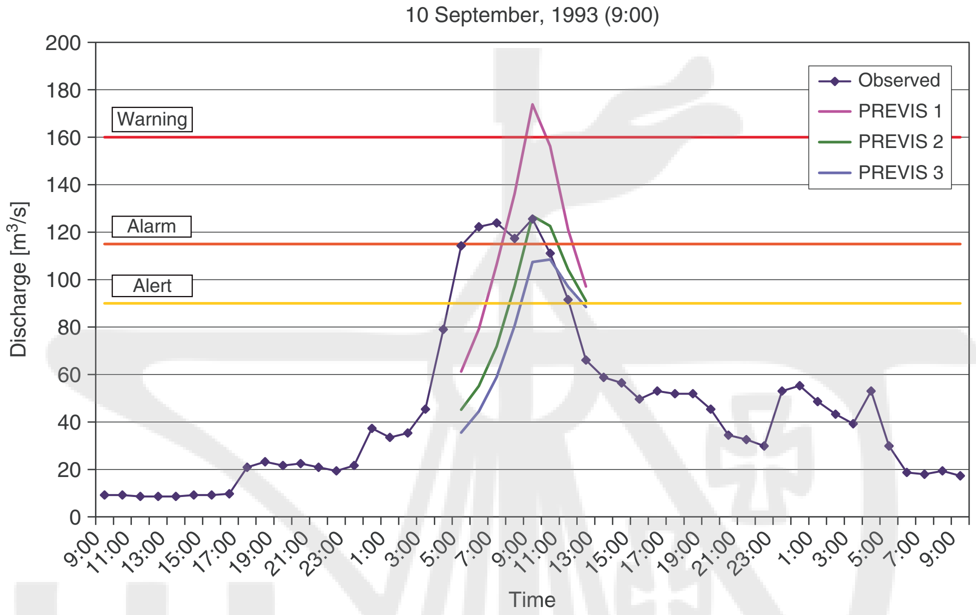

Fig. 2.12
Back analysis results: 10 September, 1999, no-flood event

which are the main effects of uncertainty on forecasting results, from different perspectives. In other words, this means that quality and value assessment supplies further knowledge by comparison with the traditional accuracy appraisal.

This is to say that the current approach is not inadequate. On the contrary, the various **steps** in the procedure can be carried out or not depending on the **specific context** in which forecasts are implemented. For instance, if actions carried out after a warning is issued do not depend on the intensity of the forecasted flood (e.g. peak time and discharge), then the correspondence between forecasts and observations is less important than the forecast ability to distinguish between flood and no-flood events. Hence, forecast accuracy assessment is not adequate for the analysis, whilst forecast value assessment is required. Otherwise, if contingency plans are tailored to forecasted values, then accuracy assessment is compulsory.

2.3.1 The need of including damages

With respect, instead, to the case study under investigation, the problem lies with the definition of "benefit" and, consequently, of forecast value; an example can better explain the point.

The event is the one occurred on 10 September 1999 (reported in Figure 2.12). On that occasion, peak discharge was equal to 125 m^3/s at 9.00, but at 5.30:

- PREVIS 1 forecast was 166 m^3/s, above the level 3 threshold;
- PREVIS 2 forecast was 119 m^3/s, above the level 2 threshold;
- PREVIS 1 forecast was 100 m^3/s, above the level 1 threshold.

In a such a forecast scenario, which indication should be followed?

By considering (for the sake of clarity) only PREVIS 1 and PREVIS 2, accuracy assessment do not bring to a rational choice criterion. In fact, it is known (see Tables 2.6 and 2.7) that, on average:

- PREVIS 1 forecasts, in this range, exceed observed value by 25%;
- PREVIS 2 forecasts are lower by 46% than the observed value.

Thus, according to forecasts accuracy, in the event under investigation, observed peak river discharge could be equal to:

- $166 - 0.25 \cdot 166 = 124.5\,\mathrm{m}^3/\mathrm{s}$, below the level 3 threshold, according to PREVIS 1;
- $119 + 0.46 \cdot 119 = 173.7\,\mathrm{m}^3/\mathrm{s}$, above the level 3 threshold, according to PREVIS 2.

This situation, of course, does not allow deciding about warning.

On the other hand, neither the quality-value assessment is useful because the two forecasts give opposite indication on warning level. Looking, for example, at Table 2.11, it is possible to state that:

- $p(o > 160 | f > 160) = 0.60$ for PREVIS 1;
- $p(o > 160 | f > 115) = 0.58$ for PREVIS 2.

This signifies that there is no clear indication about the probability of occurrence of a flood, for any forecasted values. Furthermore, PREVIS 1 and PREVIS 2 have similar PC values, even if PREVIS 1 brings mainly to false warnings whilst PREVIS 2 to missed events (see Table 2.14).

However, it must be noted that it is possible to state that PREVIS 1 and PREVIS 2 are equivalent (or have similar performance) only if missed events and false warnings (and, more in general, all the warning outcomes) are of equal consequence, but this is not what happens in reality.

In other words, to properly assess forecasts performance, an index is required that takes into account both the frequencies of warning outcomes and the size of their consequences. Then, a rational warning criterion can be defined which consists of trusting that forecast that minimise the index.

In other words, the event discussed here and, more in general, the analysis carried out in the previous sections introduce the need of including damages into the flood forecast verification process. Of course, this is just equal to the appraisal of forecast value, were benefit is defined as the capacity of the forecasting system to reduce expected damage that is just the goal of FEWSs (see Chapter 1).

2.3.2 The need of including time

Last but not least, it must be stressed that the proposed procedure is time-independent but the correspondence between the time of the forecasted event and the time of the real event is as important as the agreement between their intensities (e.g. discharge). For example, an accurate forecast which is foreseen to happen after what will be the real time of occurrence could imply a delay in the implementation of preventive measures and, consequently, a reduction in their effectiveness and an unsuccessful warning.

At present, the analysis of the uncertainty related to the time of forecasts is limited to accuracy assessment. However, further tools should be developed in the future to include in the verification process both other quality attributes and forecast value from a “time” perspective.

2.4 Conclusions

In this chapter, a procedure is proposed and applied to a case study, with the general aim of evaluating FEWSs from the forecasting point of view.

Starting from the traditional assessment of forecast accuracy, the procedure proposes to broaden the analysis by including the evaluation of forecast quality and value; analytical tools are then supplied to accomplish the required tasks.

The case study highlights that a step-by-step implementation of procedure allows to add useful information for decision making, from different perspectives. Conversely, the procedure is flexible meaning that the various steps can be implemented or not, according to the specific users needs (meaning stakeholders requirements). Even more important, the case study allows to point out the correspondence between flood forecast value and FEWSs performance (as defined in Chapter 1), being both related to the capacity of the system of reducing flood damage. The importance of including damage assessment arises consequently. Chapters 3 and 4 tackle with this point.

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Chapter 3

Damage assessment

Risk analysis, meaning damage assessment, has been proved to be a crucial step in the evaluation of FEWSs performance (see Chapters 1 and 2):

- first, because FEWSs performance should be evaluated just in terms of the capacity of systems to reduce expected damage,
- second, accordingly, because decisions about warning are usually taken aiming at maximising FEWSs performance (i.e. damage reduction).

This chapter deals with the problem of damage assessment, providing the theoretical knowledge that is required to carry out a suitable risk analysis within FEWSs design and evaluation. With reference to the general framework for warning process that has been assumed within this research, this actually means to supply all the theoretical knowledge about the set of models which is highlighted in Figure 3.1.

In accordance with Chapter 2, concepts and tools which are described in this chapter are applied to the Sondrio case study. This way, it is possible to describe real problems analysts could face in real implementation.

3.1 Damages, impacts, losses and costs

Literature on damage assessment is full of terms like damages, losses, impacts and so on. However, there is not a common agreement neither about their meaning nor their use. Some authors employ these terms as synonymous whilst others (see e.g. WMO, 2007) distinguish among them, with the result of a general sense of confusion and difficulty in comparing among different studies.

The main reason for this situation can be identified with the fact that damage assessment is not a "discipline" but rather a "matter" which has been handled in the past by different people, with different expertises (from economy to geography, from engineering to sociology) and with respect to the problems they had to face from time to time, in their particular field of expertise. Thus, the terms they used were more linked to their scientific and/or cultural background rather than to a shared glossary.

As a consequence, a brief explanation about the terminology used in damage assessments is first necessary. Of course, the intention here is not to set a glossary but rather to shed light on how and why various terms are used in different contexts. This will allow a better understanding of the contents of the rest of the chapter.

Generally, the problem at issue originates from the broad meaning lay people set to the term "damage". In fact, looking for its definition in a dictionary one can find a lot of different

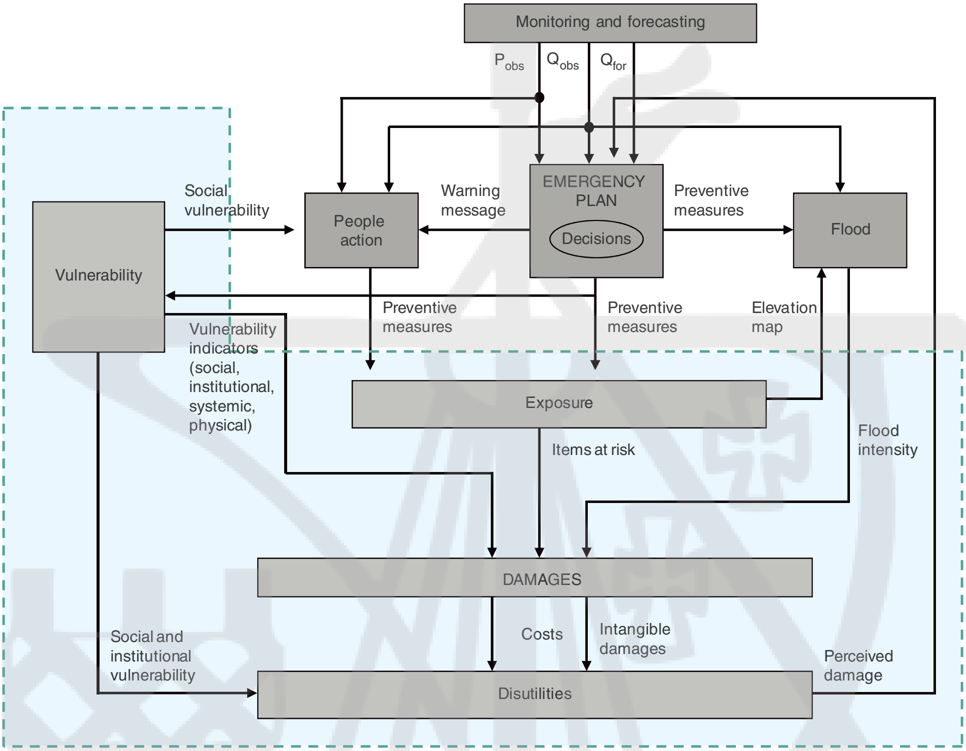

Fig. 3.1
The components of the flood warning process that represents the focus of this chapter

explanations but all of them share the same idea of something that is economic and/or physical. For example, the Oxford English Dictionary reports the following explanations:

> *Injury, harm; esp. physical injury to a thing.*
> *The sum of money claimed or adjudged to be paid in compensation for loss or injury sustained.*

However, in analysing EWS, the interest lies in all the harmful effects of a flood on a community, which cover a wide range of "impacts": impacts on humans, their health and their belongings, impacts on public infrastructures, cultural heritage and ecological systems as well as impacts on industrial production and the competitive strength of the affected economy (FLOODsite, 2007). Thus, a conflict can be observed between what damage generally means and what it is necessary to describe.

This unclear scenario brought, from the beginning, to a split among authors with the result that the word "damage" is used interchangeably with "loss" (Mileti, 1999). More in general, some authors refer to all the effects with the general term "damages", some preferred to speak about "losses" and "impacts", others to distinguish about the various terms according to different (often personal) criteria generally grounded on the economic/physical characteristics of the effect itself.

An attempt aimed at distinguishing among adverse effects of disasters was carried out, for example, by the US National Research Council – NRC (1999). According to it, the term

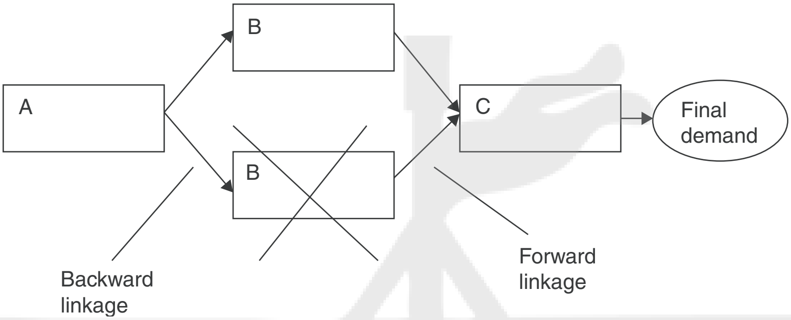

Fig. 3.2
Forward and backward linkages in a an economy (Cochrane, 1997)

"impacts" refers to both market and non-market-based effects whereas "losses" represent market-based negative impacts only. Within this definition, another distinction is made between "direct and indirect" losses. The first results from the physical destruction of building, crops and natural resources, while indirect losses represent the consequences of that destruction, such as a temporary unemployment and business interruption.

"Costs" of disasters represent cash payouts by insurers and governments to reimburse some (and in certain cases all) of the losses suffered by individual and businesses. Finally, the NRC committee defines "damages" as physical destruction, measured by indicators such as the numbers of deaths and injuries or the number of buildings destroyed.

From the economic perspective, instead, three different "costs concepts" can be identified (Van Der Veen et al., 2003). The first is the one implemented by the Flood Hazard Research Centre – FHRC, in the Multi-Coloured Manual – MCM (Penning-Rowsell et al., 2005). Based on the difference between stocks and flows[1], FHRC distinguishes between "direct costs" and "primary and secondary indirect costs" so that direct costs relate to loss of land, capital and machinery, thus to stocks, and primary indirect costs to business interruption, which means a flow. Moreover, secondary indirect effects relate to multipliers in the economy.

American authors take a somewhat different position in defining direct and indirect costs. Cochrane (1997), for example, extends the definition of direct costs by not only including the physical damage to land, plants and houses, but also induced physical effects, which are the consequence of the disaster. Moreover, he defines indirect economic effects more precise as "a result of dislocations suffered by economic sectors not sustaining direct damage. Activities that are either forward linked (rely on regional markets for their output) or backward linked (rely on regional sources of supply) could experience interruptions in their operations".

In other words, according to him, if factory B (see Figure 3.2) is damaged by a disaster, then the production of sectors A and C is affected as well, and also the production of final products. Forward and backward linkages must be then taken into account in damage assessments. On the other hand, from Figure 3.2, it can be seen that other factories of type B in non-flooded

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[1] The value of a (market) good can be represented in two ways. On the one hand, its value is represented by its price. On the other hand, the good can be considered as a capital goods, 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 price of a good is equal to the sum of its income flow values over the rest of the good's life span.

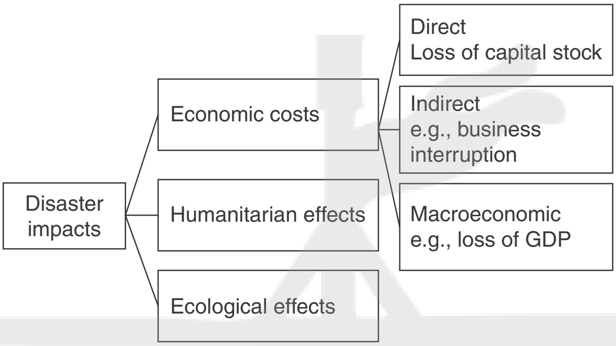

Fig. 3.3
Impacts from disasters according to the World Bank Institute (Mechler, 2003)

areas may take over the production of the damaged factory B. Also this effect must be properly evaluated.

Last but not least, the United Nations and the World Bank (Benson and Clay, 2000) take a further position in defining damage. The concepts of direct and indirect costs are extended with the concept of secondary effects. Direct costs relate to the physical damage to capital assets, including buildings, infrastructure, industrial plants and inventories damaged by the actual impact of a disaster; they can therefore be roughly equated with stock losses. Indirect costs refer instead to the damage to the flow of goods and services; indirect costs include lower output from damaged or destroyed assets and infrastructure and loss of earnings due to damage to marketing. Secondary (or “macroeconomic”) effects concern finally both the short- and long-term impacts of a disaster on aggregate economic variables thus relating to the performance of the overall economy.

In the flooding literature, there is then a long-lasting tradition to include also non-monetary effects on households such as increased stress, health damage and loss of memorabilia. From this perspective, a more systemic approach for classifying disaster impacts has been adopted by the World Bank Institute (Mechler, 2003). According to it, “in the event of natural disaster, humanitarian, economic and ecological impacts and effects may occur. Humanitarian effects include loss of life, affected people and psychological post-disaster effects, ecological effects comprise the loss of arable land, forests and damage to ecosystems”. Economic effects have been described before (see Figure 3.3).

Finally, some authors argue that impacts from disaster may be different according to the typology of disasters. Some of the most frequent economic and social effects, depending on the type of natural disaster, are shown in Table 3.1 (Otero and Marti, 2005).

In the following text, the terms damages, impacts and losses will be used without any distinctions to support the point of view according to which it is not important to distinguish among terms but rather to be clear with respect to which kind of effect is under investigation. At this perspective, this book adopts a classification among “direct and indirect” and “tangible and intangible” damages (see e.g. Penning-Rowsell and Chatterton, 1977; EMA, 2002; USACE, 1994), according to which:

- **direct losses** refer to those damages resulting from direct contact with the hazard (e.g. flood damage to building);

Tab. 3.1
Main impact produced by different types of disasters (Otero and Marti, 2005)

Impacts	Disaster type						
	Seismic	Cyclone	Flood	Tsunami	Volcanic	Fire	Drought
Short-term migrations			x		x	x	x
Permanent migration							x
Loss of housing	x	x	x	x	x	x	
Loss of industrial production	x	x	x	x		x	
Loss of business production	x	x	x	x		x	
Loss of crops		x	x	x	x	x	x
Damage to infrastructure	x	x	x	x		x	
Disruption of markets	x	x			x		
Disruption of transportation	x		x				
Disruption of communications	x	x	x	x		x	
Panic						x	
Breakdown of social order	x	x				x	

- **indirect losses** relate to those losses resulting from the event but not from its direct impact (e.g. business losses due to activity disruption, secondary physical damages and costs due to emergency): in other words indirect losses are any loss other than direct losses;
- **tangible losses** concern things with a monetary value (e.g. buildings and livestock);
- **intangible losses** regarding things that cannot be bought and sold (such as lives, heritage and environmental items and memorabilia).

The first stage in damage assessment is thus to identify what represents a damage, or in other words, to define what must be evaluated. However, as stressed so far, this is not a simple task because flood losses consist of various impacts that, in turn, can affect different exposed elements, from the built environment to people and ecosystems.

A literature review brought to the identification and classification of all likely flood damages; results are displayed in Table 3.2 where damages are characterised both according to the exposed element and with respect to their nature[2].

3.2 The evaluation of flood losses: available tools

Allowing for all the possible (typologies of) flood damages is essential in carrying out their evaluation. The Australian damage assessment guidelines (EMA, 2002) reports, for instance,

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[2] Direct or indirect, tangible or intangible.

Tab. 3.2
Flood damages

Exposed elements	**Damage**		
	Description	**Type**	**Required explanation**
Private buildings	Physical damage to structure	Direct, tangible	e.g. carpeting, painting, openings
	Physical damage to contents	Direct, tangible	e.g. furniture, cars
	Additional costs to property owners	Indirect, tangible	e.g. clean up, additional heating
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia
Commercial buildings	Physical damage to structure	Direct, tangible	
	Physical damage to contents	Direct, tangible	e.g. stock, machinery and tools
	Indirect damages	Indirect, tangible	Loss of income, additional costs (e.g. clean up)
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia
Farming estates	Physical damages	Direct, tangible	e.g. livestock, crops, machinery and tools, blocks
	Loss of income	Indirect, tangible	
	Additional costs to property owners	Indirect, tangible	e.g. repair fences, remove debris, replace soil
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia
People	Physical loss	Direct, intangible	e.g. death, injuries
	Psychological damages	Indirect, intangible	e.g. stress and anxiety
Public buildings	Physical damage to structure	Direct, tangible	
	Physical damage to contents	Direct, tangible	
	Service disruption	Indirect, tangible	e.g. health, school services including also indirect effects
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community"

(continued)

Tab. 3.2
Continued.

Exposed elements	Damage		
	Description	Type	Required explanation
Infrastructures	Physical damage	Direct, tangible	
	Service disruption	Indirect, intangible	e.g. electricity, water supply including also indirect effects
Environment	Ecological damage	Direct, intangible	
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community", loss of memorabilia
Cultural heritage sites	Physical damage	Direct, intangible	
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community", loss of memorabilia
Local authorities	Cost of warning activities	Indirect, tangible	e.g. evacuation, warning
	Cost of emergency activities	Indirect, tangible	e.g. sandbags, tools and machinery, shelters
	Loss of trust by people	Indirect, intangible	

that "Intangibles are often found to be more important than tangible losses (…) studies in Australia, the United Kingdom and the United States have consistently shown that householders place very high value on intangible losses (…) at least as highly as their tangible dollar losses". Likewise, "Previous disaster reports indicate that, as a broad estimate, indirect costs are usually in the range of 25 to 40 per cent of direct costs".

However, whilst there are quite agreed approaches to the estimate of direct losses, this is not the case for indirect and intangible ones with the result that (i) direct damages are usually present in any damage assessment (ii) indirect losses are often roughly estimated and (iii) intangibles are frequently ignored or simply mentioned, without any attempt of evaluation.

The discussion of the current state of the art on damage assessment methods is just the focus of this section. In this regard, Tables 3.3 and 3.4 display an attempt to organise and classify available tools.

In detail, in Table 3.3, different modelling approaches are identified. Each of them is then briefly described and classified according to the way in which assessment is carried out. Instead, in Table 3.4 indication is supplied about which kinds of damage each approach allows to estimate. Of course, given the complexity of the matter and the variety of the assessment methods that have been developed, it is plausible that some of them cannot be strictly assigned to only one of the suggested classes. Nevertheless, this classification is helpful, at least to better identify the main gaps and limits of available methods as they are described below.

Tab. 3.3
Damage evaluation methods: a possible classification of the state of the art

Type	Modelling approach
Explicit	*Averaging approach*: mean unit values (e.g. average loss per flooded dwelling, average loss per kilometre of inundated road and loss of value added)
	Functions approach: relative or absolute hazard-loss (typically depth–damage) functions
	Surveys: field surveys of event impacts
Indirect	*Percentages*: fixed or variable (e.g. as a function of warning time, depth of flooding) ratios of potential/direct damages
Ad hoc	*From other disciplines or experimental*: surrogate values, opportunity cost, human capital approach, hedonic price, contingent valuation, replacement costs, etc.

Tab. 3.4
Damage evaluation methods: a possible classification of their field of implementation

Damage	Tangible	Intangible
Direct	Averaging approach Function approach Survey	*Ad hoc*
Indirect	Survey Percentage *Ad hoc*	Percentage *Ad hoc*

Starting from **direct, tangible damages**, it has been already emphasised how evaluation methods are quite defined and shared among both the scientific and the practitioners' communities. However, they still present some limits which, at present, constrain their actual implementation (see Section 3.2.2).

At a broad perspective, these methods can be viewed as "explicit" as they evaluate damages directly from physical evidences. All of them, then, share the concept of the "unit loss approach" (EMA, 2002) which refers to the calculation of loss to individual unit (e.g. buildings and factories) which are then added together to give a total loss figure for the event in question. However, within this category, a distinction is possible between:

- detailed *surveys* of recent events where the evaluation simply consists of a field investigation which is carried out just with the aim of quantifying real damages, after a true event. It is quite obvious that this approach can be applied only in ex-post estimates and
- other assessments (from now on identified as "*damage functions*") which are instead grounded on historical, pre-existing data, and can be used either in ex-ante or ex-post appraisals.

More specifically, with "damage functions" two different tools (see EMA, 2002) are identified:

- averaging methods,
- stage–damage curves.

Tab. 3.5
Mean potential damages for large non-residential buildings, according to RAM

Value of contents	**Mean potential damages per m^2 (includes external, internal contents and structural damages)**
Low (e.g. offices, sporting pavilions, churches)	$45
Medium (e.g. libraries, clothing businesses, caravan parks)	$80
High (e.g. electronic, printing)	$200

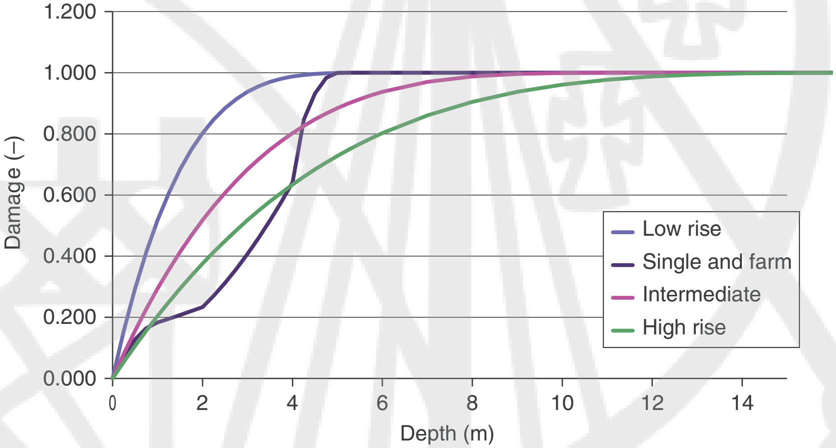

Fig. 3.4
Relative direct damage for buildings, according to the Standard Method

In the former, an average loss per flooded unit is supplied. The Rapid Appraisal Method (RAM), implemented in the state of Victoria, Australia (Read Sturgess et al., 2000), represents a good example of this approach. Table 3.5 displays, for instance, the mean potential damages, suggested by RAM, for large ($>1000\,\mathrm{m}^2$) non-residential buildings.

Stage–damage curves (otherwise called "depth–damage" curves or "stage–damage functions") model the relationship between the expected damage (at unit level) and the depth of the flood water (see e.g. Figures 3.4 and 3.5). This technique is the most widespread and implemented worldwide (see Table 3.7) although with different versions. Specifically, if not transferred from another study, stage–damage functions can be derived by (FLOODsite, 2007):

- *Survey data:* In this case, evidence about the affected properties is gathered after a flood event. At least, information on the type of each property, how deep it was inundated and what damages occurred is ascertained. Then, typical depth–damage functions, for different property types, are derived by means of a regression analysis. The German HOWAS database (see e.g. IWK, 1999; Merz et al., 2004) represents a typical example of the use of actual flood damage data;

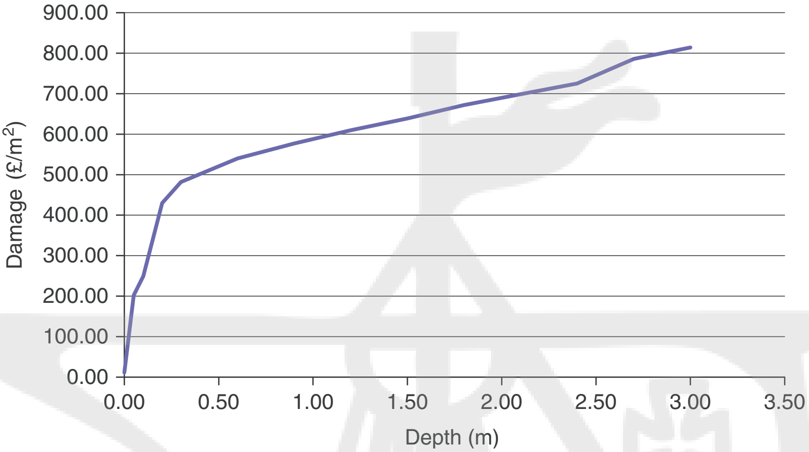

Fig. 3.5
Absolute direct damage for residential sector, according to MCM

- *Synthetic data:* In this case, damages are not estimated for actual properties but for standardised, typical property types whilst the proportional damage, depending on inundation depth, is estimated by expert assessors. Probably, the best known example for a synthetically generated database of damage functions is the English MCM (Penning-Rowsell et al., 2005).

It must be stressed however that the word "synthetic" does not mean "artificial"; as underlined by the FLOODsite project "a synthesis of all available data sources, including real flood damage data, is used, and, on the other hand, also damage functions based on survey data are often adjusted by expert estimates (FLOODsite, 2007)". Accordingly, synthetic data are not always worse than real ones.

Last but not least, damage functions can be also classified as:

- *Relative functions*: In this case, "the percentage of property value approach" (FLOODsite, 2007) is implemented that is damage is described as a share of the total unit value, per every inundation depth. This approach is followed, for example, in the "Standard Method" in the Netherlands (Kok et al., 2005). Figure 3.4 reports an example.
- *Absolute functions* which supply directly the value of damage per every inundation depth. The MCM (Penning-Rowsell et al., 2005) can be quoted, again, as an example of absolute functions application. Figure 3.5 reports one of them.

It can be observed that, looking at stage–damage functions as vulnerability functions[3], this actually means including, or not, exposure within the vulnerability assessment. Indeed, while relative functions allow for vulnerability only, absolute functions implicitly take into account the extent of the exposed item too (e.g. in terms of economic value).

As regards **indirect losses**, instead, it is possible to speak mainly about "implicit" methods as they usually infer indirect damages from the knowledge of direct ones. In detail, in the most of the cases, indirect losses are roughly estimated by means of percentages of direct

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[3] Describing the propensity of an item to be damaged because of flood in terms of likely damage.

damages (this is the case, for example, of the RAM) whilst, in a few cases, as in the MCM, indirect damages are evaluated by means of surrogate values (e.g. the cost of renting an equivalent home) or by *ad hoc* methods grounded on economics (e.g. loss of "value-added" and opportunity cost) as well as other scientific disciplines (e.g. the origin–destination matrix for the evaluation of road disruption costs). However, often, detailed field surveys are also suggested.

With respect to the items included in the analysis, they vary from method to method as well as the temporal/spatial scales they adopt. For example, in the MCM method, all the costs due to activities (e.g. business, housing and traffic) disruption are ideally included in the analysis of indirect damages, according to the damage classification adopted by FHRC (see Section 3.1). However, the MCM method supplies also suggestion on which items should be really taken into account according to the objective (i.e. stakeholder, scales) of the assessment.

On the other hand, some methods (e.g. the origin–destination matrix) can be applied only to certain categories of indirect losses.

Finally, with respect to **intangibles**, a lot of issues arise. The result is that intangibles are ignored in most of the cases, mainly because of the difficulties their assessment implies.

One of the main problems originates in the same definition of intangibles as something that cannot be evaluated in monetary terms. As a consequence, ethical objections are often expressed whereas people try to characterise intangibles in an economic way (How can we prize a life or an historical monument? How can we value a worsening in the landscape?). On the contrary, some authors (see FLOODsite, 2007) argue that, since flood damage analysis must be holistic, the inclusion of intangibles is desirable and achieving this requires to monetise all intangible damage effects.

A second impediment concerns, instead, the availability of data, against which assessment methods can be verified. Specifically, the few existing data usually refer only to the number of injured (or dead) people with the problem of gaining information for the modelling of other types of intangibles. The consequence is that the majority of studies have been so far applied to the identification of intangibles but not to their assessment (at least in a qualitative way).

On the other hand, given the last evidences on the significance of intangibles within the overall flood impact (see above), a few assessment methods have recently been developed. Nevertheless, it must be stressed that all of these methods are experimental and, consequently, not generally accepted. Moreover, unlike the techniques described so far, they usually are "specific" or, in other words, tailored to a certain category of loss (or, in other words, they differ depending on the exposed element they deal with). The intention here is not to carry out a comprehensive review of all the available techniques. However, a common feature can be identified; actually, the majority of available methods have been "imported" from the economics and "adapted" to real floods evidence (e.g. willingness to pay method, shadow price, hedonic price and bootstrapping).

3.2.1 Dealing with damage variability: hazard and vulnerability factors

One of the main challenge for damage assessment methods is how to model the variability of damage with respect to both hazard and vulnerability features. Indeed, past events analyses showed that the extent of damage after a flood depends not only on the characteristics of the flood itself but also on the features of the exposed elements and, in detail, on their susceptibility to be damaged (i.e. their vulnerability). For example, the economic damage to a residential building varies either according to the depth of flooding, its duration, the sediment load and so on (see e.g. Kelman and Spence, 2004) or with respect to the building materials, its age and maintenance and the presence of a basement. Likewise, the impact of floods on individuals varies with both the severity of the event and the physical, psychological and social characteristics of the affected people, like age, gender, health conditions, preparedness, social context and so on (see e.g. Tapsell et al., 2002).

More specifically, with respect to the **hazard**, the main factors that influence damage include:

- the depth of flooding,
- the velocity of flooding,
- the sediment and the contaminant load,
- the duration,
- the time of the year when the event occurs.

It is not possible, instead, to create such a synthetic list for **vulnerability** factors because vulnerability is a multifaceted concept, including different kinds of (and combinations of) factors/aspects on which damage can depend.

Accordingly, here, the intention is not that of supplying an exhaustive list of vulnerability factors, as for hazards, but rather to provide a brief outlook of the problem at stake. The notion of Wisner and his colleagues (2004) is emblematic from this perspective:

> *By vulnerability we mean the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process). It involves a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by a discrete and identifiable event (or series or "cascade" of such events) in nature and in society.*

First of all, Wisner's definition implicitly highlights that vulnerability factors (influencing damage) depend on types of exposed element; specifically, results from the ENSURE project (www.ensureproject.eu) show up that a substantial difference exists when exposed elements are considered as individual elements at risk or as an urban system (i.e. from a territorial perspective).

In the first case, vulnerability factors (or indicators) refer mainly to the **physical** characteristics of the elements at risk. It goes without saying that these features vary from item to item so that vulnerability factors for people differ from vulnerability indicators of buildings which, in turn, are different from vulnerability factors for roads, and so on. Table 3.6 reports, as an example, a possible set of indicators for the assessment of physical vulnerability of residential buildings.

The problem of defining vulnerability factors is even more complicated by the evidence that physical vulnerability depends not only on the type of exposed elements but it is site and event specific too; this means that also within the same exposure category (e.g. residential buildings), vulnerability factors influencing the total damage may differ from site to site and from event to event.

Referring, for instance, to Table 3.6, it is possible that not all indicators suit different territorial contexts so that "age" can be relevant for historical Italian cities but not for recent London suburbs, which are homogeneous from this perspective. The MCM, for example, supplies depth–damage curves for:

- five house types;
- seven building ages;
- four social classes of the dwellings' occupants.

Tab. 3.6
Proposed set of indicators of buildings' physical vulnerability

Indicator	Description
Location	Hazard level depends on building location
Type of use	Contents value (and, consequently, damage) depends on buildings' use (e.g. residential, commercial and public service)
Level of maintenance	Well-maintained buildings better face the impacts of floods than crumbling
Age	Age is usually linked to the level of maintenance
Materials	Some materials (like concrete and masonry) are more resistant to the flood impacts than others (e.g. timber and plasterboard)
Number of storeys	The presence of more than one storey allows people to move contents to upper floors
Presence of basement	Basements can be flooded also in case of minor events (small water depth)
Number of openings at street level	Openings at street level make water to easily enter the building
Height from street level	If ground floor is higher than street level, water is hindered to enter the building
Presence of vulnerable equipments	If vulnerable equipments are present in more flood-prone floors than damage can be higher

Even if it is assumed that these three vulnerability variables describe damage variability in the Italian context as well, this does not imply that the five classes foreseen for English "house types" are typical of the Italian context too (and the same can be argued, of course, for all the other explanatory variables).

With respect to the dependence on event type, an example can be made, taking into account building "materials". Their strength/resistance is a crucial factor with respect to flash floods whereas damages depend on the structural reliability of buildings to the high dynamic load of flooding water. On the contrary, in riverine floods, the most important factor is the permeability of building materials because, in this case, damages depend, above all, on how well these materials can face a long exposure to water.

Nevertheless, also the weight of each hazard factor depends on both the nature of the flood and the affected element. So, in flash floods, the depth and the velocity of the water as well as the load of debris are crucial whilst, in riverine floods, the most important factors are the depth of the flooding and its duration.

From the territorial perspective, instead, the interest lies in those aspects that influence the capacity of the exposed items "as a whole" to withstand the disastrous event. In this case, vulnerability factors refer thus to the features of those **functions** (or sub-systems) as well as their **systemic** links (both within the urban system itself and between the latter and the outside environment – see e.g. Lagadec, 2009) that affect the capacity of the whole system to anticipate, cope with, resist and recover from the impact.

Trying to summarise the results of the ENSURE project, these functions or sub-systems basically are:

- *Lifelines/services*: The capacity of infrastructures (like energy, water, transportation, information systems) and essential services (e.g. health, education) to meet their goals/functions

also after the occurrence of an event is crucial in shaping damage; from this perspective connections within and among affected items have a primary role;
- *Economic systems*: Links exist between business activities, banking systems and financial systems; the capacity of affected economic systems to absorb the shock due to the event is critical in defining damage;
- *Institutions*: The adequacy of institutional arrangements (i.e. laws, organisational structures and responsibilities, administrative procedures and customs) as well as institutions' level of emergency preparedness (also considering links among different institutions) influence the event impacts;
- *Social systems*: Social networks affect the productivity and capability of individuals and groups, also during an emergency.

It must be stressed that links exist not only within each sub-system but also among them so that social vulnerability affects economic vulnerability; institutional and social vulnerability are connected to each other and so on. Ideally, vulnerability must be assessed against each of these aspects (and their links).

Besides the complexity of the problem at stake, one of the main difficulty in identifying a set of vulnerability indicators for urban systems lies in the evidence that, as for physical vulnerabilities, they are site and event specific. Moreover, as links within/among sub-systems depend on the spatial and temporal scales at which the damage assessment is carried out, it is equally true that some indicators can be relevant at one scale but not to others.

Accordingly, so far, a variety of indicators have been developed but all of them refer to a specific case study; hence, the problem is still fragmented. The identification of a common set of indicators for territorial vulnerability is one of the main challenging goals of the ENSURE project.

Hence, to summarise, it is possible to state that damage is explained by a lot of variables linked to both hazard and vulnerability whose effect on the total damage is not well established mainly because it is case specific. This explains why assessment procedures have historically focused on a small number of explanatory variables (i.e. the depth of flooding and few vulnerability features, usually, related to physical aspects) whilst the incorporation of other factors, when considered relevant, has been accomplished by "add on" or percentage factors (Mc Bean et al., 1988). This implies that flood damage assessments are currently associated with large uncertainties just because these few variables are not able to describe the variability of damage data (see Merz et al., 2004). Uncertainty about damages is then added to uncertainty on event occurrence, making the decision about issuing a warning more tangled.

3.2.2 Other challenges in damage assessment

Besides damage variability with hazard and vulnerability, there are other difficulties within damage assessment that can be differently handled by assessment methods.

The first point is related to the **economic rationale** of damage assessments given that every appraisal can be carried out either in economic or financial terms. The choice actually depends on the stakeholder the analysis is performed for.

Financial evaluations look at damage from a perspective of a single person or an enterprise, neglecting public affairs and focussing on the impact of the disaster on the firm/person profit rather than the impact on the whole economy. On the contrary, economic evaluations have a broader perspective and want to assess the impact on national or regional welfare. It goes without saying then that the broader economic perspective is more appropriate when flood damage assessments must support public policy decisions, as in the case of EWSs.

The main consequence is that not all damages are relevant in every loss assessment. For example, some impacts, not counted as a financial loss by a business affected by a disaster, can be counted as losses to society (such losses would generally include all intangible losses, much of the disruption caused by disaster, and losses to the governmental sectors). Similarly, there are financial losses that are not economic losses. For example, one company may be forced to close following a disaster and thereby lose its sales market, but others may reap the lost business, resulting in no net loss to the economy.

Therefore, adopting an economic approach enables analysts to omit some damages from the evaluation. In detail, looking at indirect losses to non-residential properties, the MCM (Penning-Rowsell et al., 2005) asserts that "in the majority of cases, indirect losses are unlikely to be significant as the contribution to national economic losses is always close to zero (…) As a result of these evidences, calculating indirect damage is not recommended unless there is an indication that a property or a sector is likely to contribute significantly to the overall present value of damages". On the other hand, an economic evaluation calls for the assessment of some losses which are not relevant at an individual perspective (like costs related to emergency activities) and whose estimate is sometimes still challenging (e.g. intangible damages).

Another problem regards **the value** which is assigned to exposed items, also in the case of tangible damages. In regard to this, two different questions arise, the first being especially relevant for the appraisal of indirect damages. The problem originates from the fact that "the value of a (market) good can be represented in two ways. On the one hand, its value is represented by its price. On the other hand, the good can be considered as a capital goods, 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 price of a good is equal to the sum of its income flow values over the rest of the good's life span. Therefore, summing up both in a flood damage evaluation study would be inappropriate due to double counting" (FLOODsite, 2007). As a consequence, particular care must be taken in evaluating indirect damages given that summing up stock and flow of incomes means double counting the same damage.

The second question concerns, instead, the importance of describing the real damage to exposed elements. In particular, in damage assessments, **depreciated values** should be applied in order to reflect the actual value of a good at the time when it is damaged by a flood. Replacement costs, which instead are usually adopted by insurance companies, overestimate damages because replacement usually involves improvements.

A further matter of interest is related to the use of field surveys to carry out damage assessments. With respect to this problem, the **time of the analysis** is particularly important. Indeed, some damages (above all indirect ones) may become evident even after a long time from the flood (e.g. loss of income, stress and anxiety and damages due to deterioration). As a consequence, if the assessment is carried out too much sooner after the event, an underestimation is likely. Australian guidelines (EMA, 2002) suggest, for instance, an extended time frame of at least 3–6 months after the event. However, the most suitable time frame is site specific and event specific. Likewise, it depends on the point of view adopted in the analysis (e.g. public and private); the right time must be so established with an *ad hoc* analysis.

Last but not least, as already argued above, flood damage assessments are associated with **uncertainties** because of the difficulty in describing damage variability by means of explanatory variables. Moreover, the appraisal of flood damages imports uncertainties also from the hydrological/hydraulic domain (as those related to flood level) and adds further own uncertainties (like errors in estimating economic values rather than vulnerability features). These uncertainties are finally exported into the decision domain.

Chapter 2 has already emphasised that the characterisation of uncertainty is crucial to support the choice of issuing or not a warning. Nevertheless, this matter has been often neglected in the past when the majority of methods supplied data as certain.

The situation is now changing. For example, in the MCM (Penning-Rowsell et al., 2005) the depth–damage data for non-residential properties includes high- and low-susceptibility bands whilst the residential depth–damage data includes a confidence interval for the absolute damage estimates. Likewise, a method has been developed for estimating uncertainty about flood damage calculated according to the Standard Method (Egorova et al., 2008). In this tool, uncertainty is presented in the form of probability distributions.

3.3 Damage assessment worldwide: a critical overview

With respect to damages identified in Table 3.2, Table 3.7 supplies an overview of those assessment methods which are mainly implemented worldwide, in developed countries.

In detail, for each kind of damage, Table 3.7 displays:

- which of the investigated tools take into account that particular damage and how, that is by means of which methodology (e.g. averaging methods and surveys);
- which hazard and vulnerability factors are considered by the various methods.

In addition, in grey, the table highlights those damage categories for which no available methods have been found. The analysis allows, this way, to understand when available methods can be exported to other contexts and, in case, in which contexts.

However, some points must be clarified with respect to the reported information:

- several methods are not “public” that is the respective literature is confidential (e.g. the method developed by “Risk Frontiers” in Australia or the method under development in the European Union);
- a number of methods have been identified through the literature review about which specific literature has not been identified (e.g. the ANUFLOOD methodology, developed in Australia, the Czech methods identified in Meyer and Messner, 2005)
- literature is sometimes not in English (e.g. in the case of German methods identified in Meyer and Messner, 2005).

For these reasons only those methods for which a full literature was already, or simply, available are analysed here. Specifically, the following methodologies have been taken into account:

- the Dutch “Standard Method” (Kok et al., 2005; Meyer and Messner, 2005);
- the American “HAZUS” method (Federal Emergency Management Agency, FEMA, 2009; Scawthorn et al., 2006a,b);
- the tools suggested by Emergency Management Australia (EMA, 2002)
- the tools suggested by the English Environment Agency – EA, reported in the MCM (Meyer and Messner, 2005; Penning-Rowsell et al., 2005);

The **Standard Method** is applied to a diked area and has been developed within the framework of the Dutch Department of Public Works study “Schade en Slachtoffers”, the aim is to create a broad-based method for establishing damage and casualties caused by flooding in order to compare different studies.

Tab. 3.7
Damage assessment methods worldwide

Exposed elements	**Damage**	**Appraisal method**			
		Appraisal method	**Source**	**Hazard factors**	**Vulnerability factors**
Private buildings	Physical damage to structure	Damage curves	Standard Method	Depth, velocity	Type
			HAZUS	Depth	Type, Number of floors, presence of basement
		Averaging approach	RAM	Flood extent	–
	Physical damage tor contents	Damage curves	Standard Method	Depth, velocity	Type
			HAZUS	depth	number of floors, presence of basement
		Averaging approach	RAM	Flood extent	–
	Additional costs to property owners	Survey	FHRC	Depth	Typology, height
		Damage curves	BTE	Depth	Household earning
		Ad hoc method (from physical damage)	HAZUS	–	–
	Cost of protective action				
	Sentimental loss related to direct damages	Survey	FHRC	–	Household characteristics (age, social class)
Commercial buildings	Physical damage to structure	Damage curves	Standard Method	Depth	–
			FHRC	Depth, duration	Typology
			Au BTE (Smith)	Depth	Susceptibility, dimension
			HAZUS	Depth	Type, number of floors, presence of basement
		Averaging approach	RAM	Flood extent	Value of contents
	Physical damage to contents	Damage curves	Standard Method	Depth	–
			FHRC	Depth, duration	Typology
			Au BTE (Smith)	Depth	Susceptibility, dimension
			HAZUS	Depth	Type, number of floors, presence of basement
		Averaging approach	RAM	Flood extent	Value of contents

(*continued*)

Tab. 3.7
Continued.

Exposed elements	**Damage**	**Appraisal method**			
		Appraisal method	**Source**	**Hazard factors**	**Vulnerability factors**
	Indirect damages	Damage curves	Standard Method	Depth	–
			FHRC	Depth, duration	Typology
		Percentages	RAM	–	Type of area rural or urban
		Ad hoc method (from economy)	HAZUS	–	–
	Cost of protective action				
	Sentimental loss related to direct damages				
Farming estates	Physical damages	Damage curves	Standard Method	Depth	–
			HAZUS	Duration, timing	Type of crops
		Averaging approach	RAM	Flood extent, duration, timing	Type of enterprise
	Additional costs	Averaging approach	RAM	Flood intensity	Type of enterprise, type of damage
	Loss of income	Damage curves	Standard Method	Depth	–
			HAZUS	Duration, timing	Type of crops
		Percentages	RAM	–	Type of area rural or urban
	Cost of protective action				
	Sentimental loss related to direct damages				
People	Deaths	Damage curves	FHRC	Depth, velocity, debris content	Age, disability or sickness
			Standard Method	Depth, flow rate, rise rate	–
		Averaging approach	RAM	Flood probability	Size of population

	Injuries	Averaging approach	RAM	Flood probability	Size of population
		Damage curves	FHRC	Depth, velocity, debris content	Age, disability or sickness
	Psychological damages	Averaging approach	RAM	Flood probability	Size of population
		Damage curve	Au BTE (Handmer)		People experience
		Survey	FHRC	–	Age, social class, gender
Public buildings	Physical damage to structure	Damage curves	FHRC	Depth	Typology (schools and churches only)
			HAZUS	Depth	Type, number of floors, presence of basement
		Survey	FHRC	Depth, flood duration	–
	Physical damage to contents	Damage curves	HAZUS	Depth	Type, number of floors, presence of basement
	Service disruption	Survey	FHRC	Depth, flood duration	–
	Sentimental loss related to direct damages				
Infrastructures	Physical damage	Damage curves	Standard Method	Depth	Type
			HAZUS	Depth	Type, component
		Averaging approach	RAM	Flood extent	Roads and bridges: surface, dimension
	Service disruption	Damage curve	Standard Method	Depth	Type
			FHRC	Duration of break	Type of service, type of consumer
		Network analysis	FHRC	Flood extend	Road type
		Percentages	RAM	–	Type of area rural or urban

(*continued*)

Tab. 3.7
Continued.

Exposed elements	Damage	Appraisal method			
		Appraisal method	Source	Hazard factors	Vulnerability factors
Environment	Ecological damage	Impact on ecosystem condition	Queensland guidelines	Flood regime	Ecological community
	Services disruption	Damage curves	Standard Method	Depth	–
		Percentages	RAM	–	Type of area rural or urban
	Sentimental loss related to direct damages				
Cultural heritage sites	Physical damage	–			
	Services disruption	Percentages	RAM	–	Type of area rural or urban
	Sentimental loss related to direct damages				
Local authorities	Cost of warning activities	Damage curves	FHRC	Flood scenario (frequency), duration	Flood area (residential or commercial)
		Percentages	RAM	–	Type of area rural or urban
	Cost of emergency activities	Damage curves	FHRC	Flood scenario (frequency), duration	Flood area (residential or commercial)
		Percentages	RAM	–	Type of area rural or urban
	Loss of trust by people				

Source	Damage curves	
FHRC	Absolute	Synthetic
HAZUS	Relative	Real
Standard Method	Relative	Real

Tab. 3.8
Damage curves features

The **HAZUS** method is a nationally applicable standardised methodology that estimates potential losses from earthquakes, hurricanes, winds, and floods. HAZUS-MH is the software which has been developed to carry out the appraisal by the FEMA. The software allows estimating potential flood losses on a regional basis and can be ordered free-of-charge by Federal, State and local government agencies and the private sector.

Similarly, the Australian tools have been conceived as guidelines for a rapid and comprehensive evaluation of flood management benefits and costs, at floodplain scale. Australian tools essentially equal the methods of the Australian Bureau of Transport Economics – **BTE** (2001) and the Rapid Appraisal Method – **RAM** (Read Sturgess et al., 2000; EMA, 2002).

Otherwise, the **MCM** includes both data and methods which can be used at several scales. The methods have been developed by the FHRC at Middlesex University.

First of all, from Table 3.7, it is evident (again) that damage functions are mainly used for the estimate of direct tangible damages even if their implementation starts to extend also to other losses categories. For example, damage curves and average values have been derived to quantify flood impacts on individuals, although not in monetary terms. Likewise, some indirect but tangible damages (like those to private and commercial buildings) are sometimes evaluated by damage functions, above all, through the averaging approach. Nevertheless, these tools represent a first attempt rather than a general accepted rule and are still strictly site specific. Hence, they are related to the economy of the area for (and from) which they are derived.

The same can be maintained, however, every time absolute economic values are adopted. Among investigated methods, the one developed by FHRC is the only one that adopts absolute curves (see Figure 3.5). At the same time, it is also unique to adopt synthetic values (see Table 3.8).

Table 3.7 indicates that almost no specific methods (except for the one reported in EMA, 2002) have been developed for the assessment of floods impact on environment. From this perspective, all the investigated tools refer to methods from other disciplines, as argued in previous section. Finally, it can be inferred that little attention has been paid to sentimental losses, damages to the cultural heritage as well as the costs related to protective actions.

Changing over damage variability, the analysis reported in Table 3.7 shows that, so far, the dependence from hazard factors has been more investigated than vulnerability's. The explanation is quite obvious and matches with the current state of the art as argued in Section 3.2.1.

Nevertheless, it must be stressed that damage data are actually often supplied in terms of depth–damage curves also when other explanatory variables have been investigated. For example, in the MCM, damages to residential buildings have been examined with respect to both the depth and the duration of flooding but data are supplied by means of two different depth–damage curves, each one concerning a different duration (see Figure 3.6).

Looking instead at the vulnerability factors, the situation varies with respect to the exposed items. For private buildings, the two factors that have been mostly investigated are the presence of a basement and the number of floors. This agrees with the evidence that damages to buildings are generally lower when more than one storey is present because some facilities (like electric boxes and boilers) and/or contents (like furniture and household appliances) can be put in or

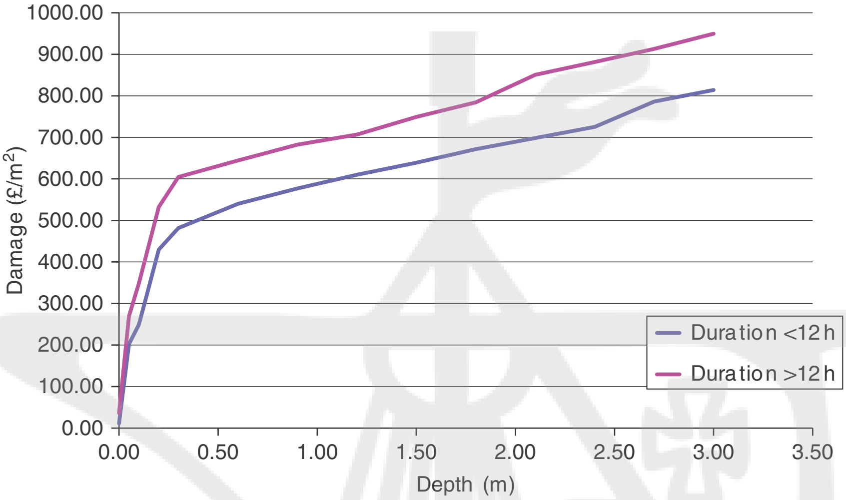

Fig. 3.6
Damage for residential sector, according to MCM, for different flood duration

moved to upper floors. Likewise, damages vary according to the presence, or not, of a floor below the ground level that can be flooded.

With respect to commercial buildings and commercial activities (like farming estates and utility services), the vulnerability factors that have been mostly investigated are the type of activity and its size. Indeed, it is plausible that both direct and indirect damages to a firm depend on how much its capital (both fixed and not) can be impaired by the flood. This, in turn, depends also on the extent of the capital itself.

Looking finally at individuals, the vulnerability factors that are mostly analysed are those related to the physical and economic skills of potential affected people (like age, gender and social class) whilst less attention has been paid to the social/psychological sphere. This is not due to any sort of evidence rather to a real, objective difficulty in both analysing physiological/social aspects themselves and in counting them in a quantitative assessment. In fact, looking at available literature one can state anything but behavioural, psychological and social aspects are not important in shaping damage. Unfortunately, these aspects are almost ignored by available methods.

Last but not least, it must be stressed that vulnerability factors refer only to physical features. Vulnerability of urban systems is usually not included in damage assessment method.

3.3.1 Exporting methods: suitable features

This section finally aims at identifying those features that make easier to export a method to other contexts than the one in which it has been conceived. Of course, the implicit objective of such an analysis is that of identifying proper tools to be applied in the case study (see Section 3.4).

First, **relative damage functions** are, in general, easier to transfer to other regions than absolute functions because they are independent from the value of assets (which, of course, is site specific). On the other hand, an advantage of the use of absolute functions is that it is no longer necessary to determine the value of elements at risk, for each study. This considerably reduces the effort of the analysis as only information regarding vulnerability has to be gathered. Nevertheless, this means that a well-developed, differentiated and frequently updated depth–damage database must be available.

Second, **synthetic data** should be preferred to real data. As reported in the MCM, in fact, there is a disadvantage in using real data which originates from "the evidence that past post-flood surveys can either exaggerate flood losses (in the immediate aftermath of the flood) or incorrectly miss significant items of flood damage (where the survey is done before the full impact of the flood has had time to emerge)" (Penning-Rowsell et al., 2005). Moreover, real data can be biased by the economic appraisal. In other words, it has to be ensured that all ex-post damages are evaluated with the same assessment concept (i.e. that depreciated values are ascertained and not full replacement values as it is often done by insurance damage adjusters).

A last aspect is finally related to the capacity of available methods to truly describe the reality. This is always crucial, above all, when one is interested in transferring available data to other regions. The problem arises here because of the variability of damage with hazard and vulnerability factors, which are usually site specific.

The point is that even when explanatory variables suit the reality of the "new" context one cannot take for granted that the respective classification is also appropriate. For instance, quoting again the example reported in Section 3.2.1, regarding vulnerability indicators for residential properties according to the MCM method, remind that it must not be taken for granted that neither MCM indicators nor their classification suit the Italian context as well (and the same can be argued, of course, for all the other explanatory variables). This aspect further limits the possibility of transferring methods and must be carefully evaluated before deciding about. At this perspective, methods with **few explanatory variables** must be preferred.

3.4 Implementing tools: the case of Sondrio

In this section, a damage assessment is carried out for the case study under investigation (i.e. the flood risk induced by the Mallero River in the town of Sondrio). Results will be used in the next chapter to evaluate Sondrio EWS performance.

As already discussed, in previous section, research on damage assessment is still at an embryonic stage; various analytical tools have been implemented but no shared or standard methodology exists. Hence, the models implemented in the following case study must not been seen as compulsory or as a standard methodology but rather as a possible (the most suitable) choice.

Likewise, previous section highlights a general lack of tools to investigate some kinds of damage (intangibles, in particular). This is a current limit to a proper assessment of flood damages. On the other hand, it is evident that their real weight depends on the particular point of view that is adopted. In the following implementation, then, the objective is not to be exhaustive but rather to identify and model those damage components that are essential for the problem under investigation that is to analyse and improve FEWSs performance.

3.4.1 The stakeholder perspective

In accordance with the results of the previous chapter, an index is required, to evaluate FEWSs performance, that takes into account both the frequencies of warning outcomes[4] and the size

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[4] False warning (FW), forecasted event (H), missed event (ME) and calm (C).

of their consequences. Then, a rational warning criterion can be defined which consists of trusting that forecast that minimises the index.

At this point, a question arises: which consequences must be taken into account? Or, in other words, which are the damages for which FEWSs are designed for?

As discussed in previous section, a damage assessment should be ideally as much comprehensive as possible; actually, the problem:

- must be simplified, because of the difficult or impossibility of evaluating some types of damages (e.g. indirect and intangibles, see Section 3.2), and
- can be simplified, given the evidence that the weight of each kind of damage depends on the **stakeholder** perspective, thus, for example, losses due to the disruption of economic activities are vital for individuals but irrelevant for the national community.

Hereby, in accordance with the rest of the book, the point of view of local floodplain managers is assumed. Hence, the following damages have been estimated:

- direct damage to buildings;
- direct damage to lifelines;
- first-aid and emergency costs;
- warning costs.

With respect to indirect economic damages, this choice is in accordance with the point of view here adopted (i.e. local floodplain manager) which justifies the assumption of an economic approach and so the omission of losses of earnings (see Section 3.2.3).

On the other hand, costs to face the emergency and intangibles can be relevant for local authorities. The former are taken into account but the latter are not included in the assessment; the reason is twofold:

- first, the author will not evaluate intangibles (e.g. lives and damage to cultural heritage) in monetary terms;
- then, the objective difficulty in their quantitative estimation that, instead, is required if one wants to sum intangibles with other damages to calculate a unique performance index.

These led to give up intangibles estimation even if this point represents an important challenge for future research and a limit of the present analysis.

Last, besides losses to individuals, environment, etc., a further intangible has not been considered here that is instead critical for local authorities: the “political cost” of warning, in terms of trust/approval by citizens. Indeed, in case of false warning or missed event, an intangible damage occurs for local authorities because in these circumstances they lose the trust of people with respect to their capacity to face the emergency; otherwise, in case of a hit event, a gain in trust can take place.

The occurrence of political costs has been observed several times in the past, however, no methods have been found to quantify them. Again, the topic represents a priority for future research.

Anyway, what it is important to stress here is that once recognised that the issue of evaluating FEWSs performance lies in the assessment of their capacity to reduce damages, then the real problem becomes the evaluation of those damages that should be avoided.

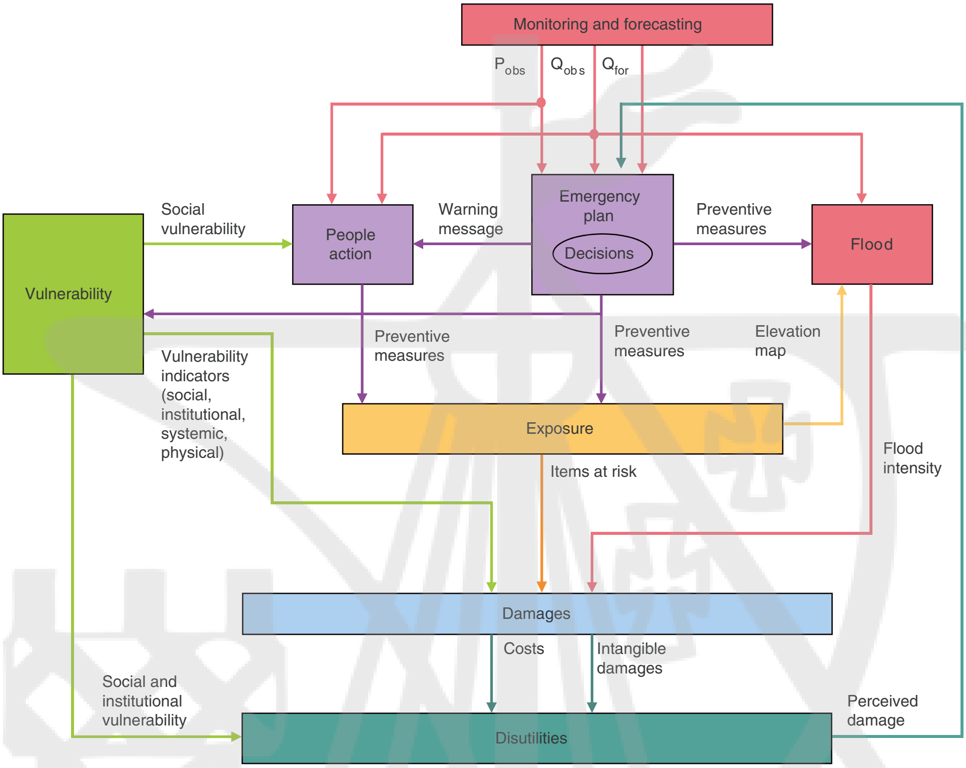

Fig. 3.7
The warning decision-making process

In other words, the framework that is assumed along the book to describe the warning process (reported, again, in Figure 3.7) should be read according to both a top-down and a bottom-up point of view:

- the flow should be followed from the top to the bottom, by applying step by step all the required models, to evaluate the value of the performance index (i.e. the damage reduction);
- on the contrary, the performance index must be first defined, meaning that what damage is, and specifically what damage reduction means, must be specified at the beginning. With respect to this, the stakeholder perspective and the actions implemented during warning/emergency (i.e. the upper part of the flow) are central.

3.4.2 Damage to buildings

Damage to buildings includes physical damages to both buildings structure and contents because of the direct contact with the flooding water. Here, it has been evaluated by means of **stage–damage** curves, deriving from available methodologies, previously investigated in Section 3.3[5].

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[5] The Dutch "Standard Method", the American "HAZUS" method, the tools suggested by Emergency Management Australia and the English MCM method.

With respect to this, the RAM method is the only one that does not implement stage–damage curves. Among the others, the tools here implemented are the curves by the Unites States Army Corps of Engineers (USACE, 2003) which are included in the HAZUS method.

This choice derives from the following considerations:

- First, even if the MCM is probably the most complete database (in terms of depth–damage relations), it implements only absolute functions, expressing damage as pound sterling without any reference to the economic value of the affected buildings. This makes the MCM difficult to apply to other contexts but the original one. Methods implementing relative functions, like the curves by USACE, seem then more suitable for the analysis of the case study;
- Second, curves by USACE estimate damage to both buildings' contents and structure as a percentage of buildings structure value. This allows to avoid the estimation of buildings contents which is a problematic point, bringing uncertainty in the whole damage assessment;
- Then, among explicative variables, USACE adopts the presence of basement which is the main explicative factor in the Italian context (Luino et al., 2009). However, this vulnerability variable is not taken into account in the other candidate method (i.e. the Standard Method);
- Next, both the last two candidate methods[6] adopt water level as the only hazard explicative variable (i.e. damage is supplied against water level) but, at the same time, both implemented physical surveys to estimate depth–damage relations. Hence, besides water level, all the curves implicitly take into account also other features of the hazard according to which they have been set. Whilst the curves by USACE derive from physical surveys after river floods, those from the Standard Method refer to coastal flooding. From this perspective, then, the curves by USACE better suit the context under investigation;
- finally, USACE supplies also a confidence interval for depth–damage curves. This can support a further analysis of the uncertainty linked to damage assessment.

Of course, the method by USACE is characterised by limiting factors as well, that would hinder its implementation in the case study. However, these limits are present in other available methods too; thus, they did not influence the final choice. Specifically, it must be stressed that:

- deriving from physical surveys, the method is based on damages that really occurred. However, it is not clear, from the available documentation, if a FEWS was in place, or not, in the examined contexts. According to definitions in Section 3.1, the point is that in the first case method would supply actual damages, on the contrary, in the second case, potential damages would be provided. Here, damages have been considered as potential;
- unlike other methods, the curves by USACE adopt few vulnerability explicative variables (i.e. the presence of basement and the number of storeys); however, this can be seen as a strength point as well. Indeed, this way, the curves are less "linked" to the original context and, thus, more suitable for the case study.

Figures 3.8 and 3.9 display the original curves that have been implemented in the case study, respectively, for buildings structure and contents. Starting from them, a unique depth–damage curve[7] has been computed that has been assumed as representative of the whole town of

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[6] The "Standard Method" and the method by USACE.

[7] Really, two curves have been calculated, for structures and contents respectively.

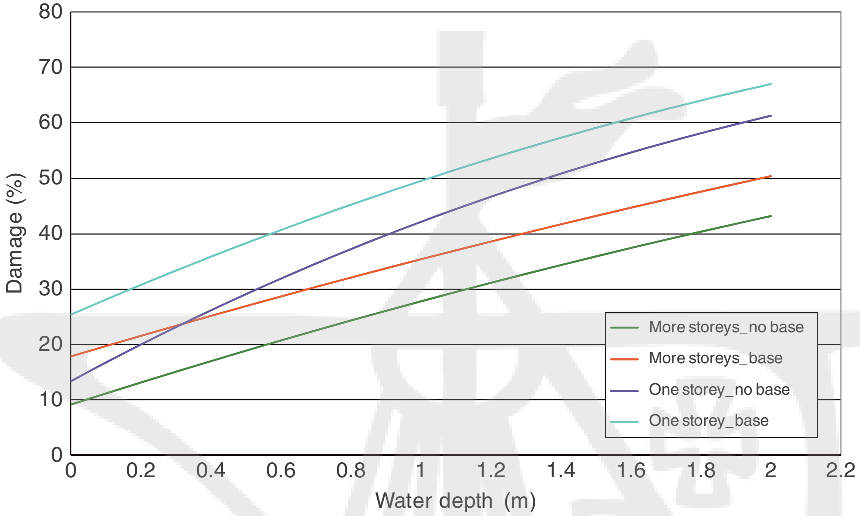

Fig. 3.8
Depth–damage curves for building structures according to UASCE

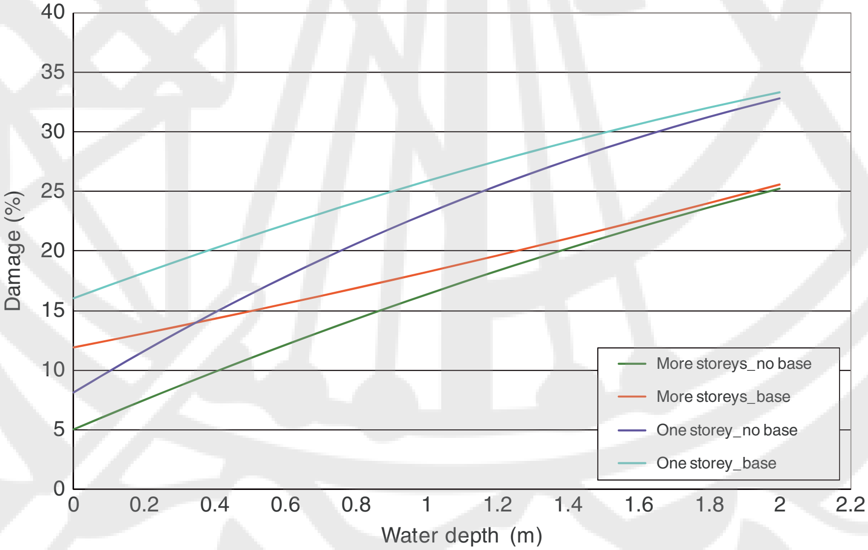

Fig. 3.9
Depth–damage curves for building contents according to UASCE

Sondrio (see Figure 3.10). The curve supplies damage (in terms of €/m^2 of exposed building) against water depth.

It must be highlighted that no specific curves have been assumed for non-residential (i.e. commercial) buildings whilst economic value differs from residential and non-residential buildings. Specifically, Table 3.9 reports the economic value (in terms of €/m^2) of building structures that has been assumed in the analysis. It can be observed that different values have been assumed for residential and commercial buildings, as well as for disused buildings.

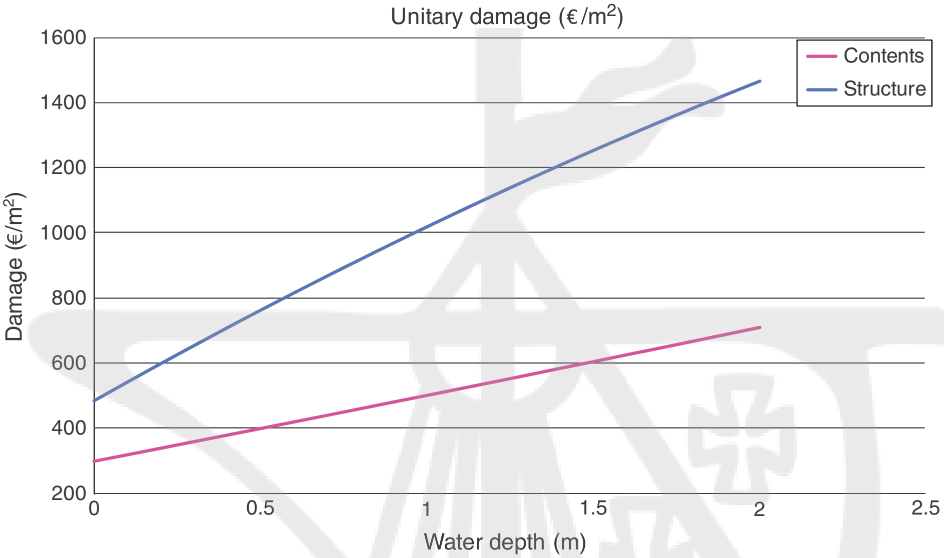

Fig. 3.10
Depth–damage curves implemented in the case study

Use of building	Economic value (€/m^2)
Residential	2100
Commercial	2750
Disuse	1500

Tab. 3.9
Buildings structure economic value

Buildings value was derived from the real estate and property price database[8] for the first semester of 2009; this should reflect the actual value of buildings at the time of the assessment (i.e. the depreciated value, see Section 3.2).

The computation of the "unitary damage" in Figure 3.10 is based on the analysis of 50 buildings for which specific data were collected, during a previous analysis (Cogefar-Cariboni, 1989). These buildings have been assumed as representative of all buildings in Sondrio.

In detail, the computation of the curve involved the following steps:

1. first, each building has been assigned to a vulnerability class (i.e. one storey–no basement, one storey–basement, more storeys–no basement, more storeys–basement);
2. second, the exposed area of each building has been calculated, in line with the evaluation criteria of the US FEMA (see Luino et al., 2009), reported in Table 3.10;
3. next, the use of each building has been defined (i.e. residential, commercial, disused); this allows to assign an economic unitary value (see Table 3.9) to every building structure;
4. then, the total economic value of each building has been calculated by multiplying the exposed area (calculated at step 2) per the unitary economic value (set at step 3);
5. the total economic value of each class has then been calculated by adding the values of the buildings within each class;

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[8] Osservatorio del Mercato Immobiliare dell'Agenzia del Territorio

Tab. 3.10
Buildings' economic value

Vulnerability features	Exposed area	
	Description	**Calculation**
No basement	Ground floor	Surface area
Basement	Ground floor and basement	Surface area + 0.25 × surface area

6. next, starting from curves in Figures 3.8 and 3.9, new relations have been calculated that supply, for every class, the absolute damage (in terms of €) against water depth; this involved multiplying the original curves per the economic value of the corresponding class, as calculated at step 5;
7. by adding all the curves that have been computed at previous step, the relation supplying the absolute damage (in terms of €) against water depth, for all the 50 buildings, has been identified; by dividing it for the total surface area of the 50 buildings, the unitary curve in Figure 3.10 has been finally derived.

By applying the relation in Figure 3.10, damage to single building can be calculated as:

$$D_j = V_j \cdot d(h_j) \tag{3.1}$$

where:

- D_j is the total economic damage to building j,
- V_j is the surface area of that building,
- $d(h_j)$ is the unitary damage (in terms of €/m^2) related to the water depth h_j (deriving from figure 3.10),
- h_j is the water depth at building j, for the hazard scenario under investigation.

Then, in order to estimate damage to buildings, three inputs are required:

- the hazard scenario (i.e. the river discharge);
- the water depth, at each building locations, for the hazard scenario under investigation[9];
- the surface area of each building.

It must be stressed that the curve here implemented does not allow to take into account the effect of water velocity and flood duration on damage which, instead, can be significant in the context under investigation. This is a present limit of available assessment tools that usually supply damage against water depth only (see Section 3.2).

3.4.2.1 *The hazard estimation*

With respect to the hazard scenario, the damage assessment has been carried out for each of the 36 events previously identified by means of the back analysis (see Chapter 2).

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[9] This implies the estimation of the exposed buildings for the analysed scenario.

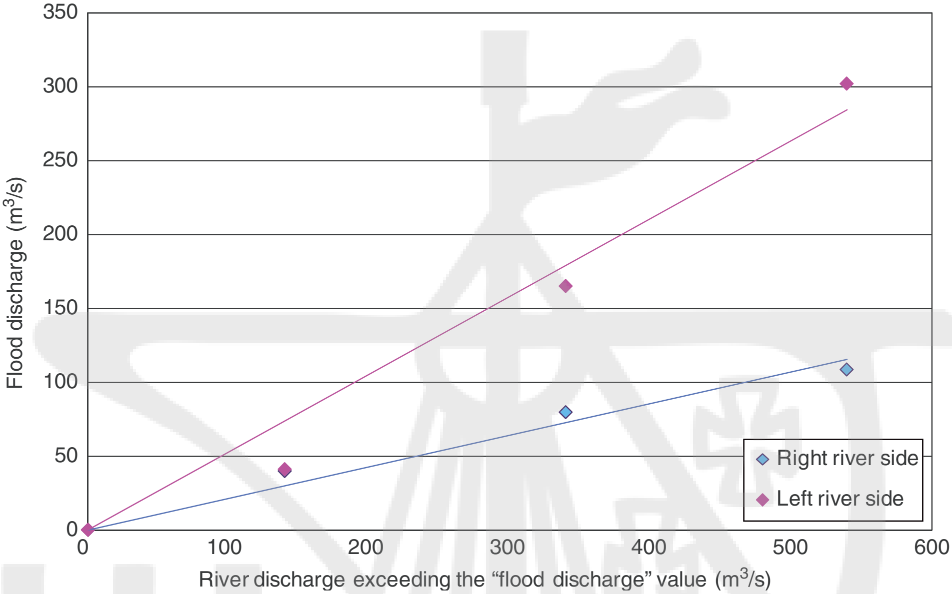

Fig. 3.11
Flood discharge against river discharge: implemented relationship according to the hydraulic model

To estimate the corresponding water depth, at each building locations, results from previous studies have been used. Specifically, the analysis carried out by Ismes-CAE (1988) has been taken as reference; it includes:

- an hydraulic analysis of the Mallero River;
- inundation maps for the city of Sondrio, for three different flood scenarios.

Starting from them, first the relation between river discharge and flood discharge was derived. Graph in figure 3.11 displays the plot of river discharge against flood discharge, derived from the hydraulic analysis; given the weak correlation among the two variables, the required relation was computed by means of the linear interpolation of data in figure 6.7. It must be noted that they refer to the case in which bridge openings are closed by gates.

The second step of the analysis consisted of a spatial interpolation of available inundation data. Specifically, pointed data on maps have been interpolated on the whole area affected by the flood. This way it is possible to know the water depth at each location, for each flood scenarios. The spatial interpolation is grounded on a triangular grid (see Figure 3.12) covering the area affected by the most severely investigated flood. Thus, external areas have been implicitly assumed as not exposed to the flood risk.

After the interpolation, a constant water depth, equal to that of the central point, has been assumed for every point within the same triangular cell.

Last but not least, the relation between the water depth and the river discharge has been derived for each cells of the grid, by a linear interpolation of available data. Hence, at this point, given a specific river discharge, the corresponding water depth can be calculated, at each location of the affected area.

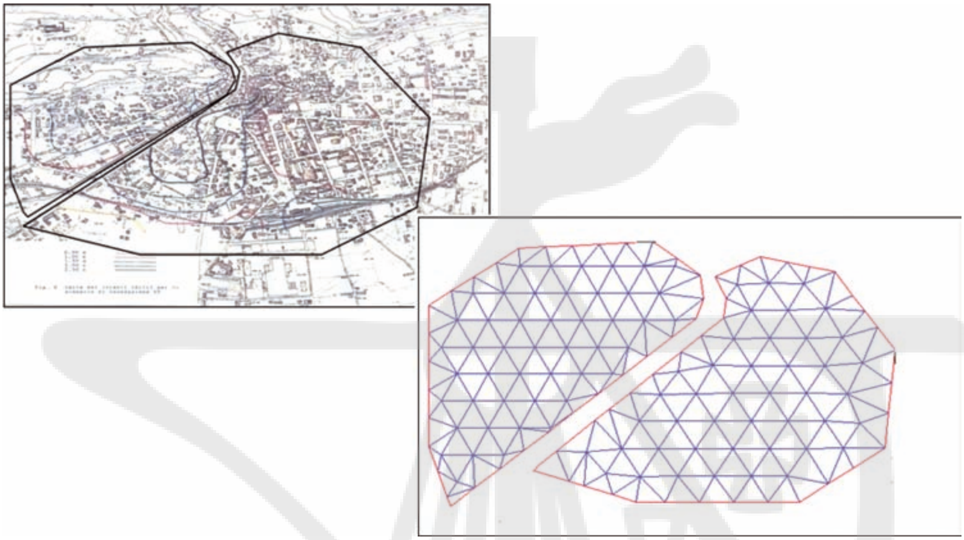

Fig. 3.12
The grid used for the spatial interpolation and flood map for the city of Sondrio

River side	Density of buildings (m^2 of exposed buildings/m^2 of affected area)
Left	0.32
Right	0.24

Tab. 3.11
Density of buildings in the area under investigation

3.4.2.2 *The exposure estimation*

To make the procedure quicker, the density of buildings has been evaluated by dividing the surface area of all the buildings within the grid by the area of the grid itself. However, the operation has been differently carried out at left and right river side (see Table 3.11), because of the difference in the urban fabric.

This way, once the area of each cell is known then an estimate of the exposed area of the buildings within the cell can be inferred as well.

3.4.2.3 *The damage assessment*

For every hazard scenario (i.e. river discharge), for each cell, the damage assessment involves the following steps:

- first, the corresponding water depth is calculated;
- second, the unitary damage is computed, by applying the depth–damage curve in Figure 3.10;
- then, the total damage is calculated, by multiplying the unitary damage per the area of exposed buildings, within the cell.

The total damage derives then from the addition of all the damages related to each cells.

Figure 3.13 displays the spatial distribution of the hazard (in terms of water depth) and of the damage (in terms of M€/m^2), for the same flood scenario. Here, the effect of the vulnerability

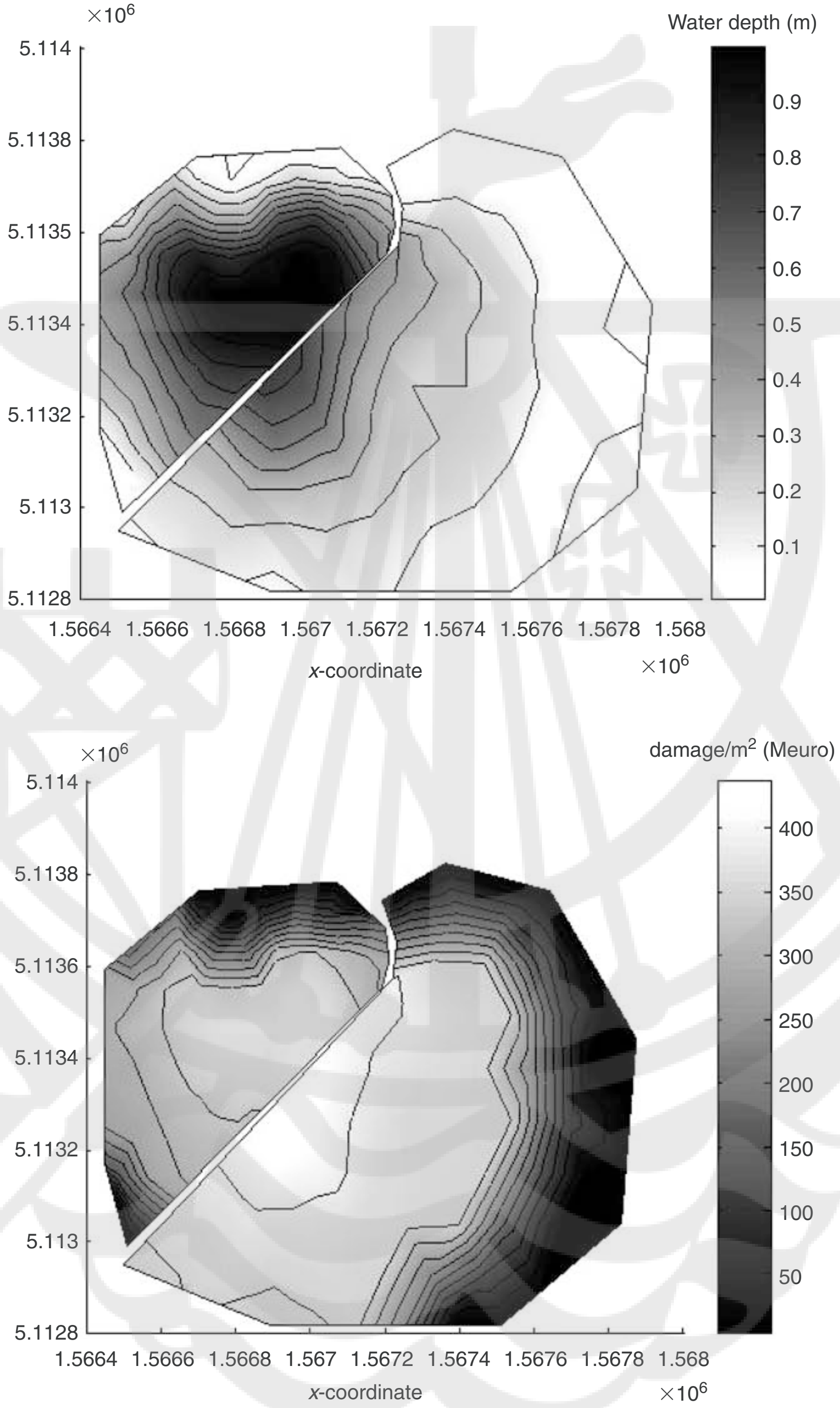

Fig. 3.13
Spatial distribution of hazard and damage for a medium hazardous scenario

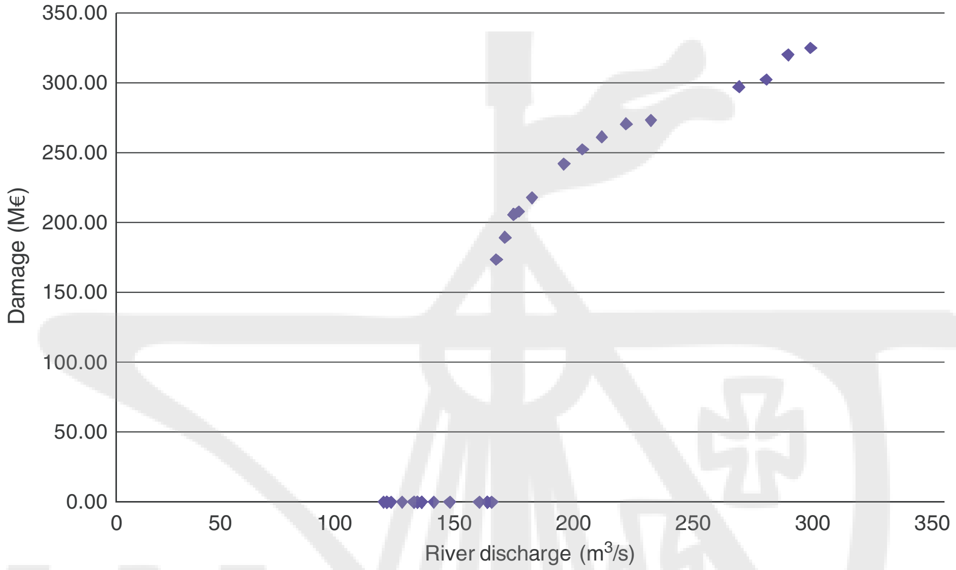

Fig. 3.14
Results of damage assessment for buildings

function (i.e. depth–damage curve) as a transfer function from hazard to damage is evident. With respect to this, it must be observed that, according to the adopted hypotheses, only hazard is actually spatially distributed. Vulnerability is assumed as a constant for the whole town (by implementing an average depth–damage curve) whilst exposure is constant and varies only with respect to the river side. As a consequence, gradients change but the spatial behaviour is the same for both hazard and damage.

Figure 3.14 displays instead buildings damage assessment results for the 36 events under investigation. Damage is equal to zero below 160 m^3/s, which corresponds to the minimum river discharge above which river floods (see Chapter 2). Then, damage increases as river discharge increases, in accordance with evidences from the past showing that the more is the river discharge, the more is the flood discharge and so the affected area.

3.4.3 Damage to lifelines

Lifelines include all those systems which supply people with required services to lead a "quite life" (e.g. water, gas, sewage, transportation and electricity). All of them are crucial during emergency and potentially all of them could be affected by a flood. Here, only direct damage to roads and railways has been taken into account, the reason being a total lack of data about other systems.

As for buildings, damage to roads and railways has been calculated by means of **depth–damage** relations. With respect to this, among investigated tools, both the Standard Method and the HAZUS method supply reference values but curves that are quoted in the HAZUS method have not been found in literature; thus, the Standard Method is the one implemented here.

Figure 3.15 displays the original curve supplied by the method. It describes the relative damage (in terms of percentage of the reconstruction cost of the system) against water depth.

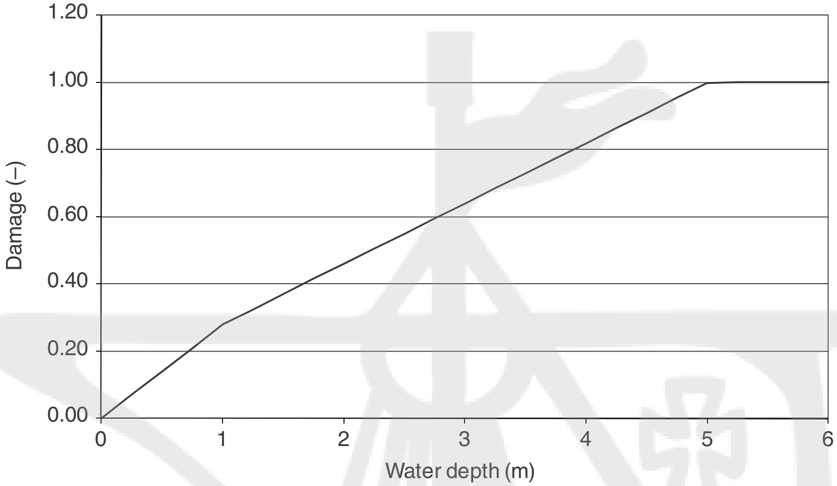

Fig. 3.15
Depth–damage curve to roads and railways according to the Standard Method

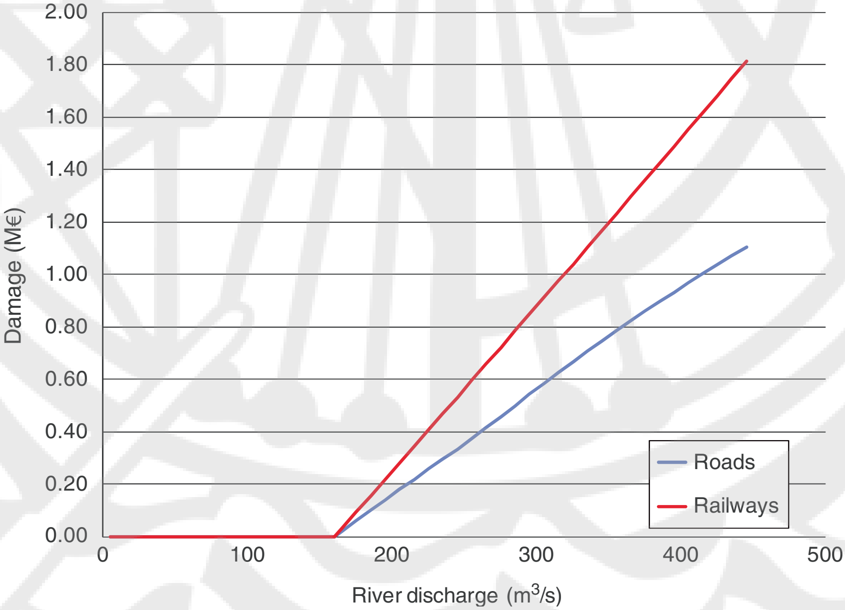

Fig. 3.16
The damage curves to roads and railways for the town of Sondrio

Starting from it, with a procedure similar to those applied to buildings (see previous section), new relations have been computed, providing, respectively, the absolute damage to roads and railways (in terms of €) against river discharge (see Figure 3.16) for the town of Sondrio.

Table 3.12 reports reconstruction costs which were implemented in the analysis (in terms of €/km). Reconstruction cost is strongly context specific and so no indication is available in

Type of items	Reconstruction cost (€/km)
Roads	1,000,000
Railway	15,000,000

Tab. 3.12
Roads and railways economic value

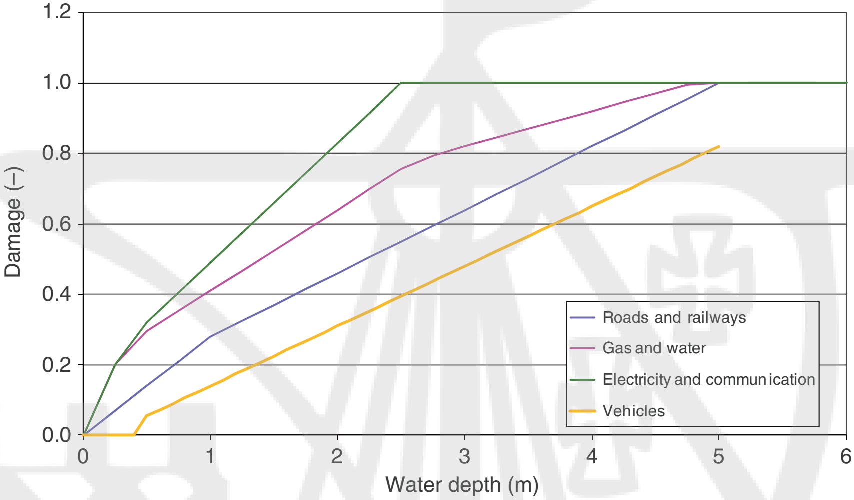

Fig. 3.17
Depth–damage curve to infrastructures according to the Standard Method

literature. Here, expert's opinion has been taken as reference. However, implemented values are in line with those assumed by the Standard Method.

By applying relations in Figure 3.16, the assessment of damage to roads and railways simply requires to know the hazard scenario (i.e. river discharge). In line with previous section, the value of the damage for the 36 events previously identified by means of the back analysis has been carried out.

3.4.3.1 *The "weight" of neglected components*

In order to get an estimate of the direct damage to neglected components[10], the procedure previously described has been carried out also to evaluate damage to gas, water and electric pipelines, under the hypothesis that their length (i.e. exposure) is equal to that of roads. Of course, this is an arbitrary assumption that cannot be taken as valid (without being verified) without impairing the goodness of the assessment. For this reason, following results have not been considered in the analysis; anyway, they represent a useful suggestion of the "weight" neglected components would have on the total damage.

Figure 3.17 reports depth–damage curves that have been implemented in the analysis which derive from the Standard Method. As for roads and railways, they supply the relative damage (in terms of percentage of the reconstruction cost of the system) against water depth.

With respect to the reconstruction cost, instead, a parametric value has been assumed for each system (in terms of €/km) that is reported in Table 3.13. As for the transportation

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[10] It must be reminded that no data are available for other lifelines than the transportation system.

Type of items	Reconstruction cost (€/km)
Water (supply)	250,000
Water (drainage)	400,000
Gas	100,000
Electricity	40,000

Tab. 3.13
Infrastructures economic value

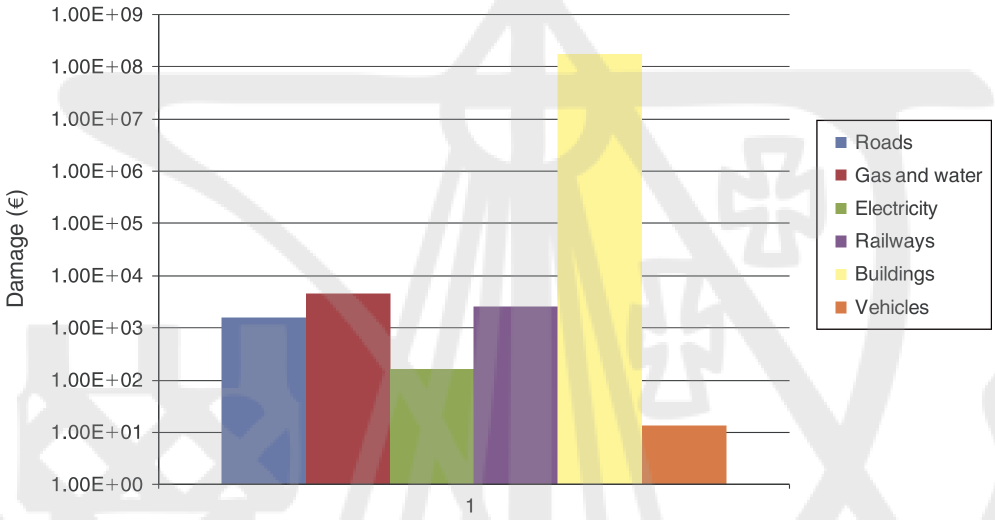

Fig. 3.18
Damage components and their weight, comparing to that of buildings ($Q = 160.4\,m^3/s$). N.B.: The log scale has been assumed for the damage axis

system, reconstruction costs are strongly context specific and so no indication is available in literature. In the present analysis, values from Italian technical reports have been taken as reference. Unfortunately, unlike in the previous case, no comparison is possible with values assumed by the Standard Method as it does not provide any reference value for other lifelines than roads and railways. This would further weaken an analysis made according to the above hypotheses, corroborating the choice of not considering, in the following, the components under investigation.

Figure 3.17 highlights that, besides damage to infrastructures, a further category has been estimated that is not included among infrastructures but whose damage is related to them, being damage to vehicles. Vehicles, along with buildings, represent one of most exposed category of items, at least in urbanised areas; thus, it is important to assess their weight.

With respect to this, it has been assumed an average of 250 vehicles for every kilometre of exposed roads and a “reconstruction cost” of 1070 €/vehicle, in accordance with the value assumed by the Standard Method.

Figures 3.18 and 3.19 display the results of the analysis for two different river discharge values which correspond, respectively, to the minimum and the maximum discharges that have been recorded during the 36 events under investigation (see Chapter 2), which originates a “virtual” flood.

It is possible to observe that direct damage to single infrastructures (including that to vehicles) is much less than direct damage to buildings; specifically damage to infrastructures

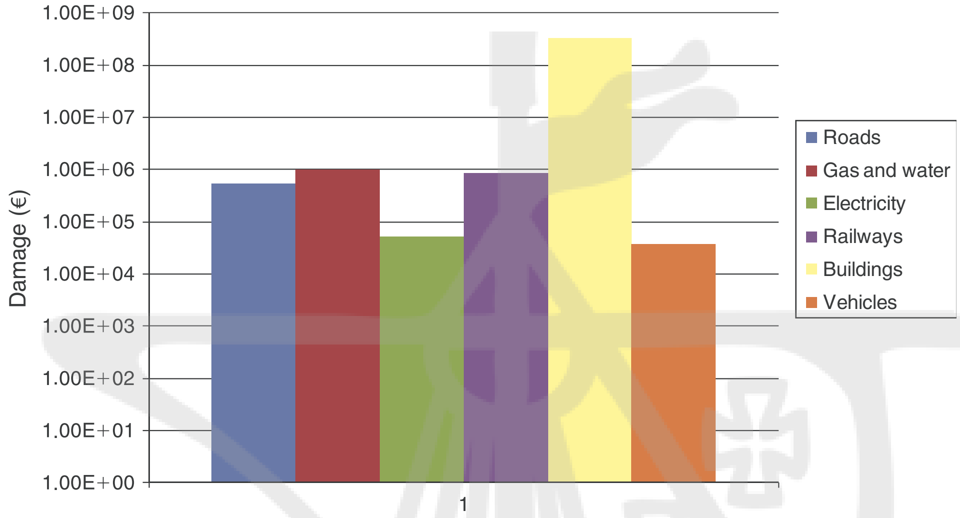

Fig. 3.19
Damage components and their weight, comparing to that of buildings ($Q = 293.1\ m^3/s$). N.B.: The log scale has been assumed for the damage axis

is, on average, five orders of magnitude less than that to buildings, for the smaller discharge, and three orders of magnitude less, for the bigger one. The reason could be that damages to infrastructure are usually mainly indirect (N.B. damage due to the disruption of traffic and economic activities are not computed here). Moreover, the present estimation does not take into account damage to installations (as bridges, tunnels, water tanks, purification plants, electric plant, etc.) which, instead, could be relevant. On the other hand, their assessment is strongly case specific and cannot be carried out in parametric terms.

To conclude, it can be stated that the error that is made by neglecting direct damage to other infrastructures than the transportation system, under the hypotheses that have been assumed in the above analysis, is limited if one compares the weight of these components and that of direct damage to buildings. On the other hand, the goodness of the adopted hypotheses should be verified.

3.4.4 First-aid, emergency and warning costs

First-aid, emergency and warning cost include all the costs incurred by local authorities to face the emergency. However, while first-aid and emergency costs exist only when a flood occurs (e.g. repairing, restoration costs), warning costs can happen also in case of no flood, if a warning is issued (e.g. costs of preventive evacuation).

Given the evidence that only few context-specific tools are available for their estimate[11], required costs to face the emergency have been set here by means of a **field survey**. In particular, damages due to the hydrogeological event that hit the north of Italy in November 2002 have been analysed; the latter being the only event for which data on losses, at the required scale (i.e. municipal), are available.

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[11] No analytical methods are available in literature to estimate first-aid, emergency and warning costs (see Chapter 3).

Tab. 3.14
Damage categories definition according to RaSDa

Type	Class	Affected item	Affected components
Public	Public infrastructures	Water supply system	Pipelines, water tanks, intake plants
		Drainage system	Pipelines, purification plants
		Telecommunication and electric system	Lines, poles, plants, antennas
		Transportation system	Roads, railways, railway stations, bridges, tunnels
		Cultural heritage	Statues, monuments, archaeological heritage
		Public facilities	Hospitals, schools, public buildings
		Chattels	
	Territory	Forests	
		River and floodplain	River bed, banks, floodplain, hydraulic works, dikes
	Emergency costs	People safety	
		Public services restoring	
Private	Residential properties	Residential buildings	
	Productive properties	Industrial buildings	
		Commercial buildings	
		Laboratories	
		Touristic buildings	

3.4.4.1 *The local database RaSDa*

Investigated damage data come from the local database RaSDa[12]. RaSDa is the system currently implemented by the Lombardia Region to collect damage data about occurred disasters; in detail, both damage to private citizens and local authorities are collected by means of the system. Damage data are classified within RaSDa in five categories:

- damage to public infrastructures;
- damage to territory;
- emergency costs;
- damage to residential properties;
- damage to productive properties.

Table 3.14 specifies items to be included in each class.

Given a specific flood event, then, it is possible to have an indication of:

- affected municipalities;
- economic damages occurred in each municipality, classified according to categories in Table 3.14.

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[12] Sistema per la Raccolta delle Schede Danni.

In addition, a description is supplied, with respect to damages affecting local authorities, from which it is possible to infer items considered as emergency costs by public bodies (see Table 3.15).

In the following analysis, with respect to the hydrogeological event that hit the north of Italy in November 2002, two different data sets have been analysed:

- damage data relating to the municipalities within the province of Sondrio (referred to as "Province of Sondrio" data set) whose analogy with the case under investigation is due to the state of spatial proximity;
- damage data referring to other towns in the Lombardia region (referred to as "City circle" data set) whose features can be considered similar to Sondrio's from both hazard (i.e. flood in an urbanised, plain area) and vulnerability (i.e. extension of the city, inhabitants and services) perspectives, defining this way the state of analogy with the case study.

3.4.4.2 The analysis of data

The first step of the analysis consisted in a comparison among RaSDa classes and the categories of damage considered within the present assessment, in order to identify analogies as well as differences among included items. Indeed, in order to properly apply results inferred from the analysis of the database to the case study, the correspondence among categories is required; Table 3.15 summarises comparison results. With respect to this, it is possible to state that:

- given that, in the area under investigation, buildings are only residential or commercial, a correspondence can be assumed between the category "damage to buildings" computed within the case study and the union of the RaSDa categories "residential properties" and "productive properties" (for this reason, from now on, referred to as "damage to buildings" as well);
- no analogy exists, instead, between the two classes related to infrastructures. Specifically, RaSDa category is broader, including not only lifelines but also public properties; moreover, damage to lifelines is not limited to the line itself (as for the case study) but includes also installations. The lack of correspondence is clear if one plots damage to buildings against damage to infrastructures for the events under investigation in the case study and data deriving from RaSDa (see Figure 3.20). In detail, Figure 3.20 highlights that damage to buildings and damage to infrastructures are of the same order of magnitude when data coming from RaSDa are considered; on the contrary, for the case study events, damage to buildings are up to three orders of magnitude higher than damage to infrastructures. Of course, this difference is due to the unhomogeneity between categories discussed above;
- third, there is not any category, among those considered within the case study, that can be compared with RaSDa category called "territory";
- finally, an analogy exists between the two categories relating to emergency costs.

The second step of the analysis consisted, instead, in the examination of RaSDa data to identify possible relations among damage categories, according to which emergency costs can be estimated. In line with the results of previous step, the analysis was limited to compare damage to buildings with emergency costs. Results are given in Figure 3.21.

Figure 3.21 shows that a linear correlation exists between emergency costs and damage to buildings; however, the value of such a correlation is less clear. Indeed, the two confidence intervals, depicted in the figure, suggest that such a correlation can spam from 1% to 100%.

Tab. 3.15
Comparison among RaSDa class and damages computed so far within the case study

RaSDa			**Sondrio case study**		
Class	**Item**	**Components**	**Class**	**Item**	**Components**
Public infrastructures	Water supply system	Pipelines, water tanks, intake plants	Lifelines		
	Drainage system	Pipelines, purification plants			
	Telecommunication and electric system	Lines, poles, plants, antennas			
	Transportation system	Roads, railways, railway stations, bridges, tunnels		Transportation system	Roads, railways
	Cultural heritage	Statues, monuments, archaeological heritage			
	Public facilities	Hospitals, schools, public buildings			
	Chattels				
Territory	Forests				
	River and floodplain	River bed, banks, floodplain, hydraulic works, dikes			
Emergency costs	People safety	Means and equipment for rescuers (sandbags, clothes, work tools, etc.); overtime work for public employees; assistance to population (e.g. evacuation, assistance in moving personal items); people sheltering (e.g. meals, accommodations)	First-aid, emergency and warning costs	First aid and emergency	For example, assistance to population, lifelines and public service restoring
	Public services restoring	Lifelines restoring; debris cleaning; means and equipment for rescuers (sandbags, clothes, work tools, etc.); dangerous points ensuring (e.g. landslides, building collapses); damage to public buildings		Warning	For example, preventive evacuation and people sheltering, overtime work for public employees
Residential properties	Residential buildings		Buildings	Residential buildings	
Productive properties	Industrial buildings				
	Commercial buildings			Commercial buildings	
	Laboratories				
	Touristic buildings				

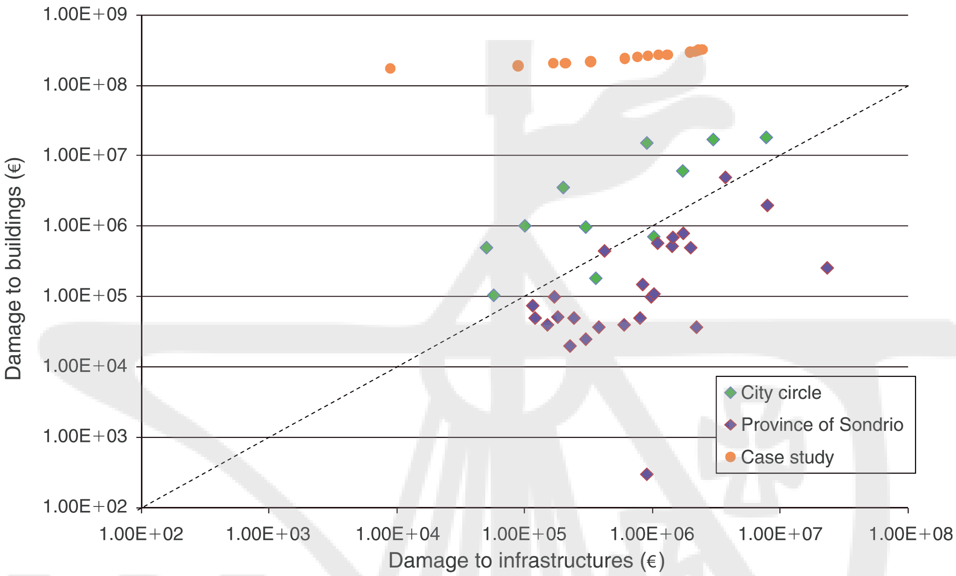

Fig. 3.20
Comparison among the extent of damage categories for the case study and RaSDa. N.B.: Axis is in the log scale

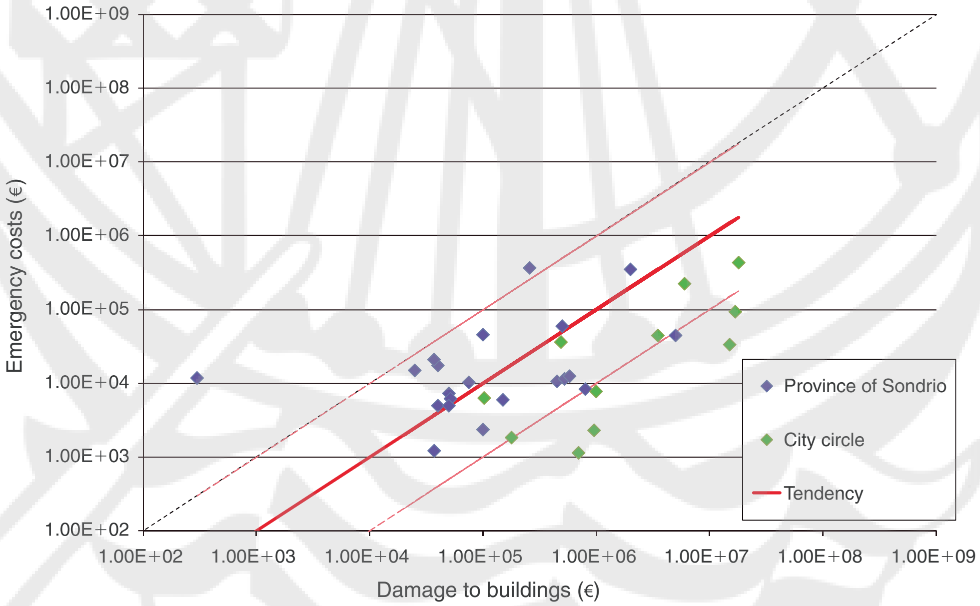

Fig. 3.21
Comparison among the extent of damage to buildings and emergency costs for the event of November 2002. N.B.: Axis is in the log scale

3.4.4.3 *The damage estimation*

Once field data have been examined, in the last step of the analysis, a rule has been defined according to which emergency costs can be estimated, for the case under investigation. In view

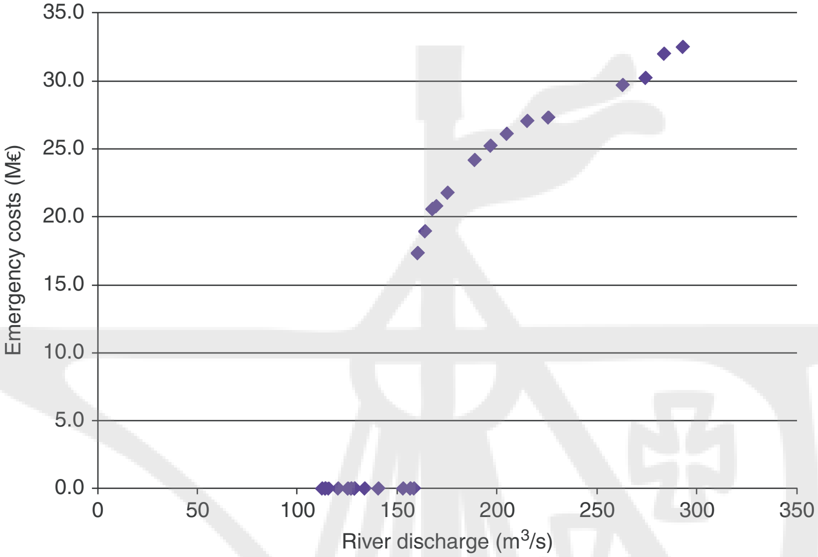

Fig. 3.22
Results of emergency costs assessment

of the results discussed in previous sections, it has been assumed that the total cost required to face the emergency can be estimated as 10% of the damage to buildings. This value is in line with the literature that indicates a percentage equal to 10.7% (Penning-Rowsell et al., 2005).

Figure 3.22 displays the result of the emergency costs assessment for the 36 events under investigation; in accordance with the hypotheses, emergency costs follow the same trend of damage to buildings.

It must be stressed that, with available data, it was not possible to distinguish between first-aid and emergency costs, on one hand, and warning costs, on the other. However, this is an important distinction, above all, when damages must be assessed according to different warning outcomes (see Chapter 4). With respect to this, further research efforts are required.

In the present assessment, as a result of the exercise, an arbitrary assumption has been made, to consider warning costs as constant and equal to the 30% of the average emergency cost[13].

3.5 Results: discussion and generalisation

Previous section represents an attempt to carry out a damage assessment which goes beyond physical damage to buildings. From this perspective, advantages with respect to the current state of the art are evident. However, mainly because of a lack of data and/or assessment tools (which derives, in turn, from the little attention that has been put on the matter in the past), limits of the analysis are many. With respect to this, Table 3.16 summarises which of the flood damages that have been identified in Table 3.1 have been estimated in the present assessment,

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[13] The average value has been computed with reference to emergency costs of "virtual" floods among the 36 events investigated in the case study.

Tab. 3.16
Synthesis of damages computed within the analysis and corresponding assessment methods

Exposed elements	**Damage**				
	Description	**Type**	**Explanation**	**Evaluation**	**Method**
Private buildings	Physical damage to structure	Direct, tangible	e.g. carpeting, painting, openings	Analytical assessment	Damage curves
	Physical damage to contents	Direct, tangible	e.g. furniture	Analytical assessment	Damage curves
			e.g. cars	Order of magnitude	Damage curves
	Additional costs to property owners	Indirect, tangible	e.g. clean up, additional heating	Not relevant to stakeholder	
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls	Not relevant to stakeholder	
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia	*Not evaluated*	
Commercial buildings	Physical damage to structure	Direct, tangible	e.g. carpeting, painting, openings	Analytical assessment	Damage curves
	Physical damage to contents	Direct, tangible	e.g. stock, machinery and tools	Analytical assessment	Damage curves
	Indirect damages	Indirect, tangible	Loss of income, additional costs (e.g. clean up)	Not relevant to stakeholder	
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls	Not relevant to stakeholder	
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia	*Not evaluated*	
Farming estates	Physical damages	Direct, tangible	e.g. livestock, crops, machinery and tools, blocks	Not relevant to investigated area	
	Loss of income	Indirect, tangible			
	Additional costs to property owners	Indirect, tangible	e.g. repair fences, remove debris, replace soil		
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls		
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia		
People	Physical loss	Direct, intangible	e.g. death, injuries	*Not evaluated*	
	Psychological damages	Indirect, intangible	e.g. stress and anxiety	*Not evaluated*	

(*continued*)

Tab. 3.16
Continued.

Exposed elements	Damage				
	Description	**Type**	**Explanation**	**Evaluation**	**Method**
Public buildings	Physical damage to structure	Direct, tangible		Analytical assessment	Damage curves
	Physical damage to contents	Direct, tangible		Analytical assessment	Damage curves
	Service disruption	Indirect, tangible	e.g. health, school services including also indirect effects	*Not evaluated*	
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community"	*Not evaluated*	
Infrastructures	Physical damage to lines	Direct, tangible	e.g. roads and railways	Analytical assessment	Damage curves
			e.g. gas and water	Order of magnitude	Damage curves
			e.g. electricity	Order of magnitude	Damage curves
	Physical damage to accessories, point works	Direct, tangible	e.g. bridges, tunnels	*Not evaluated*	
			e.g. water tanks, purification plants		
			e.g., local electric plant		
	Service disruption	Indirect, intangible	e.g. electricity, water supply including also indirect effects	*Not evaluated*	
Environment	Ecological damage	Direct, intangible		*Not evaluated*	
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities	Not relevant to stakeholder	
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community", loss of memorabilia	*Not evaluated*	
Cultural heritage sites	Physical damage	Direct, intangible		*Not evaluated*	
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities	Not relevant to stakeholder	
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of "sense of community", loss of memorabilia	*Not evaluated*	
Local authorities	Cost of warning activities	Indirect, tangible	e.g. evacuation, warning	Analytical assessment	Field survey
	Cost of emergency activities	Indirect, tangible	e.g. sandbags, tools and machinery, shelters		
	Loss of trust by people	Indirect, intangible		*Not evaluated*	

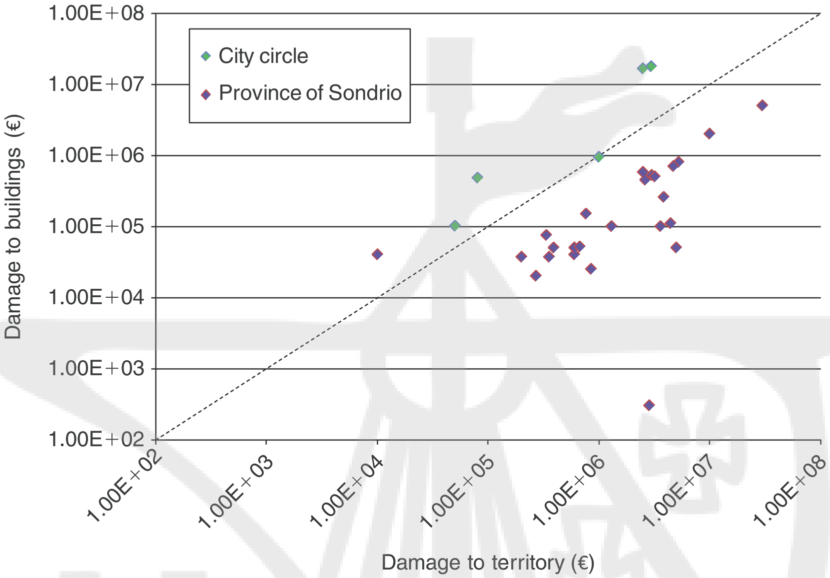

Fig. 3.23
Comparison among the extent of damage to buildings and to territory for the event of November 2002. N.B.: Axis is in the log scale

which are and which are not relevant for the assumed standpoint (i.e. local floodplain mangers') or for the context under investigation and, finally, those damages for which only the estimate of the order of magnitude was possible.

In accordance with the assumption made at the beginning of the section, looking at Table 3.16, it is possible to state that:

- intangible damages have not been taken into account in the assessment whereas they could be very important from the perspective of local floodplain managers[14];
- indirect damages (i.e. damages due to the disruption of economic and social activity) have not been considered as well; of course, they can be relevant if a different stakeholder perspective is adopted.

Moreover, it is possible to observe that:

- direct damages to other lifelines than the transportation system are not considered; however, the analysis implemented in Section 3.4.3 suggests that their weight on the final result could be negligible. On the other hand, data coming from RaSDa (see Figure 3.20) advise that, because of a lack of data and methods, it is possible that some damages have been omitted whose weight is comparable to that of damage to buildings. The same can be state looking at damage to territory (see Figure 3.23);
- emergency costs have been evaluated by means of a field survey which actually refers to only one event; thus, results cannot be confirmed by other evidences or by literature.

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[14] One could think, as an example, to the "cost" of people dying because of a missed evacuation order.

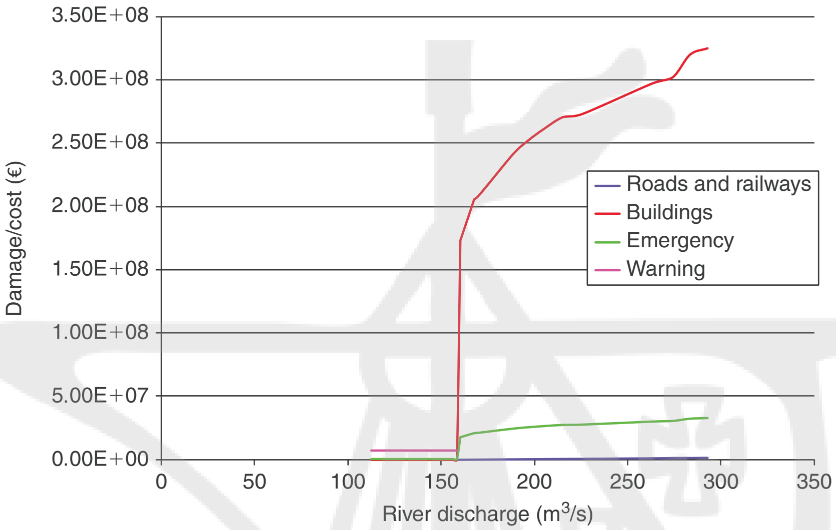

Fig. 3.24
Results of damage assessment: comparison among the extent of damage for different categories. N.B.: The log scale has been assumed for the damage axis

The importance of gaining more data/knowledge on questions related to damage assessment is so evident.

On the other hand, looking at the results with the aim of identifying those damage components that are essential for the evaluation of FEWSs performance, besides modelling choices (that already highlight which components are considered as crucial), quantitative estimation (see Figure 3.24) shows that:

- direct damage to buildings seems the component that makes up almost the total damage;
- other components seem to be insignificant.

However, regarding this, it is important to remind that:

- the assessment of emergency costs (and warning costs) is required by the scope of the analysis and, moreover, these costs represent one of the main variable of the system that can be influenced by a proper warning or not;
- an underestimation of direct damage to lifelines is possible because of the explanation provided before.

To sum up all the damages that have been estimated within the assessment (which are displayed in Figure 3.24) are considered as significant within FEWSs context. Furthermore, the estimation of intangibles should be included as well as a better estimate of damage to infrastructures should be implemented.

3.6 The role of scientific uncertainty

As discussed in Chapter 1, scientific uncertainty affects all the steps of the assessment from the hydraulic analysis (that has been assumed as the starting point to estimate the hazard scenario),

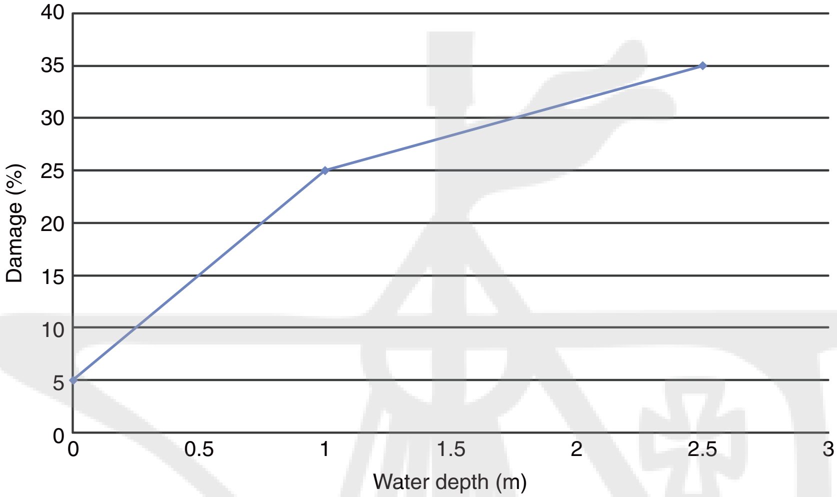

Fig. 3.25
Depth–damage curve by Luino et al.

to the assumptions made to derive hydraulic data of interest (from hydraulic analysis results), to the modelling of damage by depth–damage curves or fixed percentages, to, finally, the exposure and vulnerability assessments. A sensitivity analysis should then be carried out in order to evaluate the robustness of the results with respect, at least, to input data and, ideally, to implemented models too.

Putting attention on tools required to evaluate damage, as this is the focus of this chapter, an uncertainty analysis should be carried out with respect to both damage models and vulnerability and exposure assessments. Actually, no data/information is currently available to carry out such an evaluation which represents, then, a crucial point for future research. However, as an example, the effect of a change in building damage model is discussed here; specifically, a different depth–damage curve has been implemented in the case study to evaluate damage to building structure.

Before going on, however, it is important to stress how results and discussion in previous section supplies a general suggestion on the confidence one can put in the damage assessment carried out within the case study, highlighting the high uncertainty affecting available results (mainly because of neglected components).

The “new” curve implemented is reported in Figure 3.25. It derives from a recent analysis by Luino et al. (2009), which presents various analogies with the case under investigation. Indeed, the study aims at evaluating damage due to flash floods in a small river basin in the Italian alpine region[15].

With respect to the curve in Figure 3.25 some explanations are required, before proceeding with the analysis:

- First, the curve derives from real damage data, which were observed in the investigated area, during past events. As a consequence, it should be considered as site specific and not

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[15] The Boesio stream, in the Lombardia region.

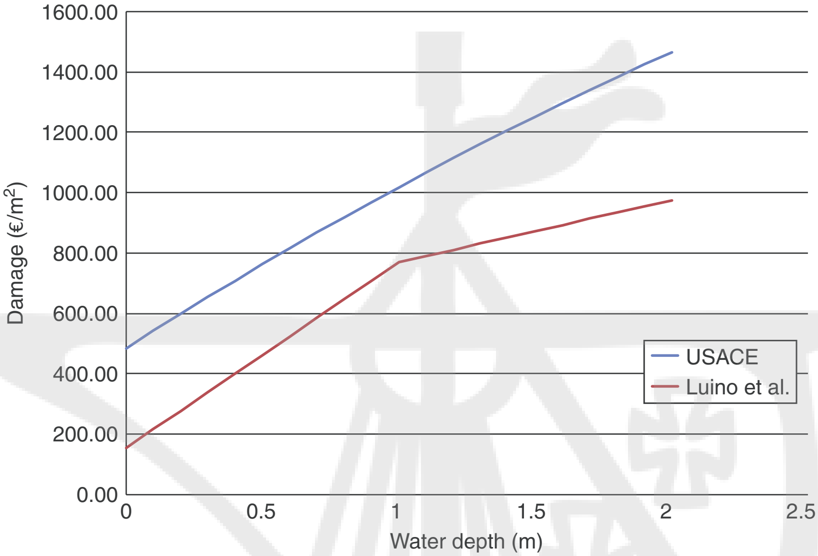

Fig. 3.26
Unitary damage: a comparison between results gained from USACE and Luino et al.

suitable to be applied to other contexts. On the other hand, a lot of analogies occur between the study by Luino et al. and the case under investigation. This justifies the adoption of the curve as verification tool.

- Second, the specificity of the analysis is reflected by the fact that no vulnerability explicative variables are considered but a unique curve is supplied for the whole area[16].
- Finally, damage to building contents is not taken into account by the curve which instead describes only the effect of floodwater on masonry, floor, doors, windows and installations. As a consequence, the curve has been assumed as replacing USACE curves to describe only damage to building structure.

Figure 3.26 reports the comparison between unitary damage (to building structure) for the city of Sondrio, calculated according to both USACE curves and the curve by Luino et al. Of course, the two curves have been derived following the same procedure that is described in Section 3.4.2.

It is possible to observe that the two "models" differ significantly to each other. This gap is shifted to damage to building structures, for the 36 events under investigation, as well (see Figure 3.27). Furthermore, as better explained in the following chapter, such an uncertainty significantly affects the final results of the analysis, in terms of expected damage, too.

On the other hand, the choice of implementing the curve by Luino et al. is equally justified than that related to USACE curves, that is, the choice is arbitrary with available knowledge. From this perspective, the importance of reducing scientific uncertainty (by reducing the gap

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[16] According to the authors, residential buildings with basement made up the bulk of damaged structures. Thus, depth–damage curve refers to this vulnerability "class" only.

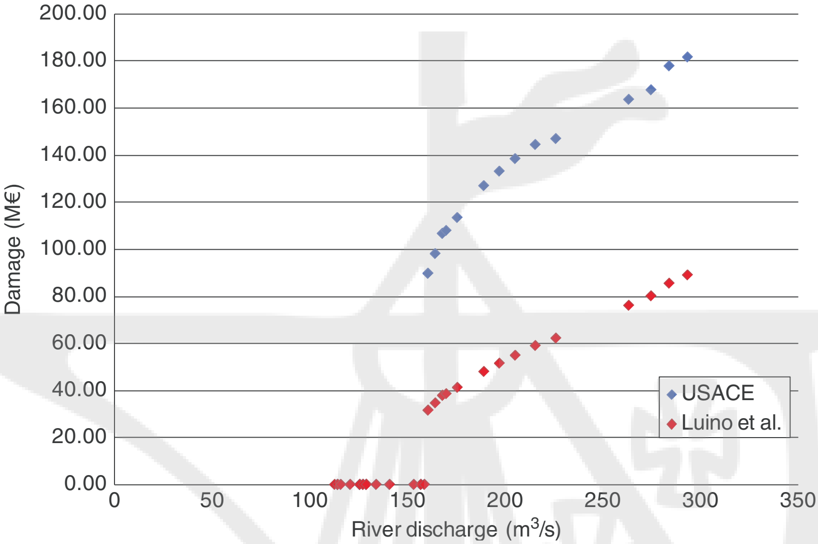

Fig. 3.27
Damage to building structure: a comparison between results gained from USACE and Luino et al.

between the two sets of curves or by collecting better evidences to guide the choice) as well as of carrying out a proper sensitivity analysis is maintained.

3.7 Conclusions

This chapter tackles with the problem of damage assessment which, as stressed in previous chapters, is an unavoidable step to evaluate FEWSs performance. To summarise main findings, this chapter depicts a very challenging scenario where various analytical tools have been implemented but no shared or standard methodology exists; the main reason being the specificity of available methods with respect to the spatial (and event) context. Accordingly, the models implemented in the case study must not been seen as compulsory or as a standard methodology but rather as a possible choice.

This chapter also highlights a general lack of tools to investigate some kinds of damage (indirect and intangibles, in particular). This is a current limit to a proper assessment of flood damages. Indeed, given their potential weight in the overall flood impact (see Section 3.2), an error in the estimate of indirect and intangible losses might invalidate the whole damage evaluation. On the other hand, it has been discussed how their real weight depends on the particular point of view that is adopted.

It is worth noting that the damage assessment carried out in the case study is not intended to be exhaustive (i.e. modelling everything, see Section 1.6) but to identify and model those damage components that are essential for the problem under investigation (i.e. to analyse and improve FEWSs performance). The results of the case study met such goal by the identification of the main significant damage components.

On the other hand, case study results show that one of the main current limit to carry out damage assessments is represented by the lack of data and tools to properly estimate damages of interest. This makes current damage assessment characterised by a high degree of uncertainty.

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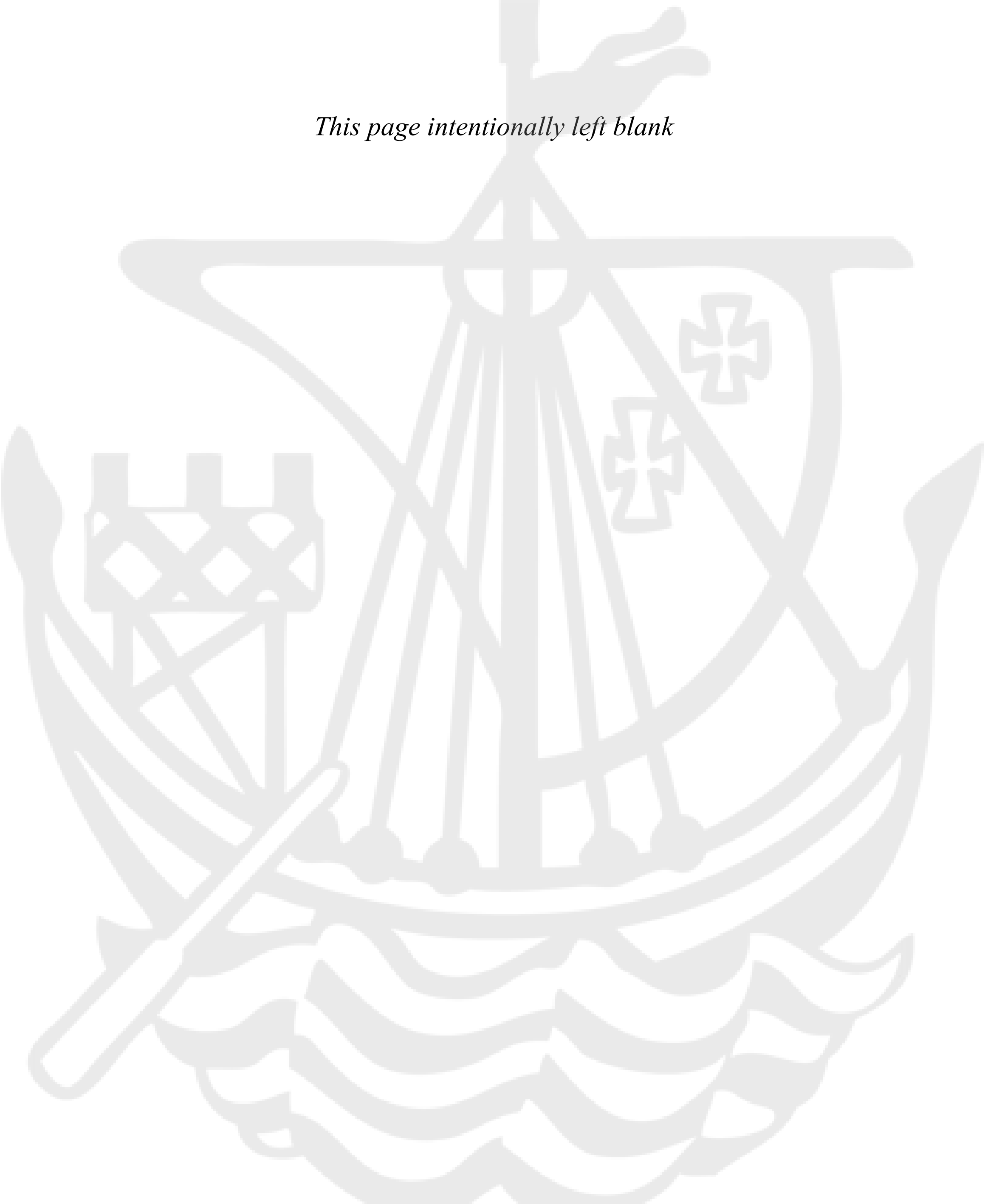

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Chapter 4

Warning, emergency management and damage reduction

As discussed in Chapter 1, when a warning is issued people usually react to it, in line with planned or unplanned strategies. Then, the forecasted event (for which warning is issued) can occur or not. On the other hand, it is possible that an event happens without being forecasted. Also in this case, people tend to react when they realise a flood is occurring.

The delineated scenario gives rise to four possible warning outcomes according to the combination between warning and reality (see also Chapter 2):

- a false warning, when a warning is issued but no flood occurs;
- a missed event, if a flood occurs but no warning is issued;
- a forecasted event, if a forecasted flood occurs;
- a situation of calm, when no flood is forecasted and occurs.

Given that people respond to warning to reduce possible damages and that warning as well as individual and community reactions have a cost, it goes without saying that the expected consequences (damages) of an event differ along with the warning outcome. On the other hand, it has already been discussed that the decision of issuing, or not, a warning is actually based not only on the probability of the forecasted event but also on the likely damage. As a consequence, the capacity to evaluate and quantify flood damages in all of the above circumstances becomes crucial for FEWSs performance. The first part (from Sections 4.1 to 4.2) of this chapter discusses this problem from a theoretical point of view. Actually, this is equal to discuss how models highlighted in Figure 4.1 can be implemented in practice.

Theoretical tools are then applied, in the real case study of Sondrio (see Chapters 2 and 3) on the problem of evaluating FEWSs performance (or, in other words, of evaluating forecasts value in terms of the capacity of the forecasting system to reduce expected damage). As stated before (see Chapter 2), this actually means to evaluate an index that takes into account both the frequencies of warning outcomes and the size of their consequences.

In the second part of this chapter (from Sections 4.3 to 4.5), the above index is defined and is calculated for the case study under investigation. Then, a proper warning rule is defined that optimises the FEWS performance. Of course, in order to do that, actual damages must be first calculated.

4.1 The effects of warning on expected damages

Referring to the most quoted terminology in available literature, the problem of evaluating damage reduction can be viewed in terms of the estimate of potential versus actual

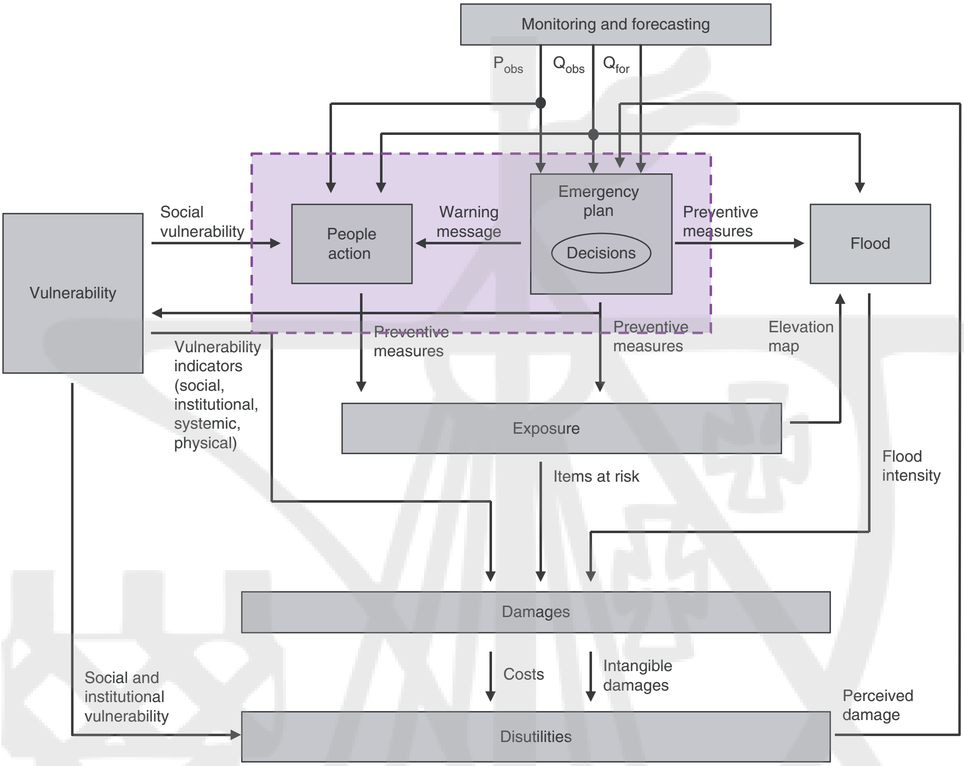

Fig. 4.1
The components of the flood warning process, which represent the focus of this chapter

damages where:

- **potential** damages are those damages that might happen when no warning systems are implemented or no warning is issued;
- **actual** damages are damages that would really happen in the presence of an EWS.

A literature review showed that, in the past, most of the studies were grounded on some wrong hypothesis like:

- an effective flood warning is capable of reducing almost any flood loss;
- damage is almost zero in case of false warning;
- damages equal potential damages, in case of missed event.

However, past events proved the opposite. As stated in the report T10-07-12 of the FLOODsite project (2008), "flood losses avoided by any particular flood warning appear to be a function of a range of variables, including flood warning lead time (defined here as the time between the receipt of a flood warning and the onset of flooding at a location), and the speed and appropriateness of the response to the warning by those affected and those responsible for defending communities against floods". In case of false warning, instead, damages are anything but zero: costs associated to prevention and mitigation activities which usually follow the warning issue are, in fact, still present. Likewise, costs related to the warning activities (e.g. forecasting) are present also in case of missed event.

The last three columns of Table 4.1 represent then an attempt to explain these evidences. In detail, for each of the likely damages in case of flood (which were previously identified in Table 3.1), a chromatic scale has been used to characterise the extent of that damage, for the various warning outcomes. Thus, a green mark signifies damage does not happen whilst a yellow or red mark identifies both the presence of that damage and its intensity[1].

To be clearer, two examples can be discussed. First, one can consider the case of physical damages to structures. They are present both in case of missed and forecasted event but it can be assumed that, if a warning is issued, some mitigation actions are taken by owners that imply a reduction in losses. On the opposite, damages to structures will be absent in case of false warning. Differently, if one looks at costs of protective actions, the situation changes. These costs are present whatever the warning outcome is but they are greater when a warning is issued. In fact, whilst some activities can be implemented also when people realise water is entering their house (e.g. moving contents) others require some notice (e.g. sandbagging).

It must be specified that the "calm" outcome has not been considered in Table 4.1. However, in such a situation only forecasting costs could be present. Specifically, when forecasting activity is continuous (in time) then forecasting costs occur. Otherwise (e.g. forecasting procedure is triggered only when potential flood conditions are detected) forecasting costs can be present or not, according to the specific event. The assumption made in Table 4.1 is so equal to set forecasting costs to zero or equal to a constant value that is always present, whatever the outcome is, not affecting, this way, the comparison between potential and actual damages. As continuous systems are the most widespread, this assumption seems the most reasonable too.

4.2 Assessment methods: how actual damages can be evaluated?

The literature review shows that although there is an extensive body of literature on flood warnings (especially from USA and Australia), a fault is present on how to evaluate their actual benefits and costs, particularly from the economic perspective. An exhaustive synthesis of available methods is supplied by Carsell et al. (2004); briefly, it can be stated that, in most cases, actual damages are simply evaluated by means of a fixed percentage reduction in average potential damages whilst few data and no methods exist to evaluate warning costs (i.e. costs of forecasting, warning dissemination and first aid) for which *ad hoc* analyses are thus required.

In any case, then, available methods are usually site (event) specific, being conceived starting from collected data. Thus, their application to different contexts could be inappropriate.

Focusing on the estimate of actual damages, one could think of the effect of a warning as a change in the "depth–damage" curve[2] describing potential damages. However, two different changes can actually occur which are described in Figure 4.2.

The point is that, after a warning is issued, two kinds of mitigation action can be put in place (see Figure 4.1):

- those reducing the intensity of the hazard (bridge gates, temporary dikes, etc.) which are usually carried out by emergency services and
- those aiming at limiting exposure and vulnerability (moving contents, temporary water gates, etc.) which are implemented by both emergency services and individuals.

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[1] Yellow means medium intensity and red signifies crucial importance.

[2] See Chapter 3.

Tab. 4.1
Flood damages and the effects of warning

	Damage			Warning outcomes		
Exposed elements	Description	Type	Required explanation	Missed event	Forecasted event	False warning
Private buildings	Physical damage to structure	Direct, tangible	e.g. carpeting, painting, openings	++	+	🟩
	Physical damage to contents	Direct, tangible	e.g. furniture, cars	++	+	🟩
	Additional costs to property owners	Indirect, tangible	e.g. clean up, additional heating	++	+	🟩
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls	+	++	++
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia	++	+	🟩
Commercial buildings	Physical damage to structure	Direct, tangible		++	+	🟩
	Physical damage to contents	Direct, tangible	e.g. stock, machinery and tools	++	+	🟩
	Indirect damages	Indirect, tangible	Loss of income, additional costs (e.g. clean up)	++	+	+
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls	+	++	++
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia	++	+	🟩
Farming estates	Physical damages	Direct, tangible	e.g. livestock, crops, machinery and tools, blocks	++	+	🟩
	Loss of income	Indirect, tangible		++	+	+
	Additional costs to property owners	Indirect, tangible	e.g. repair fences, remove debris, replace soil	++	+	🟩
	Cost of protective action	Indirect, tangible	e.g. sandbags, pumps, temporary walls	+	++	++
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of memorabilia	++	+	🟩

People	Physical loss	Direct, intangible	e.g. death, injuries	++	+	🟩
	Psychological damages	Indirect, intangible	e.g. stress and anxiety	++	+	+
Public buildings	Physical damage to structure	Direct, tangible		++	+	🟩
	Physical damage to contents	Direct, tangible		++	+	🟩
	Service disruption	Indirect, tangible	e.g. health, school services including also indirect effects	++	+	+
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of ''sense of community''	++	+	🟩
Infrastructures	Physical damage	Direct, tangible		++	+	🟩
	Service disruption	Indirect, intangible	e.g. electricity, water supply including also indirect effects	++	+	+
Environment	Ecological damage	Direct, intangible		++	+	🟩
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities	++	+	+
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of ''sense of community'', loss of memorabilia	++	+	🟩
Cultural heritage sites	Physical damage	Direct, intangible		++	+	🟩
	Services disruption	Indirect, tangible	e.g. tourism, recreational activities	++	+	+
	Sentimental loss related to direct damages	Indirect, intangible	e.g. loss of ''sense of community'', loss of memorabilia	++	+	🟩
Local authorities	Cost of warning activities	Indirect, tangible	e.g. evacuation, warning	+	++	++
	Cost of emergency activities	Indirect, tangible	e.g. sand bags, tools and machinery, shelters	++	+	🟩
	Loss of trust by people	Indirect, intangible		++	🟩	+

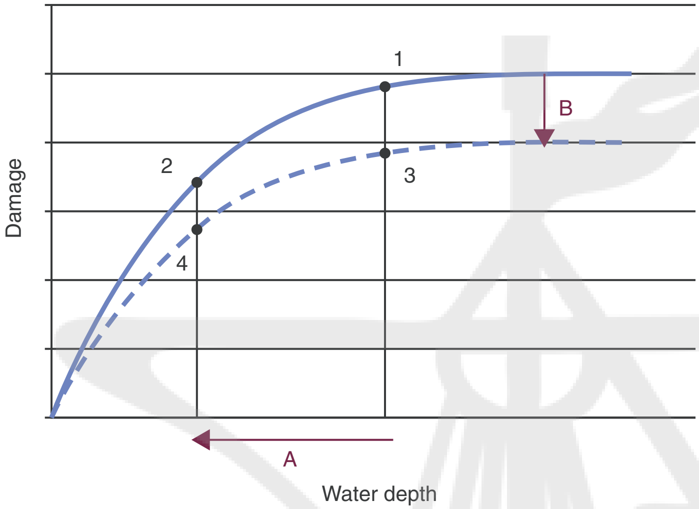

Fig. 4.2
Effect of hazard reduction (A) and exposure and vulnerability reduction (B) on potential damages (1)

In both cases, actions effectiveness depends on the level of preparedness as well as the available time for their implementation, but their effect on the "original–potential" curve is different. In the first case, mitigation actions imply that, for the same event, the depth of flood water decreases. Thus, a shift (identified by A in Figure 4.2) occurs in the curve: if 1 represents the starting point for potential damages, the new value for damage, after mitigation actions (actual damage), is 2.

Differently, it is possible to think of the effect of actions on exposure and vulnerability as a "new–actual" depth–damage curve that can be interpreted as the consequence of a shift (identified by B in Figure 4.2) in the "original–potential" one so that for a certain event which corresponds to a certain water depth, damage is less, just because of exposure and vulnerability reduction. Accordingly, if 1 represents the starting point for potential damages, the new value for damage, after mitigation actions (actual damage), is 3. Clearly, the combination of the two kinds of action brings the original damage to point 4.

Ideally, actual damages estimation requires the evaluation of both the effects. In reality, whilst the effect of mitigation actions on hazard reduction can be always estimated by means of a hydraulic analysis, the evaluation of the consequence of mitigation actions on exposure and vulnerability is still an open question. As argued above, the majority of the methods adopt fixed percentages of reduction; however, some more detailed tools have been recently developed even if they are focused on damage reduction due to individual actions only.

These methods are essentially grounded on the evidence that actual damages mostly depend on how people respond to a warning and that, in turn, people reaction is strongly related to the context in which the event takes place as well as the characteristics of the event itself. In depth, the following aspects (or explanatory variables) have been recognised as crucial in shaping people response (Handmer and Ord, 1986; FLOODsite, 2008):

- disaster characteristics (e.g. riverine or flash flood and presence of environmental cues and/or indicators);
- situational context such as the time of the day or the day of the week and lead time;
- local context including sociopolitical culture, preparedness, disaster education, previous experience and community involvement;

- community context including peoples' age, gender, length of residency, ethnicity, income, education, personality and family context;
- warning characteristics including timing, warning source (which involves credibility), mode of communication and warning message (which involves coverage).

Available methods try so to describe actual damages by means of these explanatory variables.

In detail, two different approaches can be identified, the latter being a generalisation of the former:

- in the first case, actual damages are estimated as a proportion of the average potential damage whereas this ratio is a function of one or more explanatory variable. As displayed in Figure 4.3, this is the case of the methods developed by Day (1970), Handmer and Smith (1990) and Read Sturgess et al. (2000) as well as the methodology implemented by FHRC at Middlesex University (Parker et al., 2005);
- the second approach instead evaluates actual damages by means of "new–actual" depth–damage curves that can be interpreted as the consequence of a shift in the "original–potential" ones. These methods supply thus actual/potential ratio for every depth of flooding as a function of one or more explanatory variables. As examples (see Figure 4.4), methods developed by Chatterton and Farrel (1977), Handmer and Smith (1990) as well as by USACE (1994) can be taken into account.

More specifically, with respect to the methods analysed in deep in Chapter 3[3], the problem of actual damages estimation, because of actions on exposure and vulnerability, is faced only by the English and the Australian methods which suggest fixed percentages of the total potential damages. Figure 4.5 synthesises, for example, suggestions reported in the MCM.

4.2.1 The "event-tree" approach

Available methods do not allow to properly describe the variability of actual damages, mainly because there is an objective difficulty in taking into account either all the explanatory variables or their interconnections. Hence, starting from the framework suggested by USACE (1994), an analytical tool is proposed here which tries to overcome the above limits. The objective is to model people behaviour and its effect on damage reduction. Thus, the approach does not assess actual losses directly; instead, it estimates the changes from potential losses drawing on existing data. On the other hand, modelling people behaviour implicitly means taking all the explanatory variables into account given that people response is just the results of their effects (e.g. the individual capacity to notice a warning depends on local and community contexts as well as warning characteristics).

The suggested model is in the form of an **event tree**[4] representing human behavioural steps in the flood warning process that needs to be satisfied before action to reduce damages or increase safety occurs.

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[3] The Dutch "Standard Method", the American "HAZUS" method, the tools suggested by Emergency Management Australia and the English MCM method.

[4] An event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event (i.e. the warning). Event-tree analysis is based on binary logic, in which an event either has or has not happened or a component has or has not failed.

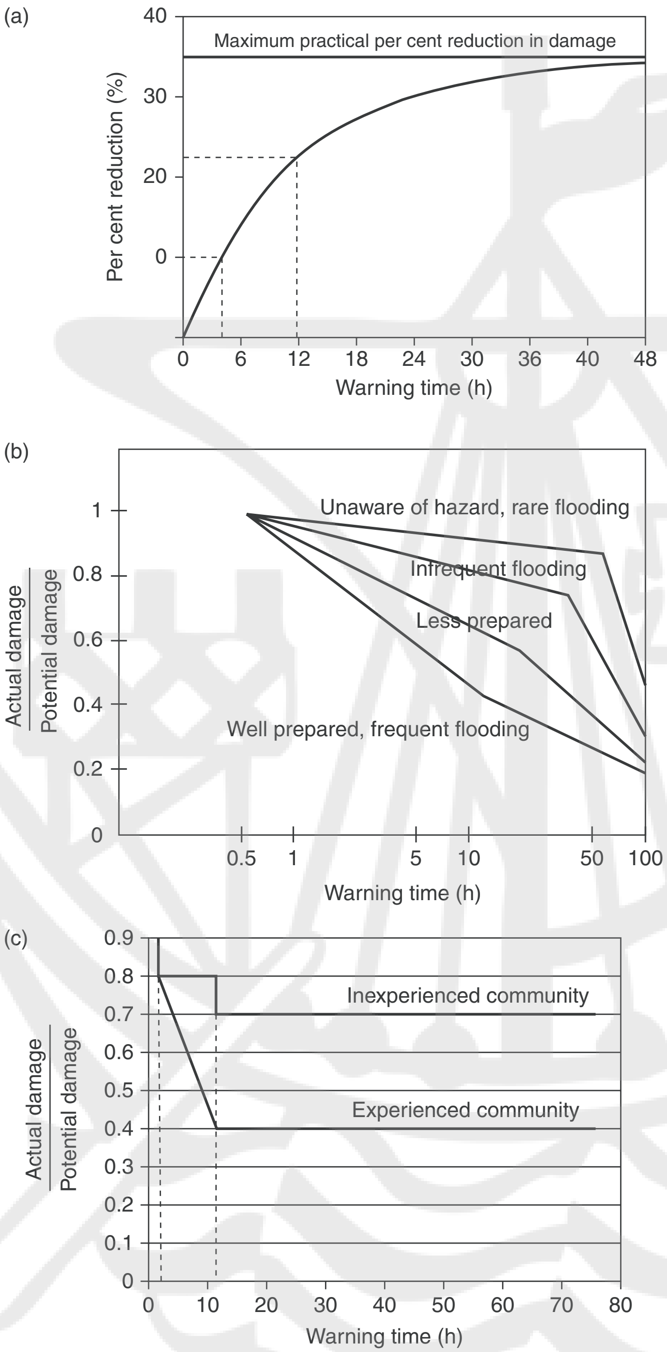

Fig. 4.3
Actual damages as a function of warning time (A – Day) or of warning time and experience (B – Handmer and Smith; C – Read et al.)

Specifically, this proposal is grounded on the evidence that a few common trends can be identified in people response. In detail:

- not all people notice a warning (FLOODsite, 2008; Parker et al., 2009) which means that not all people can be alerted by official or unofficial sources rather than by self-warning (i.e. detecting environmental signals by themselves);

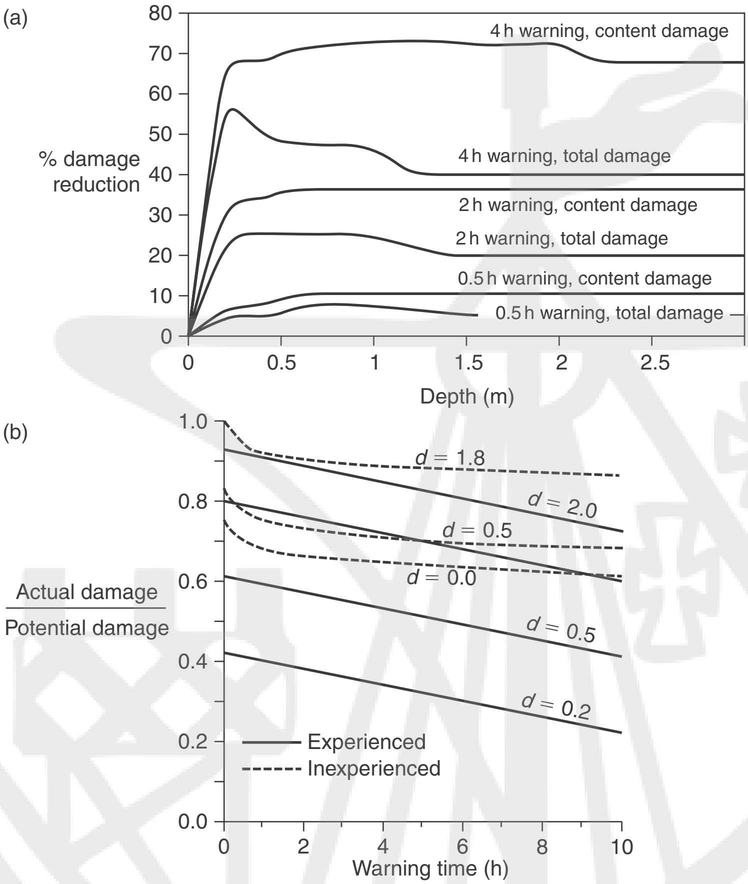

Fig. 4.4
Actual damages as a function of warning time and flood depth (A – Chatterton and Farrell) or of warning time, experience and flood depth (B – Handmer and Smith)

	Description	£(*x*)	%(*y*)	Calculation
A	Total potential damage (TPD)	30,000	100	
B	Potenial inventory damage (PID)	15,600	52	$By^{x}Ax$
C	Moveable inventory damage	6,396	41	$Cy^{x}Bx$
D	Households in receipt of warning		38	
	Effectiveness of:			
E	< 8 h warning		55	
F	> 8 h warning		71	
	TPD saved by			
	<8 h warning	1,337	4.5	$Ay^{x}By^{x}Cy^{x}Dy^{x}Ey$
	>8 h warning	1,726	5.8	$Ay^{x}By^{x}Cy^{x}Dy^{x}Fy$
	PID saved by			
	<8 h warning	1,337	8.6	$Cx^{x}Dy^{x}Ey$
	>8 h warning	1,726	11.1	$Cx^{x}Dy^{x}Fy$

Fig. 4.5
Flood warning damage reduction according to MCM, for different warning times

- even when a warning is noticed, not all people are able to understand the meaning or consider themselves at risk that is to realise that the warning applies to them (Pfister, 2002, reports by Molino Stewart Pty Ltd, 2006, 2007, 2008);
- not everyone trusts the warning (Parker et al., 2009; Handmer and Ord 1986; Handmer, 2000);
- one of the first reaction, before acting, is to seek confirmation of the warning (Parker et al., 2009; USACE, 1994, reports by Molino Stewart Pty Ltd, 2006, 2007, 2008);
- not all people know how to react (FLOODsite, 2008);
- not everyone is able to react (Parker et al., 2009; USACE, 1994).

These commonalities are just those features that make possible to create a tool for an ex-ante estimation. On the other hand, the tool can be applied also within an ongoing estimation process that starts from plausible hypotheses (ex-ante appraisal) that must be validated once an event occurs (ex-post estimate). In other words, the method here proposed is comprehensive and flexible, at the same time, enabling analysts either to consider all the full range of plausible responses or to reject the unlikely ones with respect to the specific context.

The assessment **procedure** involves, in practice, four steps.

1. First, the structure of the event tree is outlined. This means identifying which actions/ behaviours people take and when. Each action/behaviour represents an “event”.

On the bases of the common responses set out above, Figure 4.6 displays the event tree here proposed; the first assumption is that people can be subjected to three kinds of

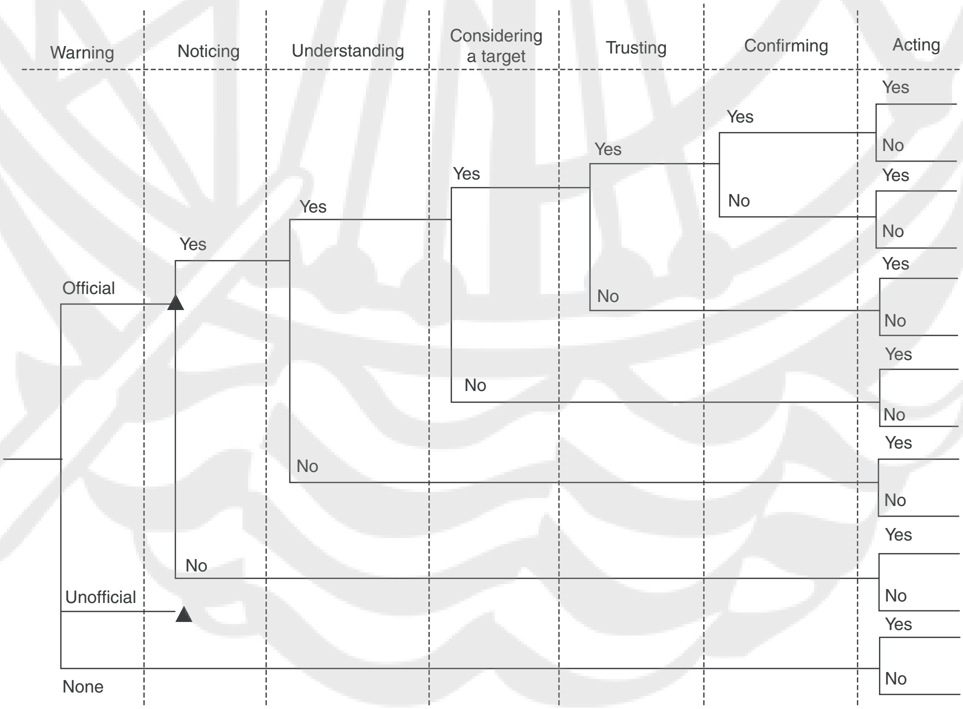

Fig. 4.6
The general event tree proposed in this book

information: an official warning, an unofficial warning (including self-warning) or no warning. The event tree foresees then the following possible behaviours:

- in case of warning (official or not), not everyone notices the warning (column "noticing" in Figure 4.6);
- if the warning is noticed, not all people understand its meaning (column "understanding" in Figure 4.6);
- if people understand the meaning of the warning, not everyone thinks the warning applies to them (column "considering a target" in Figure 4.6);
- once people realise that the warning applies to them, not everyone trusts the warning (column "trusting" in Figure 4.6);
- even if people trust the warning, they usually look for confirmation before acting (column "confirming" in Figure 4.6);
- once a warning is confirmed, not everyone takes effective action;
- in case of no warning or ineffective warning, people may take some action anyway (i.e. when they realise water is entering their house).

As mentioned earlier, the tree has been conceived as being comprehensive by including all the plausible responses. This way, the full tree is suitable also when specific data (referring to the particular observed case) are lacking, for either an ex-ante or an ex-post estimation. On the other hand, if specific data are available the event tree can be modified, enabling analysts to depict the real situation (see case studies in Appendix 4.A).

2. The next step consists of defining the rate of occurrence of each action or behaviour. In the case of ex-ante appraisals, it means to assume the most plausible probability given the information available. From this perspective, literature can be helpful by supplying average data from field surveys (see e.g. FLOODsite, 2008). On the other hand, more reliable estimates can be obtained through the investigation of the specific context. In the case of ex-post analyses, the rate of occurrence equals instead frequency. Again, it must be assessed by means of a field survey.
3. The third step consists of the appraisal of damage reduction. An estimate of the expected probability of an individual taking effective action can be obtained as the product of all the probabilities. The next step is to estimate the percentage of the damage reduced as a result of the effective actions taken. It can also be evaluated through an analysis of the behaviour (real or plausible, depending on the time of the appraisal) of a community rather than by referring to average data from the literature. Multiplying the proportion of people taking effective action by the per cent reduction in damages yields the expected damage reduction for the community under study.
4. The last step consists of reiterating the three previous steps, for various flood levels. This allows estimation of the shift in the whole potential depth-damage curve or, looked at another way, of the difference between actual and potential losses.

The **strength** of the proposed approach is that it takes variables which are crucial for people's response explicitly into account (allowing, this way, to better describe damage variability). As a consequence, it is possible to analyse how the value of each variable affects the final result (i.e. the damage reduction) as well as the effect of adding or deleting variables from the model. This enables analysts to understand and identify which actions weigh most on system effectiveness (see first case study in Appendix 4.A). Moreover, the analysis can be made more or less simple by adding or deleting components of the model, for example, because of data availability. Specifically,

- the analyst can choose to include fewer variables (behaviours/actions) to describe people's behaviour;
- each behaviour/action can be modelled, in turn, as a function of other variables (e.g. given the evidence that the probability of receiving a warning could be related to the age, sex, income, etc. of the individual, this can be modelled by another event tree);
- instead of fixed values, it is possible to consider a probability distribution for each rate of occurrence or expected damage reduction (e.g. a triangular distribution can be adopted to describe the evidence that no less than 70% and no more than 97% notice the warning, with 85% of the people most likely noticing a warning; likewise, the average damage reduction of all people who take effective action can be assumed to have a uniform distribution over a range of, e.g., 0.5–15%).

The proposed approach has, of course, its **limits**. Despite all the shortcomings which are typical of a model as a picture of the reality, the major limit of the proposed approach is that it does not allow for feedback, or for alternative sequences such as obtaining trust or understanding after seeking confirmation. Moreover, the "time" variable is not taken explicitly into account but analysts should consider it whilst setting model variables (e.g. by reducing the percentage of people who take actions if there is no time, or limited time, to react). However, the advantages represented by both the model and quantitative estimation outweigh these limitations.

Furthermore, one big pitfall, which still limits to fully exploit the tool, is the lacking of data about the damage reduction (percentage) that results from every effective action taken. Even when it is known, this information is usually supplied with respect to the community as a whole whilst damage reduction related to every branch is required to totally take advantage of the method. In particular, this information is the one that really permits to identify actual damage curves which consider all the explanatory variables in the tree. In other words, without this information, the tree is useful to analyse how each action/behaviour affects the final flood loss figure (as well as the impact of changing them by potential improvements to the warning system) but, in terms of actual damage estimation, it supplies the same result available tools give if the percentage of acting people is known. Of course, this represents a current limit but, at the same time, it stresses the importance of collecting this kind of data as future research effort.

In Appendix 4.A, two case studies are supplied to explain how the procedure can be implemented in practice.

4.3 Implementing tools: the case of Sondrio

In this section, tools previously described are implemented to the problem of evaluating FEWSs performance in terms of its capacity to reduce expected damage, for the case study already discussed in previous chapters (i.e. the warning system in the town of Sondrio).

4.3.1 The performance index

Once defined the benefit of a forecasting system as the capacity of the system to reduce expected damages, the value of a forecast can be assessed just by means of the expected damage associated to that forecast or, better, in terms of the expected damage reduction with respect to the case in which no forecast is supplied.

Tab. 4.2
Mitigation actions according to the emergency plan of Sondrio. In blue, modeled items are highlighted.

Mitigation action	Expected effects on damage
– Levees temporary rising, reinforcement – *Bridges gates*	– *Damage reduction* (river conveyance increases) – Cost due to personnel and material needs
– Bounding/guarding of risky areas	– Reduction in people exposure – Cost due to personnel and material needs
– Arrangement of emergency areas	– Cost due to personnel and material needs
– Precautionary evacuation	– Reduction in people exposure – Cost due to people assistance/aid – Reduction in people taking mitigation actions
– *Individual actions* (e.g. lift contents and turn off gas)	– *Damage reduction*
– Dissemination of information	– Increase in mitigation actions effectiveness – Cost due to personnel and material needs
– Surveillance	– Damage reduction – Cost due to personnel and material needs

As previously discussed, for a specific event, damage depends not only on the intensity of the event[5] but also on the warning outcome[6] (see Table 4.8). Thus ideally, to evaluate expected damages, the probability distribution of each warning outcomes should be known as well as the damage associated to each flood-warning scenarios.

In the case under investigation, available data are not enough to infer such information. Indeed, the 36 events previously identified by means of a back analysis (see Chapter 2) are all conditioned to the river bed aggradation scenario occurred in 1987 that is a very rare event whose probability distribution is unknown.

For this reason, in the present analysis, the **mean economic damage** associated to the above 36 events has been simply assumed as performance index. Of course, this is not representative of the expected damage but it is suitable for the scope of the analysis.

For each forecast data set[7], the computation of the performance index included the following steps:

- first, the warning outcome of each event (forecast–observation pair) was defined;
- second, the damage associated with each event was computed;
- finally, the mean economic damage was evaluated as the average of the damage associated with every event.

Actually, the mean economic damage was evaluated for two further forecast scenarios:

- the case in which no forecast is supplied;
- the case in which a perfect forecast (with no errors) exists.

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[5] The river and, consequently, flood discharges.
[6] False warning (FW), forecasted event (H), missed event (ME) and calm (C).
[7] PREVIS 1, PREVIS 2 and PREVIS 3 (see Chapter 2).

This allowed evaluating forecast value in terms of the capacity of the system to reduce damage with respect to the case in which no forecast is supplied and, from this perspective, to have a benchmark.

4.3.2 The actual damage estimation

The estimation of the damage associated to each event is grounded on the damage assessment carried out in Chapter 3. However, it must be taken into account that, when a warning is issued, mitigation actions are usually implemented, aiming at reducing potential damages. Specifically, according to Section 4.2, these actions can be split in two groups:

- those limiting/reducing hazard,
- actions limiting/reducing exposure and vulnerability.

Table 4.2 reports the actions that have been planned, in case of warning, in the contingency plan of Sondrio.

Here, only damage reduction due to bridges gates and individual actions was considered because no data/assessment tools are available neither for other actions (e.g. damage reduction due to local authorities' action) nor to assess additional costs (e.g. warning).

4.3.2.1 The effect of bridge gates

Bridge gates affect the intensity of the incoming event (i.e. the hazard), thus, according to Section 4.2, their effect can be assessed by means of a hydraulic analysis.

Specifically, the arrangement of bridge gates involves an increase in river conveyance and, consequently, an increase in the minimum river discharge above which river floods. In terms of damage, this means that the same river discharge implies less damage.

Looking at the documentation about the hydraulic analysis of Ismes-CAE (1988) that was taken as reference for the damage assessment in Chapter 3, it is possible to state that the hydraulic analysis has been carried out under the hypothesis that bridge gates are in place. So, here, the problem of evaluating the effect of bridge gates becomes the opposite with respect to the one described above. In other words, the reduction in the minimum river discharge above which river floods as well as the increase in flood discharge (and damage) associated with a particular river discharge must be estimated.

With respect to this, bridges that required to be closed during a flood have been first identified. According to the water profile supplied by the hydraulic analysis (see Figure 4.7), the Marconi Bridge and the railway bridge are not flooded, even when river discharge is equal to the highest analysed value (i.e. $700\,m^3/s$). On the other hand, the pathway bridge is not included in the river stretch which the analysis refers to.

In line with this, in the following analysis, it was assumed that bridge gates are arranged only for the Matteotti Bridge and the Marconi Bridge.

Bridge openings have been modelled as rectangular **weirs**. Figures 4.8 and 4.9 display the geometry of the openings that has been assumed for the two bridges. It is possible to observe, how, in both cases, the water depth of the weir varies along with river discharge and is equal to that supplied by the hydraulic analysis (i.e. steady flow profile).

Table 4.3 summarises the water depth above bridge extrados, deriving from the hydraulic analysis. Moreover, the outflow discharge, deriving from the weir modelling, is supplied.

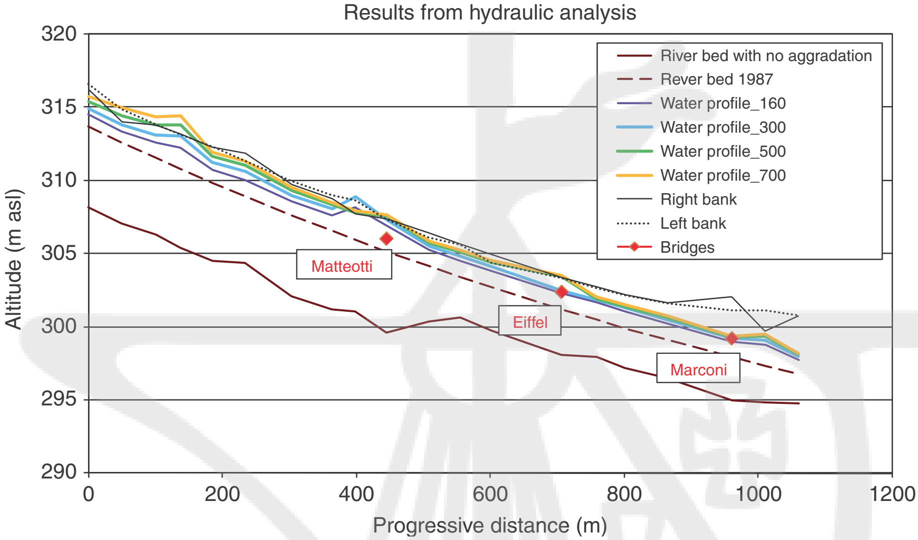

Fig. 4.7
Water profile for the Mallero River according to Ismes-CAE (1988)

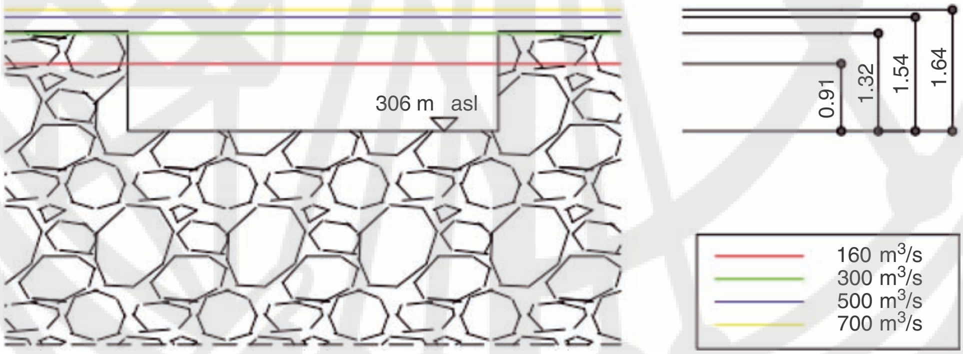

Fig. 4.8
Opening section and water levels at Metteotti Bridge

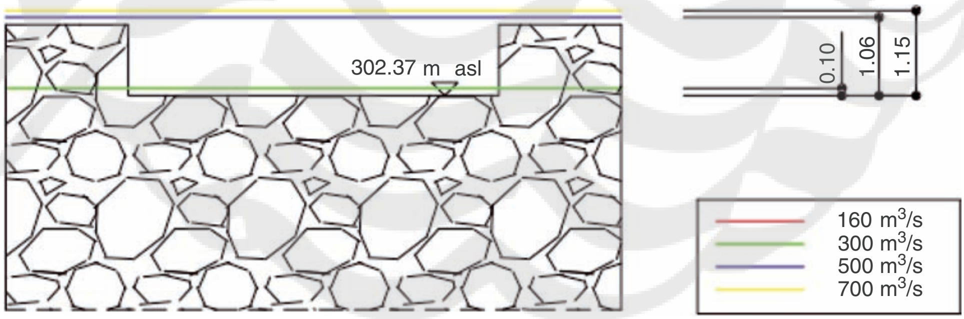

Fig. 4.9
Opening section and water levels at Eiffel Bridge

River discharge (m^3/s)	Water depth above extrados (m)		Outflow discharge (m^3/s)	
	Matteotti Bridge	Eiffel Bridge	Matteotti Bridge	Eiffel Bridge
160	0.91	0	15	0
300	1.32	0.1	26	1
500	1.54	1.06	31	18
700	1.64	1.15	33	20

Tab. 4.3
Outflow discharge through buildings openings

River discharge (m^3/s)	Food discharge (m^3/s)		Increase (%)
	Bridge gates	No bridge gates	
160	0	30	–
300	81	134	+65
500	245	343	+40
700	411	517	+25

Tab. 4.4
Flood discharge in case bridge gates are in place or not

It must be specified that the backflow has not been included in the calculation because it was already evaluated in the assessment of flood discharge by Ismes-CAE. With respect to this, Table 4.4 shows just the increase in flood discharge, due to bridge openings, with respect to the previous analysis.

According to it, and by assuming, in line with previous chapter, a linear relation between river discharge and flood discharge, the minimum river discharge above which river floods goes down to 109 m^3/s and 135 m^3/s (respectively, at right and left river side), when bridge gates are not in place.

Given the above result, physical damage to buildings as well as to roads and railways has been computed again, this time under the assumption that no gates are in place. Clearly, the damage assessment procedure is the same of that implemented in Chapter 3.

Figure 4.10 displays the comparison between damage assessment results in case, or not, of bridge gates.

As expected, unlike the case in which no bridge gates are in place, even minor events, being characterised by a river discharge above 109 m^3/s, imply damage; the latter further increases when river discharge exceeds 135 m^3/s, when river starts to flood at each river side. Above 160 m^3/s, instead, the difference between the two scenarios is less pronounced because the majority of flood discharge is now due to water overtopping river banks rather than bridge outflow.

4.3.2.2 *The effect of individual actions*

Individuals usually take actions (as moving building contents to upper floors, arranging doors gates, sand bags, etc.) whose effect is a reduction in damage to building contents (a shift in the depth–damage curve, see Section 4.2). This reduction has been here evaluated by means of a fixed **percentage of potential damages** (to contents), even if, the event tree, previously proposed, would represent a more suitable choice. Unfortunately, no enough data are available for its implementation.

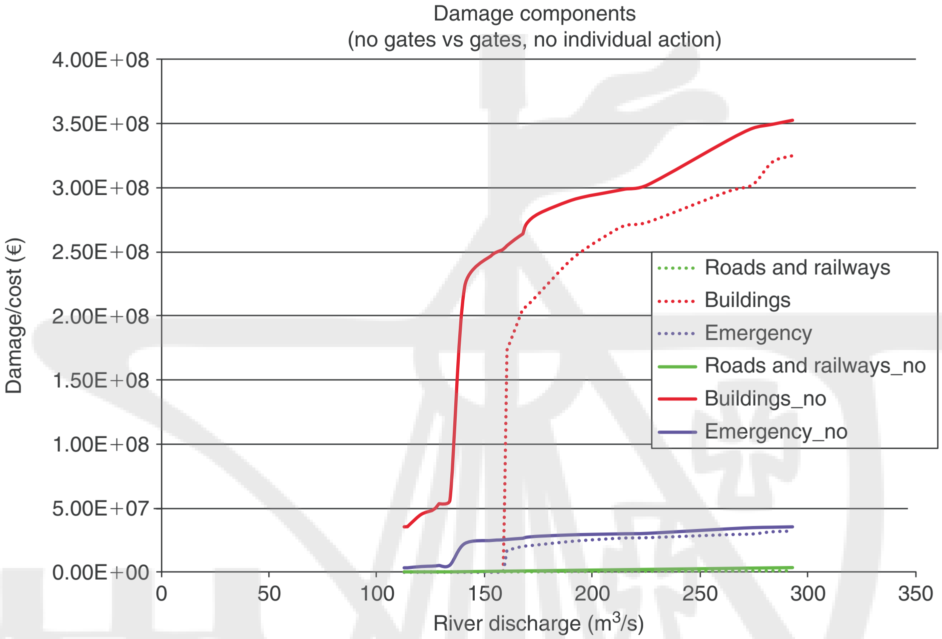

Fig. 4.10
Results of damage assessment in case of gates or not. N.B.: The log scale has been assumed for the damage/cost axis

Among investigated tools[8], both the MCM and the RAM methods supply reference value. However, they disagree to each other, showing that the effectiveness of individual actions is strongly context specific. Furthermore, as discussed in Section 4.2 (see Table 4.8), it depends on the warning lead time, setting the time available for action. In the present case study, the most precautionary value has been applied, which is that supplied by the MCM. Moreover, the following assumptions have been assumed, which are in accordance with the context under investigation:

- the warning lead time is less than 8 h;
- population have no previous flood experience.

In such hypothesis, the effectiveness of individual actions is equal to 4.5%.

Figure 4.11 displays the comparison between damage assessment results in case, or not, of individual action for the case in which bridge gates are in place. Of course, the reduction due to people actions is less than that resulting from bridge gates. On the other hand, it is one of the few variables, influenced by the warning outcome.

4.3.3 The forecast value assessment

To evaluate the performance index (i.e. the mean economic damage), first, damage components which are related to every warning outcomes must be defined. Table 4.5 summarises the

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[8] The Dutch “Standard Method”, the American “HAZUS” method, the tools suggested by Emergency Management Australia and the English MCM method.

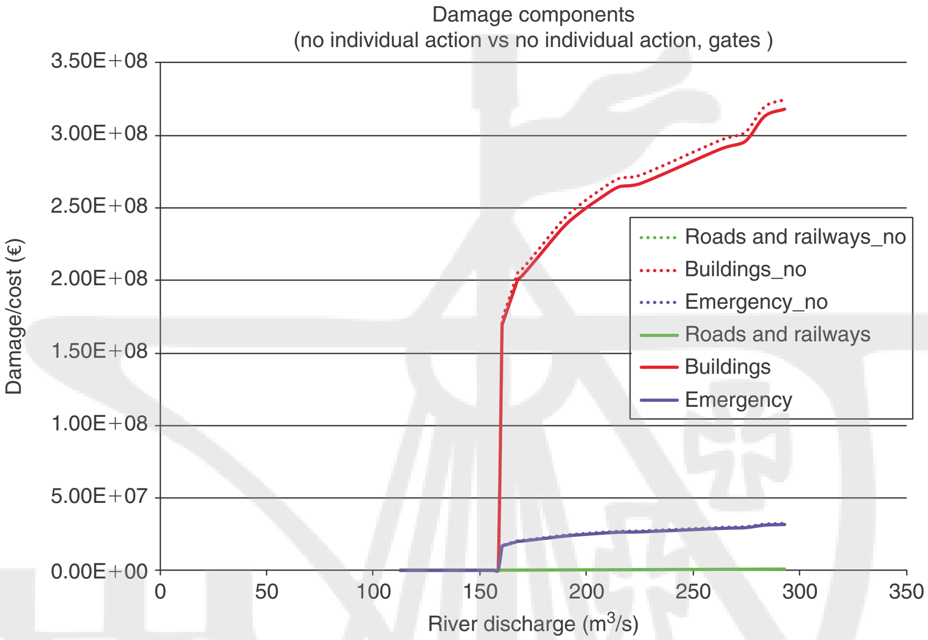

Fig. 4.11
Results of damage assessment in case individual actions are taken or not, for the case in which gates are in place. N.B.: The log scale has been assumed for the damage/cost axis

Warning outcome	Considered damage
Forecasted event	Physical damage to buildings (actual) Physical damage to lifelines (actual) First-aid and emergency costs Warning costs
Missed event	Physical damage to buildings (potential) Physical damage to lifelines (potential) First-aid and emergency costs
Calm	None
False warning	Warning costs

Tab. 4.5
Damage components according to warning outcomes

assumptions made within the case study, according to the results of previous chapter and the above actual damage estimation. However, some points require further discussion:

- first, with respect to the difference between potential and actual damages, only the effect of individual actions has been here considered. Specifically, it has been assumed that bridge gates are always arranged even if forecast is below level 3 threshold[9]. Indeed, according to the assumptions made in the analysis, bridge gates have no costs; the main cost is related to the discomfort and economic loss due to traffic disruption but this component has not be

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[9] For example, when forecast exceeds the "level 1" threshold, see Chapter 2.

Tab. 4.6
Performance evaluation results

Forecast scenario	Mean damage (M€)	Benefit with respect to no forecast	
		M€	%
No forecast	126.1	Not defined	Not defined
Perfect forecast	123.4	2.6	100
PREVIS 1	126.0	0.1	3
PREVIS 2	**125.4**	**0.7**	**27**
PREVIS 3	125.8	0.2	8

included in the assessment (see Chapter 3). On the contrary, the damage reduction because of the bridge gates is relevant, above all, during minor events. From this perspective, bridge gates are always useful and should always be arranged;

- second, in case of missed events, first-aid and emergency costs should be higher than in case of forecasted events, when community mitigation actions are implemented. For this reason, the percentage of these costs (with respect to damage to buildings) has been kept equal to 10% even if warning costs are not present. This implies to include in the assessment also a rough estimate of community actions;
- in case of false warning, when no physical/direct damage occurs, warning costs have been evaluated as constant and equal to the 30% of the average emergency cost[10] (see Chapter 3);
- finally, in case of "calm", damage has been set to zero. As described in Section 4.1, this is equal to set forecasting costs equal to zero or to a constant value that is always present, whatever the outcome is, not affecting, this way, the comparison between damage related to different outcomes.

Results for the performance assessment are eventually summarised in Table 4.6. In detail, in the second column, the mean economic damage is reported for:

- the scenario in which no forecast is provided;
- the ideal case in which a perfect forecast (with no error) exists;
- the three real forecast scenarios (i.e. PREVIS 1, PREVIS 2 and PREVIS 3).

The difference between damage in case of no forecast and in case of forecast represents the benefit the forecasting system brings with respect to the case in which no warnings are issued. This is the real performance measure, according to which FEWSs effectiveness should be evaluated. Specifically, the difference related to the perfect forecast represents the optimum (i.e. a benchmark) according to which forecasting performance can be assessed.

In this regard, in the fourth column, the ratio between the real benefit (for each forecast data set) and the optimal benefit is reported, in terms of percentage.

4.4 Results: discussion and generalisation

Looking at Table 4.6, first of all, it is important to note that, even in the optimal case, the benefit is limited to 2.6 M€ (equal to 2% of the maximum mean damage). This result, however, is not due to forecasts accuracy but rather to the characteristics of the affected area and of the

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[10] The average value has been computed with reference to emergency costs of "virtual" floods among the 36 events investigated in the case study.

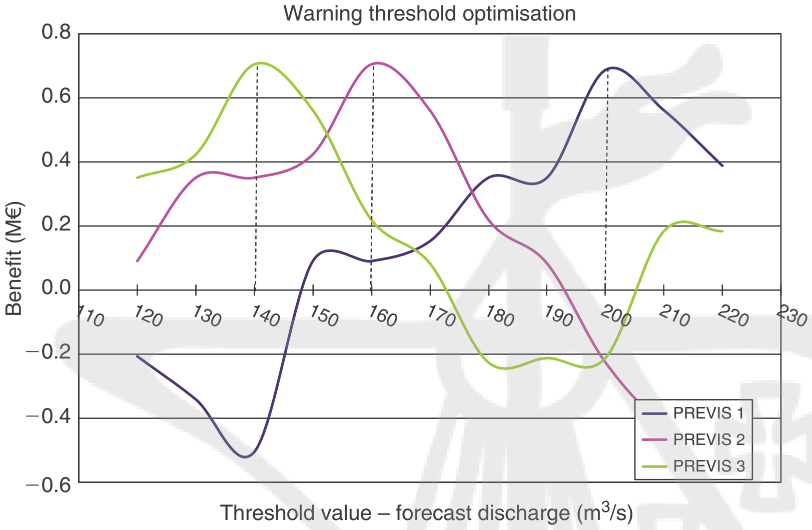

Fig. 4.12 Economic benefit for different warning thresholds

emergency response. Thus, improving vulnerability and response effectiveness (in terms of both damage reduction and warning costs) can increase the FEWS potential benefit.

On the other hand, considering, instead, the influence of forecasts errors, Table 4.6 shows that the maximum benefit is further limited just because of the errors and it is limited, in the best case (i.e. PREVIS 2), to 27% (i.e. 0.7 M€) of the optimal value. However, thanks to the evaluation performance, a warning criterion can be now defined. Indeed, if the decision maker (i.e. the local floodplain manager) aims, in the long term at limiting economic damage, then they should follow information PREVIS 2 supplies.

Hence, eventually, it has been proved that, by proper defining of forecast benefit in accordance with the stakeholder perspective as well as the application context, the assessment of forecast value allows to identify a proper warning rule, meaning to identify a forecast that is better than others, for the specific problem under investigation.

Last but not least, Figure 4.12 displays the effect of changing warning threshold, keeping the actual forecasting system. Specifically, the economic benefit (in terms of damage reduction with respect to the case in which no warning is issued) against warning threshold value (in terms of forecasted river discharge) is reported, for the three forecast data sets.

It is possible to observe that, because of forecasting errors, the optimal warning threshold value (that is the one that maximises the benefit) can differ from the physical one which is the actual warning threshold value (see Chapter 2). Indeed, it goes up to about 200 m^3/s for PREVIS 1 while it is equal to 140 m^3/s for PREVIS 3.

It is easy to verify that the "new" threshold values agree, respectively, with the tendency to over forecast for PREVIS 1 and the tendency to under forecast for PREVIS 3 as set in Chapter 2. On the other hand, the current threshold value seems to be the optimal for PREVIS 2.

This is to say that, by proper evaluation of forecasting value, it is also possible to identify proper management rules to optimise the performance of existing FEWSs.

4.5 The role of scientific uncertainty

Uncertainty affects all the steps of the above assessment, from the hydraulic analysis (that has been assumed as the starting point to estimate the effect of bridge gates) to the modelling of

Forecast scenario	Mean damage (M€)	
	USACE	Luino et al.
No forecast	126.1	86.3
Perfect forecast	123.4	83.6
PREVIS 1	126.0	85.7
PREVIS 2	**125.4**	**85.4**
PREVIS 3	125.8	85.9

Tab. 4.7
Comparison among results coming from the implementation of USACE curves and Luino et al. curve

bridge gates, to the damage assessment carried out in previous chapter (that has been assumed as the starting point to evaluate actual damages) to, finally, the estimate of the effects of individual and community actions. As already emphasised in previous chapter, a sensitivity analysis should then be carried out in order to evaluate the robustness of the above results (i.e. the identified warning rules) with respect, at least, to input data and, ideally, to implemented models too.

Putting attention on tools required to evaluate warning effects (in terms of damage reduction), as this is the focus of the chapter, an uncertainty analysis should be carried out with respect to both bridge gates and individual actions models.

About the former, a better estimate of both weir geometry and a comparison with the results coming for other kinds of models should be carried out. However, given that the effect of bridge gates is not taken into account in the estimation of the performance index, uncertainty related to this point would not influence the robustness of the results. On the other hand, it is possible that an uncertainty analysis brings to the evidence that bridge gates effects should be differently considered than it has been done (e.g. bridge gates are useful for certain river discharge only).

With respect, instead, to the effect of individual actions, the main problem is a general lack of data against which results can be verified. In other words, the definition of a confidence interval for input data is impossible but by collecting other information on the specific case under investigation.

Looking instead at the uncertainty coming from previous analyses (supporting the assessment of actual damage), in accordance with the previous chapter, the effect of replacing the original curves for building structure with another one has been evaluated. In detail, Table 4.7 reports a comparison between the mean economic damage deriving from the implementation of USACE curves and that deriving from the adoption of the curve by Luino et al. (2009).

It is possible to observe how the original scientific uncertainty is transferred to final results as well, highlighting the so called “cascade” of uncertainty discussed in Chapter 1.

Uncertainty and, more in general, sensitivity analysis have only partially been talked within this study but it can be stated that results uncertainty is high. This is due mainly to the uncertainty deriving from the estimation of damage components whose reduction represents a priority for future research efforts.

From this perspective, results must not be seen in terms of “absolute values” but rather as a suggestion of the behaviour (performance) of the system. In practice, it is not possible to state that, on average, the mean economic damage is equal to 125.4 M€ if PREVIS 2 is followed but it is likely that the mean economic damage will be minimised (if PREVIS 2 is trusted). This information is relevant for warning decision makers, even more than information on forecast accuracy.

Tab. 4.8
Flood damages, explicative variables and assessing methods according to warning outcomes

Damage		**Warning outcome**			
		Missed event	**Forecasted event**	**False warning**	**Calm**
Losses	*Components*	• Direct damages • Indirect damages	• Direct damages • Indirect damages	• Indirect damages (e.g. because of traffic and economy disruption)	
	Main explicative variables	• Flood water depth • Flood duration • Vulnerability indicators • Time to return to normality	• Flood water depth • Flood duration • Vulnerability indicators • Time to return to normality • Warning lead time • Response effectiveness/ preparedness	• Vulnerability indicators • Time to return to normality • Warning lead time • Preparedness	
	Assessment methods	• Damage functions (including depth–damage curves) • Indirect methods (i.e. percentages) • Physical surveys • *Ad hoc* analyses	• Indirect methods (i.e. percentages) • Shift in depth damage curves (including the event-tree approach) • Physical surveys • *Ad hoc* analyses	• *Ad hoc* analyses	
Costs	*Components*	• First-aid and emergency cost (public and private)	• First-aid and emergency cost (public and private) • Warning costs (public)	• Warning costs (public)	• Forecasting costs
	Main explicative variables	• Flood water depth • Flood duration • Vulnerability indicators • Time to return to normality	• Flood water depth • Flood duration • Vulnerability indicators • Time to return to normality • Warning lead time • Response effectiveness/ preparedness		*Not analysed here*
	Assessment methods	• *Ad hoc* analyses	• *Ad hoc* analyses	• *Ad hoc* analyses	*Not analysed here*

4.6 Conclusions

Chapter 4 is focused on the current state of the art on the assessment of actual damages, meaning, in general, potential damages when mitigation measures are in place, as a consequence of a warning. Main findings can be summarised in two main weak points:

- On the one hand, it can be stated that available assessment tools allow the modelling of damage reduction due only to people (individual) response. Yet, as regards, research is still at an embryonic stage and models can be considered as a little bit more than rough estimations;
- On the other hand, it has been observed that no methods exist and few data have been collected to evaluate both community response (i.e. damage reduction due to emergency services actions) and warning costs.

Even when available, estimation tools are then usually site (event) specific so that their implementation in other contexts (rather than the one where they have been derived) is unsuitable. For this reason, *ad hoc* analyses (e.g. field surveys) seem to be the most suitable choice for actual damage estimation. This brings to high uncertainty of current estimations, mainly because of the impossibility to validate results by comparison with other collected data.

On the other hand, this chapter starts stressing the necessity (for FEWSs performance assessment) of evaluating and quantifying flood damages which could be borne in correspondence of all the possible warning outcomes: being false warning, missed event, forecasted event and a situation of calm.

The contents of this chapter and of the previous one supply all the knowledge that is currently available in the literature to face the problem at stake, both in terms of damage identification and assessment methods. From this perspective, Table 4.8 supplies a synthesis of main findings.

In this chapter, a FEWSs performance index has been defined and calculated for the case of Sondrio. The index is grounded on the definition of forecasts benefit as the capacity of the FEWSs to reduce expected damage. This way, it is possible not only to evaluate the effectiveness of FWESs but also to optimise their performance by setting proper warning rules. The above analysis (as well as that carried out in Chapter 3) highlights all the real problems that the inclusion of damage in the performance assessment implies (i.e. the lack of data and assessment tools). On the contrary, the benefits of including all the warning chain, with respect to the traditional approach, in terms of information/knowledge supplied to end users, are discussed.

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Appendix

4.A Actual damage estimation: a real implementation of the event-tree approach

In this appendix, two applications of the methodology proposed in Chapter 4 are discussed. Specifically,

- an ex-post analysis of a real event;
- an ex-ante evaluation of the benefits brought by the implementation of a FWS.

The two case studies have been chosen with a twofold objective: explaining how the event-tree approach can be used in practise and identifying both its strengths and shortcomings.

4.A.1 The Gippsland flood

One capability of the proposed approach is that it allows assessing the effectiveness of an existing FEWS in the aftermath of a flood. The first case study is analysed from this perspective.

The case is the flood that hit the Gippsland region of the state of Victoria (Australia) during late June 2007. Data come from a report by Molino Stewart Pty Ltd (2007) undertaken for the Victoria State Emergency Service (VIC SES).

This flood was triggered by intense rainfall across the region from Tuesday June 26 to Saturday June 30. The first warning was issued by the Bureau of Meteorology (BOM) on June 25 and various flood warnings were issued subsequently. However, the floods inundated many localities including the towns of Bairnsdale and Newry as well as some communities

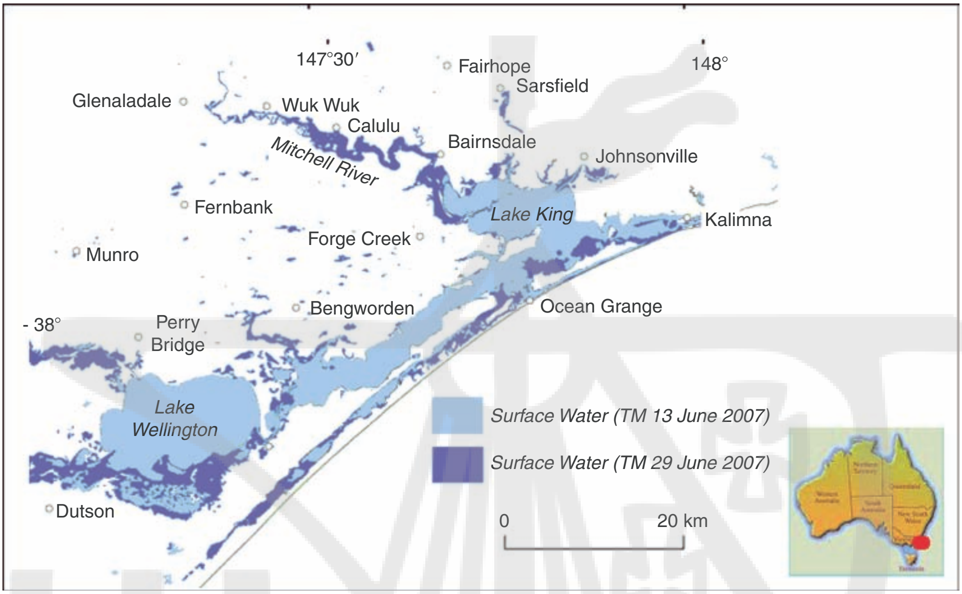

Fig. 4.A.1
The Gippsland area affected by the June 2007 flood

around the Gippsland lakes. The nature of the floods can be defined as riverine, with return periods between 20 (for most streams and lakes) and 80 years (for the Mitchell and Macalister rivers). Given that the affected area (see Figure 4.A.1) is wide, rivers flooded at different locations at different times with lead times ranging from 24 to 48 hours.

During the flood progressive warnings were issued, nevertheless flood damages were very large: about 1500 properties were damaged and 320 buildings were damaged or destroyed. Losses to agriculture and breeding were massive too, with about 40,000 head of livestock lost and 18,500 ha of land damaged. One person died.

Because of the heavy losses, BOM and VIC SES charged Molino Stewart Pty Ltd with doing an ex-post survey in affected areas with the aim of evaluating flood warnings and response to help BOM and VIC SES improve their services. Indeed, the huge amount of damages that occurred, notwithstanding the presence of an EWS, could be due to two different causes:

- expected damage reduction is low for the area under investigation, even in the presence of a perfect warning and an optimal response;
- damage reduction has been low during the event, because of an ineffective warning and response.

The ex-post survey has just the aim of evaluating flood warnings and response effectiveness during the event.

The analysis (Molino Stewart Pty Ltd, 2007) includes three different surveys: interviews with agencies, media monitoring and a community survey. Here, the interest is in data coming from lay people. Specifically, 68 interviews were completed in the survey of residents and businesses that experienced the flood. Results highlighted that:

- around 40% of respondents heard an “official” warning but only around 60% of these thought it applied to them;

- when respondents were asked to identify what first alerted them to the likelihood of flooding, the majority of answers (around 55%) identified unofficial warnings[11]. The next most frequent response (around 40%) concerned official channels[12], with about 12% answering "other", without specifying the source. However, these data cannot be considered strictly representative of the experience of those at risk. Although the question only permitted one response, some people gave multiple answers with the result that the sum of percentages is over 100%. Nevertheless, given that the objective is not to evaluate the survey methodology used in this case study, but to show how survey data can be mapped onto the event tree, the percentages have been considered useful (and reliable) to deduce trends. So only specific answers have been considered strictly representative (about 95% of responses) and it has been assumed that the complement to 100% (around 5%) is the percentage of people who did not notice any kind of warning;
- if alerted, more than three quarters of people (around 76%) of those who had some sort of warning (about 95%) looked for further information about the flooding;
- nearly everyone (more than 99% of those who had some warning) took some actions to reduce losses to their property[13]. The report does not specify whether the above results refer only to people who received a warning or to all the respondents. Here the assumption is that no actions have been taken by those who received no warning. It is of course possible that people took action after seeing rising water.

Figure 4.A.2 displays the survey results by means of the event tree. It can be observed how the original framework has been modified in light of the available data. Specifically, as data derive from a survey in which people themselves identify warning sources, it has been assumed that in case of warning everyone notices it. Moreover, as no information has been collected about understanding, it has been assumed that those who receive a warning understand it as well. Accordingly, the linked columns have been deleted. Finally, a typical behaviour has been observed with respect to trusting. In the community under investigation those who trust the warning do not look for confirmation, while all those who do not trust the warning they received look for confirmation. The original event tree has then been modified according to this evidence.

The event-tree approach enables analysts to examine warning performance during the flood as well as to evaluate how this performance could be improved, and what would be the likely effect of each improvement. With respect to the Gippsland case study, it is possible to state that:

- from a broad perspective, the warning (both official and not) appears to have been effective. In fact by adding the probability of action for each possible branch (sequence of actions/behaviours), it results that about 78% of the respondents took action with respect to about 22% who did not.

$$\sum P(\text{act}) \approx 0.78$$

$$\sum P(\text{no}) \approx 0.21$$

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[11] Mainly personal observation or notification from friends.

[12] Radio, television, doorknock and BOM web site.

[13] Lifting possessions above flood waters, attempting to stop water entering the building, removing cars, switching off the power, evacuating, etc.

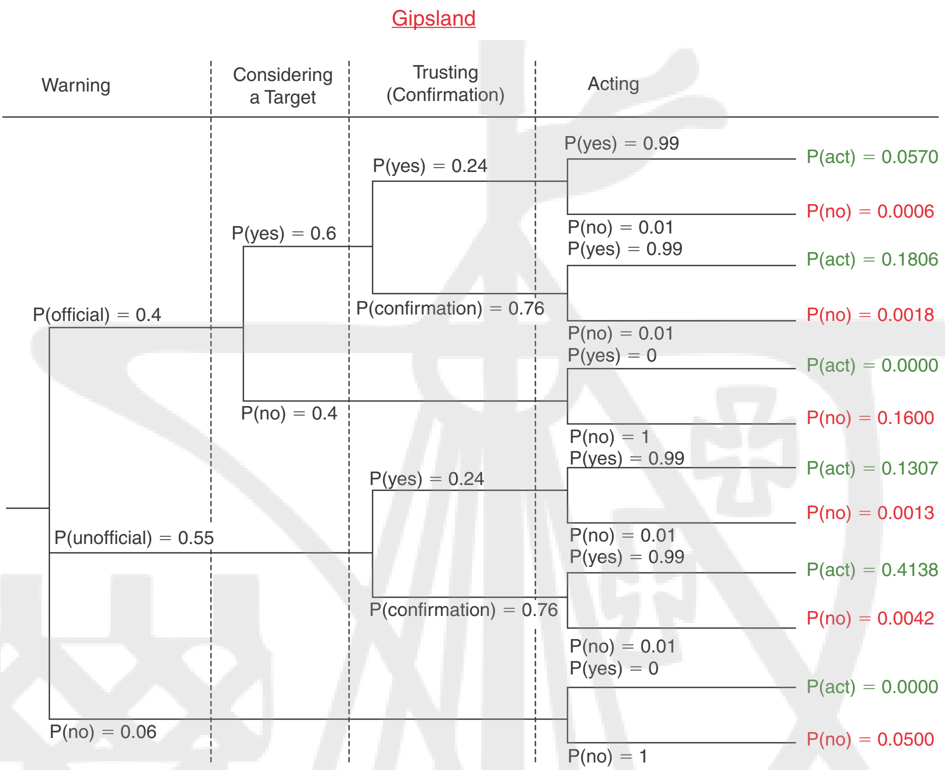

Fig. 4.A.2
The event tree for Gippsland event

- about 70% (54% of 78%) of people took some kind of measure after an unofficial warning:

$$\sum P(\text{act} \mid \text{unoff}) \approx 0.54$$

This means that the effectiveness of the official FWS was less that it first appeared to be;

- about 76% of people looked for a confirmation before acting. Given that confirmation takes time, this means that the time people actually spent in taking action was reduced with respect to the maximum potential one. This evidence – along with the speed of flooding – could also explain the large amount of damages,
- 73.4% of those who did not take action (16.5% of 22%) were lead by the belief they were not at risk rather than a failure to notice the warning:

$$\sum P(\text{no} \mid \text{no trust}) \approx 0.165$$

This evidence suggests again that the effectiveness of the official FWS could be improved by ensuring that people know that they are at risk.

In terms of potential improvements, most respondents suggested that specific localities should be mentioned in warning messages. The event tree in Figure 4.A.2 implicitly corroborates this through the proportion considering them targeted by the warning as well as the proportion seeking confirmation. The literature suggests that more targeted messages could both reduce the number of people looking for a confirmation and increase the proportion who realise that the warning is for them. According to the model, this would result in a general increase in people taking damage reducing actions, so that analysts seeking ways of improving FWS could come to similar conclusions by analysing the event tree rather than using field surveys.

But the event tree also allows evaluating the weight of the suggested improvement or its target value. For instance, imagine that the final aim is to increase people taking action from 78% to 80% (in a population of 50,000 people this will be 1000 extra people). According to the model, this same objective can be achieved in different ways. One approach for example, would be to reduce the percentage of people who did not consider themselves at risk and a target for the warnings. The real objective then may be to reduce this percentage from 40% to 35.5% (2250 people of 50,000 at risk). Another approach would be to act on those who did not notice the warning. In this case, the real objective is about increasing the percentage of people who receive an official warning from 40% to 43% (1500 people of 50,000 at risk). Of course, one can think about a mix of measures as well. What is important is that the event tree provides an approach to estimate the value of a specific measure in terms of the proportion of people whose behaviour is to be changed. The final choice then depends on factors such as the technical feasibility, cost, etc.

Unfortunately, the event-tree approach also has limits. For instance, as already stated, confirmation takes time and this will slow the implementation of damage reduction actions. When the lead time is short, as in the case of flash floods, then a reduction in the effectiveness of damage mitigation actions can occur as well. The event tree does not explicitly model this aspect. However, if considered relevant, the limited availability of time (and the consequential reduction of mitigation effectiveness) can be taken into account by adjusting the value of expected damage reduction. For example, if in the case of plenty of time, mitigation actions can reduce damage up to 15% of the potential, but in the case of limited time (e.g. because of the nature of the flood or because of the time taken for people to implement actions) one can assume that the damage reduction would be less. Given these limitations, the event tree can be seen as an exploratory tool.

4.A.2 The Maitland and Newcastle flood

The second case study refers to a flood that occurred in New South Wales (Australia) in early June 2007. This second application aims at describing how the proposed methodology can be used to evaluate *ex-ante* the benefits of a FWS. For this reason, the analysis entailed the following steps:

- First, two affected towns have been chosen with the scope of identifying two areas with different "levels of development" of flood warning systems (as set out in Parker and Fordham, 1996).
- Then, the outcomes of the flood for both the towns have been analysed by means of the event-tree methodology. In particular, the effects on potential damage reduction of the two different kinds of warning have been compared.
- Finally, again through the proposed method, the benefits of the implementation of a more tailored FEWS for the location with a less developed system have been assessed.

Case study data derive, as before, from a field survey by Molino Stewart Pty Ltd (2008).

The towns chosen are Maitland and Newcastle (see Figure 4.A.3) in the valley of the Hunter River. The pair of locations allows comparison between an official FEWS for the city

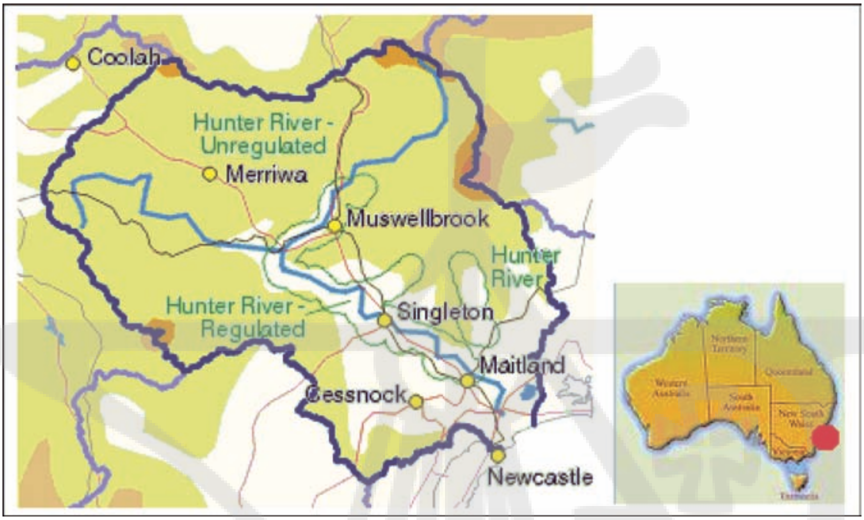

Fig. 4.A.3
The Hunter River basin

of Maitland, which was established by the BOM, and a limited warning system for Newcastle. During the flood, various specific warnings (with clear information on likely flood location, severity and time) were issued for the city of Maitland, including an evacuation order. But no specific warnings were issued for Newcastle, which received only a simple "Severe Weather Warning" (see Opper and Gissing, 2005) with a general indication on expected flash flooding in a specified region within a certain time. Maitland is prone to riverine floods with lead times of the order of 2 days, and Newcastle is subject to flash floods events, with lead times of hours. No specific damage data appear to have been recorded after the flood; however, the event was quite intense and more than 4000 people evacuated.

Table 4.A.1 sets out the survey results which are of interest with respect to the aim of this study. It is stressed that reported results come from a first preliminary data processing.

However, this does not affect the validity of the comparison because the same hypotheses have been assumed in processing data from both locations. Further detail and explanation are set out below:

- Five subsequent warnings were issued for Maitland during the flood. Percentages of respondents who noticed them and thought that they were the target vary for each warning. Here only the last warning before the flood (the one including also an evacuation order) has been considered.
- With respect to the warning channels: radio, TV and door knocking have been included in official warnings, while heavy rain, self-warning and friends/neighbours are considered unofficial.
- There is a difference between the percentage of people who noticed an official warning and the percentage who considered official warnings as reliable sources. This has been explained by assuming that the gap is due to a lack of trust in official sources.

Figures 4.A.4 and 4.A.5 display the modelling of the problem by means of the event tree whose framework, as in the previous case study, has been modified by combining categories

Tab. 4.A.1
Data about peoples' behaviour during the Maitland and Newcastle flood

	Maitland	**Newcastle**
Percentage of respondents who noticed warnings	74	40
Percentage of respondents who noticed warnings and thought they applied to them	73	79
Sources that first made respondents think they must be flooded	Radio and TV: 26 + 11 Door knocking: 25 Heavy rain: 13 Friends/neighbours: 5 Water enters in the house: 14 None: 6	Radio and TV: 6 + 1 of 32 Door knocking: 0 Heavy rain/self warning: 18 + 6 of 32 Friends/neighbours: 12 of 32 Water enters in the house: 68 None: 57 of 32
Percentage of respondents who checked the information	71	71
Percentage of respondents who lifted contents to upper floors	84	86

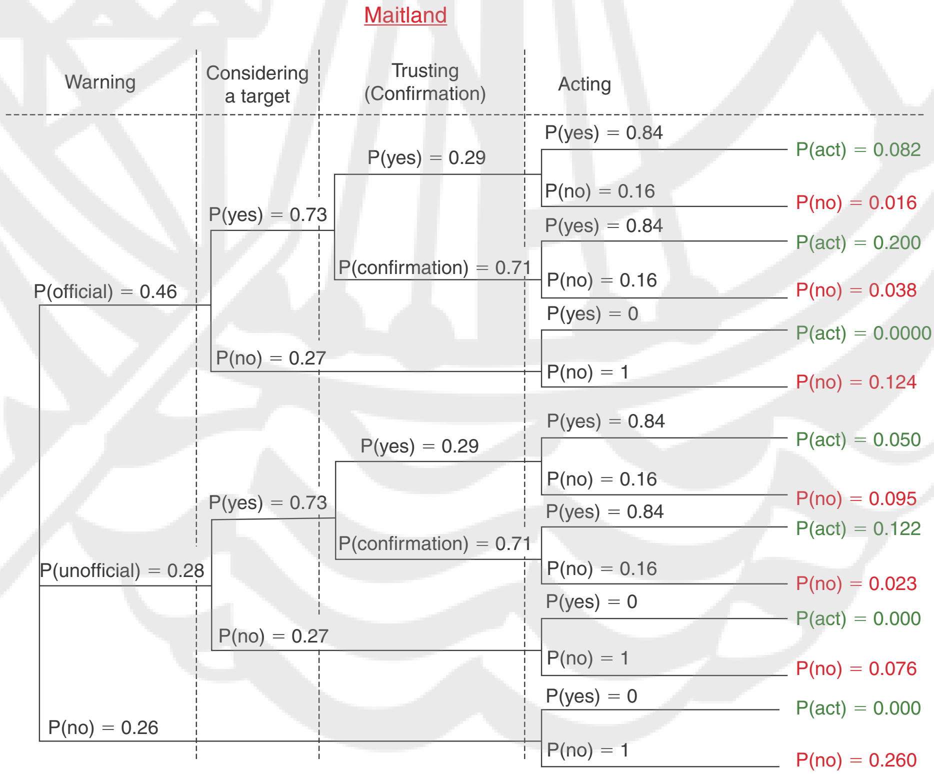

Fig. 4.A.4
The event tree for the town of Maitland

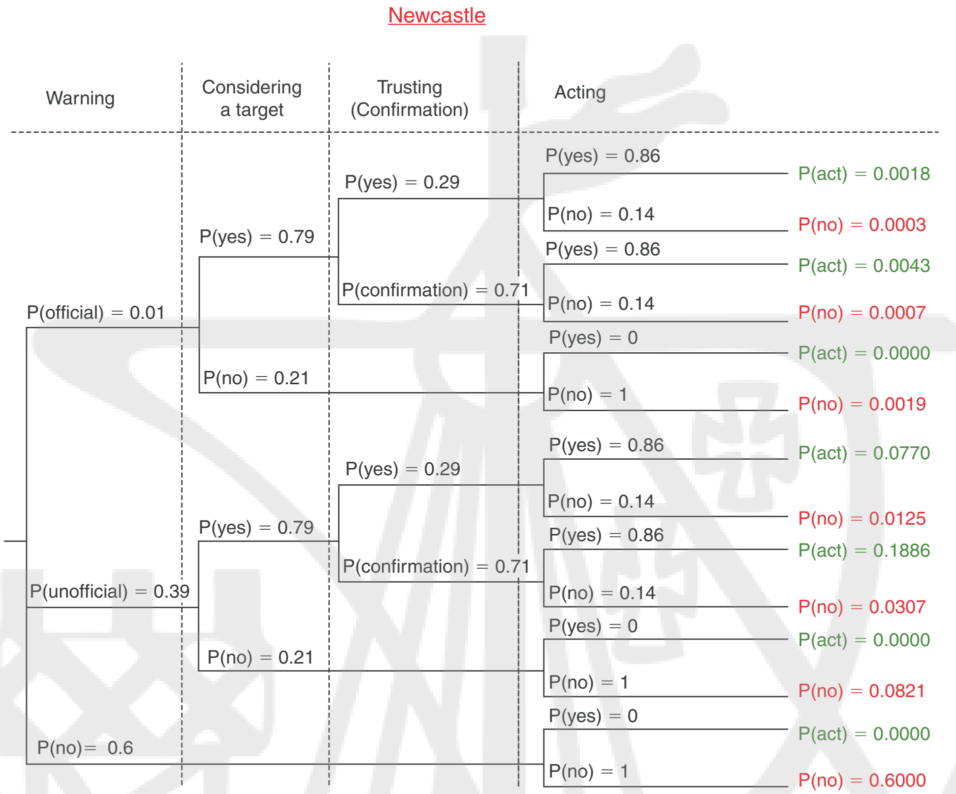

Fig. 4.A.5
The event tree for the town of Newcastle

to align with the data that was collected in the surveys. Moreover, the following assumptions have been adopted so that full use can be made of the available data:

- everyone who does not consider that warnings apply to them does not take action;
- people that do not need to confirm the warning take action;
- people who not receive a warning do not take action.

The analysis shows that in Maitland, where a specific FWS has been well established, the percentage of people who took action was in total about 45% whereas it was only 27.2% in Newcastle where only a general severe weather warning system exists.

The event-tree model has then been used to evaluate whether the implementation of a more specific warning system would produce benefits for Newcastle, in terms of people who would take action in case of a future flood. Based on the results for Maitland, plausible behaviour change has been estimated for a hypothetical warning system in Newcastle.

From the Maitland data, it can be seen that, running from a first "Severe Weather Warning" to the last warning, the percentage of people who heard the message increased from 51% to 74% (+45%), while the percentage who considered themselves as a target increased from 64% to 73% (+15%). Supposing that the same increases could be observed in Newcastle in case of a new FEWS development (given the homogeneity of both the exposed populations and the warning authorities), the corresponding percentages for Newcastle would increase from 40%

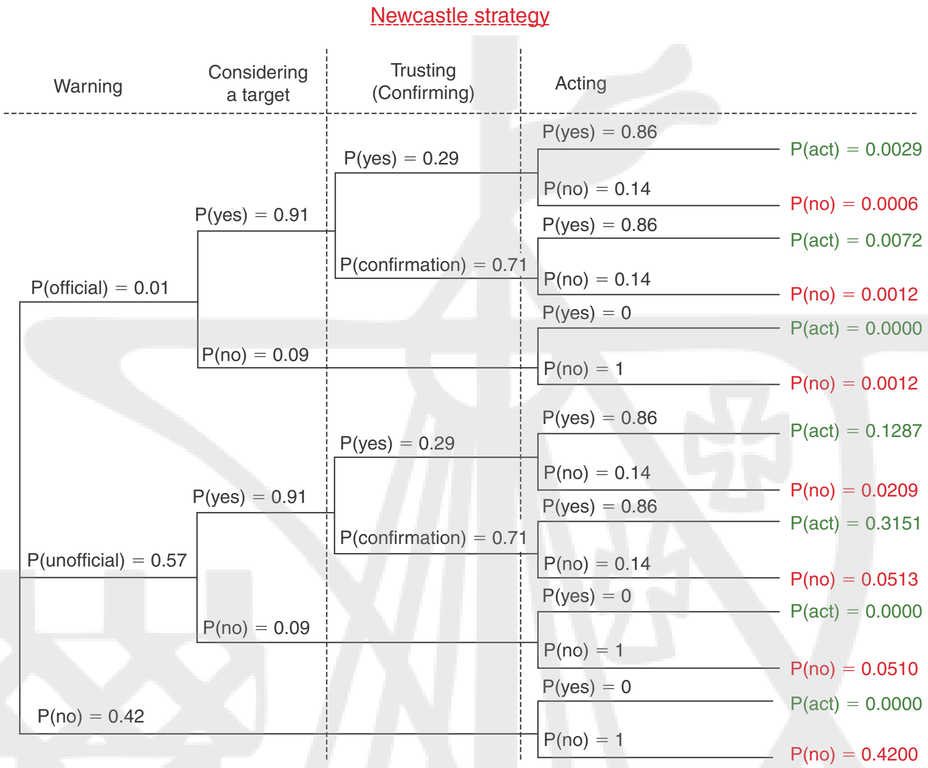

Fig. 4.A.6
The event tree for the town of Newcastle in case of a new FWS

to 58% and from 79% to 91%, respectively. As displayed in Figure 4.A.6, this would imply an increase in people who would take action from 27.2% to 45.4%. This improvement would almost double the warning system's effectiveness.

The event-tree approach allows carrying out other considerations. For example, it is known that, in case of flash floods, seeking to confirm a warning could mean wasting much if not all of the time available to take action. This factor can be mapped on the event tree in Figure 4.A.4 by reducing the percentage of people who take action after a confirmation to 0%. This would imply that the percentage of all those at risk from flooding who would take effective action decreases from 27.2% to 7.8%. In this context, reducing the percentage of people seeking confirmation from 71% to 60% would lead to an increase in FWS effectiveness of about 10%. In a location with a population of 140,000, the increase (+3.8%) is equal to more than 4000 people. The event tree would support the implementation of a program aiming at increasing trust in authorities by those at risk and not waiting for confirmation before taking action. In other words, the use of the event tree can help with a detailed problem-oriented approach to warning system improvement.

4.A.3 Final remarks

The cases showed some of the possibilities of the model to support the design and improvement of FEWSs, through both *ex-ante* and *ex-post* assessments. Specifically, in both case studies the event-tree approach allowed to identify the potential benefits from improvements to flood warning systems currently in place as well as desirable behaviour changes.

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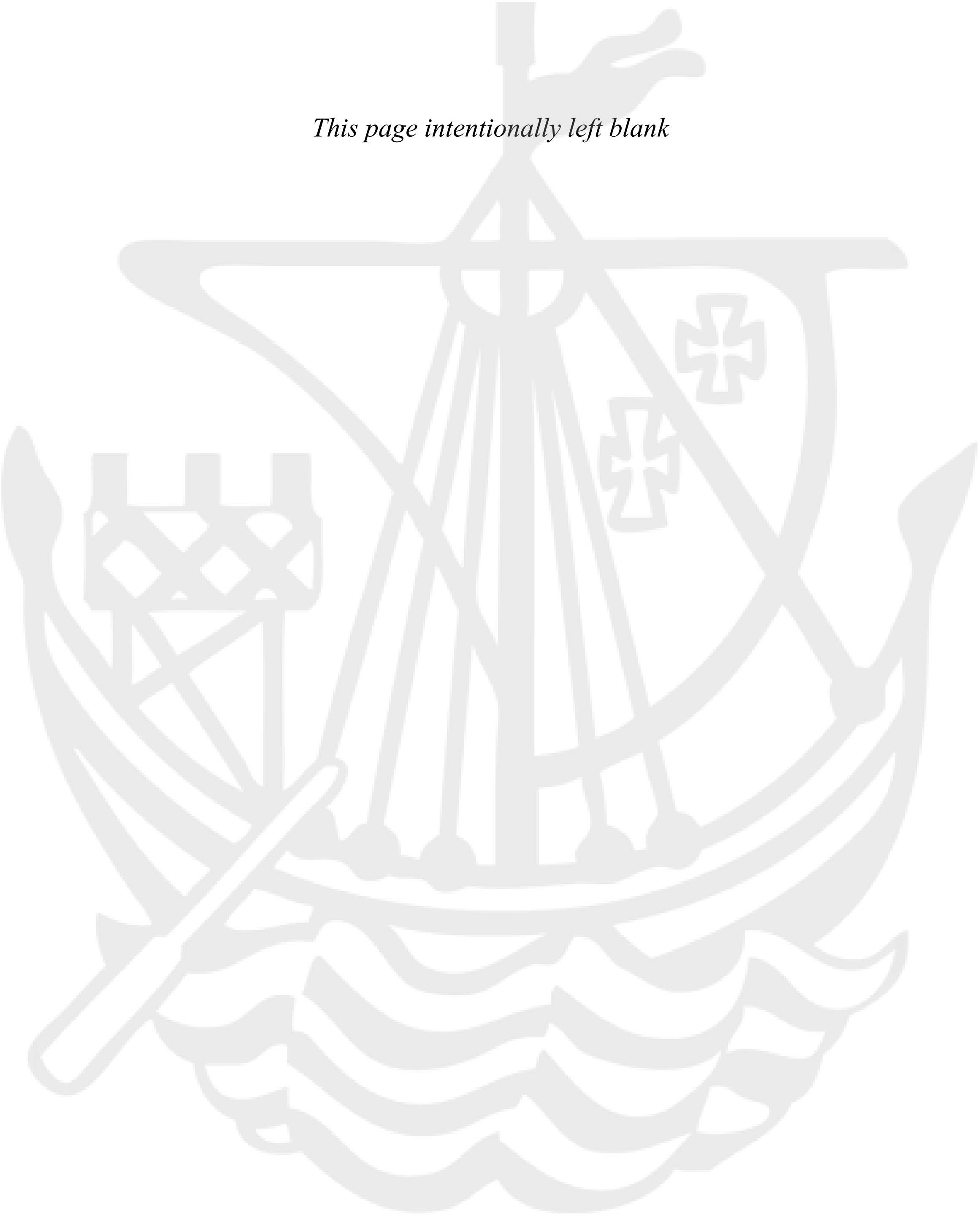

Conclusion

Summary of contents and critical discussion

C.1 Summary of contents

This book aims at assessing a procedure to evaluate FEWSs performance.

This requires first (see Chapter 1) to face some "open questions" concerning the identification of what an FEWS is, which its components and functions are and which are its peculiarities (weak points). Then, a possible approach to evaluate FEWSs performance can be developed (see Chapters 2–4).

With respect to its general objective, this book presents two peculiarities:

1. First, it collects and organises most of available knowledge.
2. Second, at the same time, it supplies new concepts and tools which support the analysis of the problem at stake (i.e. FEWSs performance assessment).

The main innovation is the definition of a possible **framework** to describe the flood warning process, which has been taken as a reference along the whole book; the framework is reported again in Figure C.1.

This conceptual tool goes further the conventional vision of EWSs as simple technical tools to monitor and forecast impending events, representing, this way, an innovation with respect to the traditional approach to EWSs. As Ballio and Menoni (2009) argue, working in the real word, decision makers could not abstract one aspect (i.e. the forecasting) from its context. This means that they do not limit their consideration to hazard probability of occurrence only, but they also take into consideration exposure and **vulnerability** (i.e. they consider risk). In other words, once decision makers are supplied with a flood forecast, the choice of issuing or not a warning depends also on the related expected **damages** in terms of economic costs, affected people, environmental damages, etc. (Keys and Cawood, 2009). As highlighted in Figure C.1, this is just the vision of the problem this book adopts.

On the other hand, the framework can be read also at the perspective of "**Total Warning Systems**" which is in line with the above considerations. In detail, the concept of Total Warning System (which was first developed by Australian authorities – see EMA, 1999 – but it is now shared among both the researchers and the practitioners communities) considers EWSs as made up of four sub-systems, strictly interconnected to each other so that a failure in any one link can mean the failure of the whole system:

- A monitoring and forecasting sub-system, to monitor and forecast hazards to produce information about impending events.
- A risk information sub-system, to develop risk scenarios to figure out the potential impact of an impending event (on specific vulnerable groups and sectors of the society).

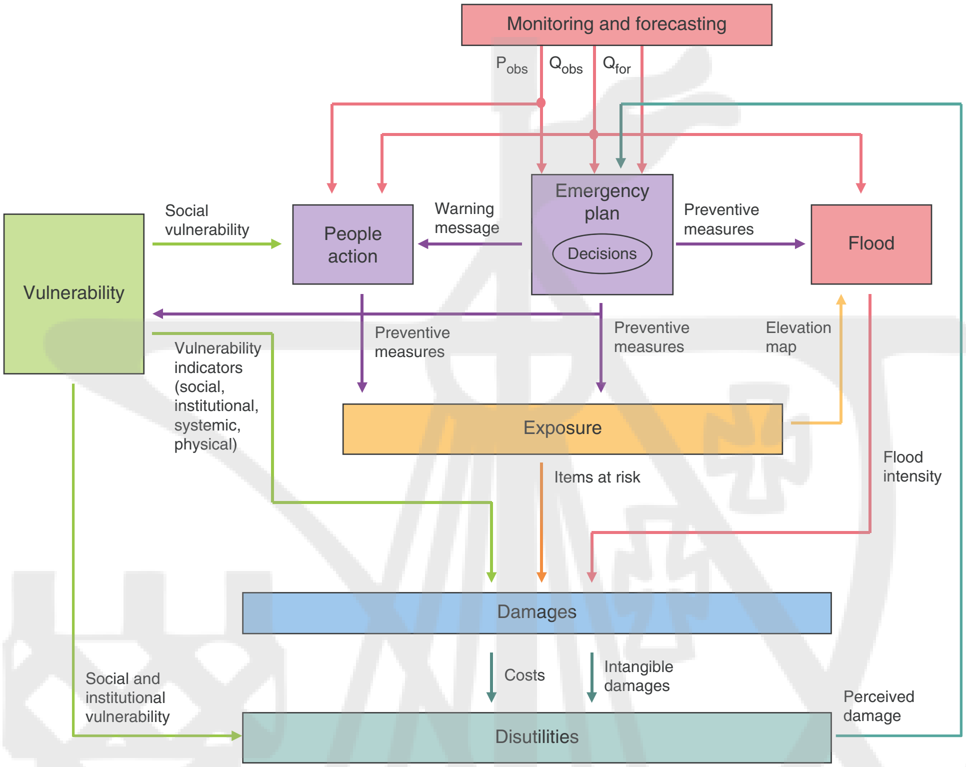

Fig. C.1
The figure displays the warning decision-making process, as conceived in this research. Arrows represent variables, while rectangles represent processing steps which need to be modelled

- A preparedness sub-system, to develop strategies and actions required to reduce the damage from an impending event.
- A communication sub-system, to communicate timely information on an impending event, potential risk scenarios and preparedness strategies.

Figure C.2 shows how these sub-systems can be mapped on the framework proposed here. In detail:

- The pink box refers to the monitoring and forecasting sub-system.
- The light blue box identifies the risk information sub-system.
- The violet box refers to the preparedness sub-system.

Of course, the communication sub-system cannot be mapped on the scheme as communication occurs everywhere along the “warning chain”. Thus, involving functions and actors from different sub-systems, it should be seen as something that is shared between the other components of the chain, rather than a well-defined entity.

By analysing the warning process, in terms of its components, its actors as well as the decisions they perform, it is possible to state that a tool like the one defined in Figure C.1

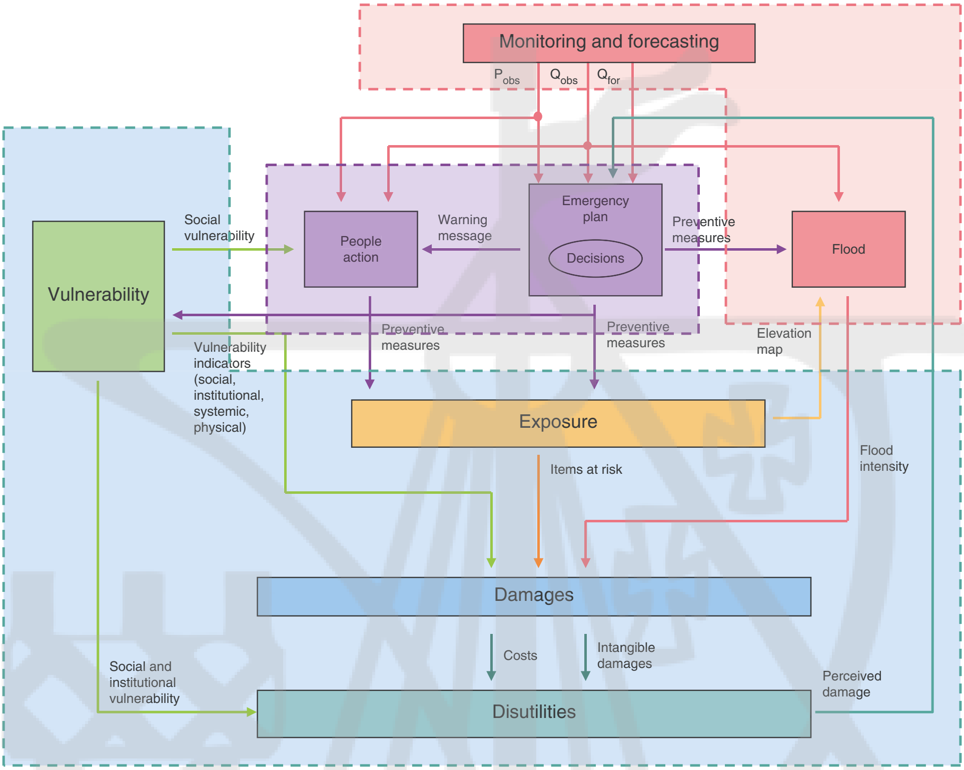

Fig. C.2
The figure maps Total Warning System components on the framework describing the warning process

would allow analysts to evaluate systems at three different perspectives (which are all crucial for FEWSs effectiveness):

1. First, from the forecasting point of view, meaning looking at the goodness of flood forecasts in terms of their capability to predict the features of incoming floods.
2. Second, at the perspective of risk scenarios, that is considering the capacity of the system to properly figure out expected damages in case of flood (on which mitigation actions can be planned).
3. Finally, from the point of view of damage reduction, that is investigating the ability of the system (and, in particular, of the strategies which it implements to copy with the event) to lessen expected damages.

Such an approach goes further the traditional formulation of FEWSs performance assessments (which, instead, are focused only on the evaluation of monitoring and forecasting) and represent just the topic of Chapter 2–4.

Indeed, in these chapters, all the knowledge and tools which are required to carry out a performance evaluation, which would meet the above requirements, are supplied. Specifically a procedure is proposed to analyse FEWSs; the procedure is also tested in a case study to highlight its potential.

In a nutshell, the procedure proposed in the book is grounded on the **forecasts verification** process, as conceived by Murphy (1993). In detail, by evaluating forecasts accuracy (meaning the correspondence between forecasts and observations) and forecasts value (meaning the incremental benefits of forecasts to users, in terms of expected damages reduction), the procedure allows to analyse FEWSs just from the three perspectives identified above.

However, it is important to stress that forecasts verification (and so the assessment of FEWSs performance) should not be seen as a universal process, but it should be tailored to the particular **context** in which forecasts are implemented or, in other words, to the specific standpoint of a **stakeholder** (Murphy and Winkler, 1987). Indeed, the definition of "expected damages" (or, in other words, of "the value" of a forecast) is not universal but varies from problem to problem and from user to user within a specific problem. For example, if a damage assessment is carried out just after an event strikes (e.g. to manage the emergency response), then long-term impacts are probability not relevant. Likewise, if the decision maker, during a warning process, is the major of a small village, then the spatial scale of the damage analysis will be probably limited to their municipality, but if the stakeholder is the regional authority then all the (potentially) affected areas within the regional board will be likely taken into account.

In this book, the local floodplain managers point of view has been adopted and, according to an economic perspective, the **average economic damage** of previous events has been implemented as a measure of the disutility associated with forecasts.

C.2 Critical discussion

The strength of the Total Warning System concept (which this book embraces) is that of discussing and promoting a **systemic vision** of the warning problem, in which hazard and vulnerability as well as technical and non-technical aspects are combined. The main innovations this book entails come just from the adoption of such a vision.

In detail, the **first innovation** this book proposes is the **inclusion of damage** among the variables on which forecast verification process (and, more in general, FEWSs performance assessment) is grounded. With respect to this, the analysis of damage assessment methods in Chapters 3 and 4, as well as the damage assessment that is carried out within the case study, represents the core of this book whose results can be generalised and applied to the wider problem of risk assessment.

Chapters 3 and 4 constitute, in detail, a first attempt to organise/rationalise all the available knowledge on flood damage and its modelling. This brought, on one hand, to determine and classify all the possible impacts in case of flood that ideally should be included in a damage assessment; on the other hand, to identify and analyse available tools in a critical way for such an assessment. Moreover, the case study allowed to identify all the **criticalities** that presently hinder the development of suitable damage assessments and, in turn, to recognise priorities for **future research**:

1. First is the present "local" nature of direct damage assessment tools (with particular attention on depth–damage curves for the assessment of damage to buildings) and the limited possibility to export such instruments to various hazard and vulnerability contexts. From this perspective, further efforts are required in the following directions: (i) the investigation of available damage data in order to evaluate whether they enable the identification of context specific models and (ii) understanding on which degree existing models can be exported to different contexts and which is the uncertainty this operation implies.

2. Second is the lack of tools to evaluate indirect and intangible damages, with particular attention on those damages (i.e. costs) sustained by communities to face the emergency (e.g. warning costs and rescue costs). As a consequence, these losses have not been taken into account in the assessment even if past events showed their importance in shaping the whole damage after the occurrence of a flood. Focusing on intangibles, the implementation of disutility functions seems a suitable choice. Disutility functions describe flood impacts in terms of the subjective importance/weight each stakeholder puts on a specific damage. This way, intangibles could be not only evaluated but also included in the estimation of floods damage. Indeed, one of the main problems in current damage assessment is the use of different metrics for different kinds of damage, above all when some of them all only qualitatively estimated. By means of disutility functions, damages can be expressed as dimensionless so that direct, indirect and intangible damages could be compared and add to each other. However, the analysis carried out in the book shows that research on disutility, at least in the field of flood damage, is still at an embryonic stage.
3. Third, a lack of data (from field surveys) to carry out ad hoc analyses – when analytical assessment methods are not available – came into light; from this perspective, the case study corroborates pressing concerns of the research community on the availability and quality of existing databases. The establishment of shared definitions and common methodologies to gather data is required along with systematic procedures for their collection in the aftermath of an event. The aim should be enabling analysts to infer damage figures and to carry out comparative analyses an inter-operability level so that, data from one database can be exported to another one and vice versa.
4. Finally, there is the lack of criteria to define the scales of the analysis; whilst in hazard assessments the spatial and the temporal scales of the analyses are dictated by the features of the phenomena under investigation (e.g. river basin extension and hazard dynamics), the spatial and the temporal scales of damage assessments depend on the point of view that is adopted or, in other words, on the stakeholder(s); thus disutility comes into light again. The temporal and the spatial scales of the analysis are important for a twofold reason: (i) different scales (both spatial and temporal) imply different (types of) damages to be included in the assessment; (ii) it is possible that different scales of the analysis also imply different tools to estimate the same type of damage. Research is then required in this direction.

Yet, the case study allowed to put some light on the above critical points. For example, by analysing the warning context and by means of a rough sensitivity analysis, those damage components which significantly affect FEWSs performance have been identified, at least, from the local floodplain perspective (this allowed to face some questions related to disutility and scale as well). Moreover, a first attempt has been implemented to carry out a context-specific assessment of costs required to face the emergency.

On the other hand, the inclusion of damage within the performance assessment represents also a critical point of the proposed methodology. Indeed, it can be stated that, at present, results uncertainty could be high, above all because of the uncertainty deriving from the estimation of damage components. From this perspective, it is important to stress that results supplied by the forecasting value assessment in Chapter 4 must not be seen in terms of "absolute values" but rather as a suggestion of the behaviour (performance) of the system. In contrast, just the utility of the information supplied by the value assessment overcomes limitations due to damage models. Despite all the uncertainty which presently affects case study's results, it clearly demonstrates that the inclusion of the whole warning chain (from forecasts to damage, to communication with people) in FEWSs performance evaluation supports the decision-making process about warning. Indeed, more information is supplied to decision makers in order to take rational choices.

The **second innovation** deriving from the systemic vision can be identified instead with the FEWSs performance assessment **procedure** proposed here, which, specifically, presents different strengths:

1. First, the procedure is *complete*, meaning that it allows to evaluate the warning process (as described in Figure C.1) from the top to the bottom[1] analysing, this way, all the components which constitute a total warning system (although partially); in other words, by implementing the whole procedure (i.e. by carrying out both forecasts accuracy and forecasts value assessments), it is possible to verify forecasts with respect to all their functions (or, equally, from different perspectives/points of view).
2. Moreover, the procedure is *fixed* and involves defined steps/methods. It must be stressed that, unlike for seismic risk, no standards exist in the field of flood risk for related analyses but few scientific attempts/guidelines (see, for example, Ernst et al., 2010); from this perspective, the contribution this book brings is relevant.
3. In the other hand, the procedure is also *flexible* in the sense that the different steps/approaches previously discussed (i.e. forecasting accuracy vs. value) can be partially or totally adopted, depending on the specific context in which the procedure is implemented. For example, considering the forecasters point of view, the first approach gives enough information to take decisions about forecasts suitability. On the opposite, the forecast value assessment approach best matches local authorities' needs and FEWSs assessment requirements.
4. Last but not least, despite all its limitations (i.e. uncertainty), the procedure is also an *operational* tool supplying quantitative results (i.e. numbers) that allow analysing and comparing systems.

Furthermore, the procedure also presents various **potentialities**, with respect to both its real implementation and to further improvements. Regarding the former aspect, the procedure can clearly be extended to a wider class of problems than the one in the case study, like the comparison of different forecasting systems as well as the evaluation of forecasting contexts. Criteria discussed here within the different performance evaluation strategies can be used for the optimisation of FEWSs with respect to any possible variable, comprehending choices among different flood forecasting models (e.g. a rainfall–runoff model, a black-box model and a hydraulic model) or, simply, warning thresholds within a given system.

With respect instead to the second point, forecast value assessment could potentially include further kinds of disutilities associated with the warning outcomes, like indirect and intangible damages. This would meet the increasing pressure of the risk assessment community about the need of including also social aspects in the evaluation of FEWSs performance (see, for example; Handmer, 2000). Of course, this implies first to face some "open questions" about damage assessment (e.g. how intangibles can be quantified? How subjectivity does affect and can be included in the assessment?).

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[1] Or from the bottom to the top, according to the point of view that is adopted, see Section 4.3.

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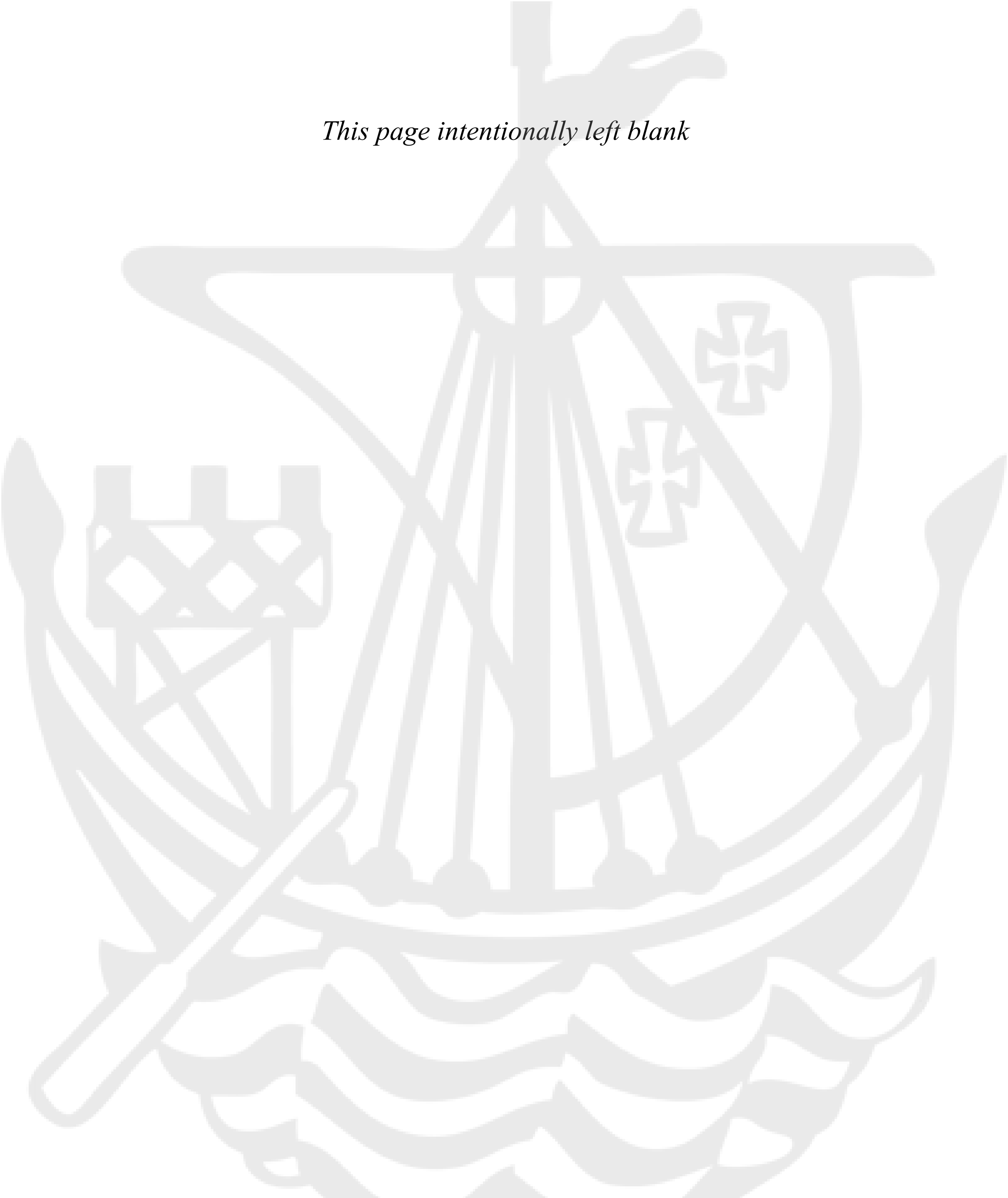

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