CHAPTER 3
UNDERSTANDING DISASTER RISK: HAZARD RELATED RISK ISSUES - SECTION III

 understanding disaster risk: hazard related risk issues

SECTION III
Meteorological, climatological and biological risk

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Section III. Meteorological, climatological and biological risk

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Introduction

The following subchapters cover meteorological, climatological and biological risks. In terms of meteorological risks, hazards from different types of storm systems as well as extremes of temperature are covered. Climatological risks include droughts and wildfires, and the biological risks posed by epidemics and pandemics are also examined. Each of these hazards is described in turn:

• There are two types of storm in meteorology: (1) the hazardous weather phenomena themselves (e.g. windstorms, rainstorms, snowstorms, thunderstorms and ice storms) and (2) the meteorological features in the atmosphere or storm systems that are responsible for the adverse weather. The latter includes tropical cyclones, extra-tropical cyclones and convective systems.

• Temperature extremes are rare high- or low-temperature events that may occur over a range of time and geographical scales. They usually occur because of a change in the weather pattern over a few days or several weeks.

• In terms of climatological risks, droughts result either from a shortfall in precipitation over an extended period of time, from its inadequate timing in relation to the needs of the vegetation cover, or from a negative water balance due to increased potential evapotranspiration caused by high temperatures.

• Wildfires refer to fires affecting grasslands, shrublands and other non-forest land covers. Although they are mainly initiated by human actions, their intensity and the effects they cause are mainly driven by fuel condition and availability, vegetation structure and prevalent meteorological and topographic conditions, and thus they are termed a natural hazard.

• An epidemic is the widespread, and often rapidly extending, occurrence of an infectious disease in a community or population at a particular time. A pandemic is the extension of an epidemic to many populations worldwide or over a very wide area, crossing many international boundaries and affecting a large number of people.

All of these hazards can lead to a range of substantive direct and indirect impacts on human activity and infrastructure. Compared with other meteorological disasters, extreme temperatures (particularly high rather than low temperatures) can cause the most severe consequences in terms of human lives lost. Droughts can affect extended areas and large populations, putting socioeconomic systems and the environment at risk. Wildfires emit large volumes of smoke and gases that can aggravate respiratory problems, resulting in the
deaths of susceptible individuals. Demographic, physical, socioeconomic, behavioural and institutional factors may moderate a population’s vulnerability to most hazards, particularly temperature extremes and epidemics. Thunderstorm asthma is a term used to describe an observed increase in acute bronchospasm cases following severe thunderstorms, which can have significant impacts on individuals’ health and on health services.

Of particular concern is the evidence that human-related climate change is increasing the frequency of these hazards. The accelerated growth in global mean temperature since 1975 and the projected increase over the next several decades have implications for the occurrence of temperature extremes. A number of researchers have also highlighted the potential changes in fire climate regimes in different parts of the world, which may result in increased fire risk and an exacerbation of the effects of wildfires.

However, these hazards do not always occur in isolation and can often interact with or influence one another. This is explained in chapter 2.5 where evolution of risk can be even so complicated that one hazard changes the vulnerability conditions for the next. For example, epidemics of Rift Valley fever often commence when a period of drought is followed by flooding or intense rainfall, so climate perturbations may herald an increased risk of outbreaks in at-risk regions. Similarly, prolonged droughts and heat waves dry out fuels, creating conditions which can exacerbate uncontrollable wildfires.

The following subchapters describe the current knowledge regarding the risk assessment and management of each hazard in detail, identifying a set of recommendations for key stakeholders to reduce and manage their risks.
3.7 Meteorological risk: extra-tropical cyclones, tropical cyclones and convective storms

Thomas Frame, Giles Harrison, Tim Hewson, Nigel Roberts

3.7.1 Storm types and associated hazardous phenomena

3.7.1.1 Storms

Conceptually, there are two types of storm in meteorology: (1) the hazardous weather phenomena themselves (such as windstorms, rainstorms, snowstorms, hailstorms, thunderstorms and ice storms (freezing rain)), and (2) the meteorological features in the atmosphere — the ‘storm systems’ — that can be said to be responsible for this adverse weather (notably tropical cyclones, extra-tropical cyclones and convective systems). These storm systems, which are a focal point in the following discussion, can be distinguished from one another by their mechanism of development (growth), their structure, their geographic location, their spatial scale and their typical lifetime. Other types of storm system do exist, but these can be considered subtypes of the three systems listed above.

3.7.1.2 Extra-tropical cyclones

Extra-tropical cyclones are large rotating weather systems that occur in the extra-tropics (more than 30° latitude away from the equator). They consist of an approximately circular region of low surface pressure, of a radius of 100–2 000 km, accompanied by cold and warm fronts. They typically develop in regions of strong horizontal temperature gradients, which are commonly denoted on a weather chart as a cold or quasi-stationary front. In turn, such fronts often connect to a pre-existing decaying extra-tropical cyclone, which itself is situated some way downstream (typically to the north-east). At the same time, high up in the atmosphere (around 10 km altitude) one commonly finds a jet stream relatively close by. Indeed, the intensity of an extra-tropical cyclone is closely related to the strength of this jet stream. The strongest extra-tropical cyclones occur in winter months when the jet stream is at its strongest.

Storm systems can be distinguished from each other by their mechanism of development (growth), structure, geographic location, spatial scale and typical lifetime.

Periods when the jet stream is unusually strong can lead to two or more strong cyclones occurring within days of each other. The total lifecycle of an extra-tropical cyclone from birth (genesis) through to development and on to decay (lysis) can occasionally be more than 10 days; however, somewhere in the range of 2–5 days is much more typical (Ulbrich, 2009).
The major hazards associated with extra-tropical cyclones are high winds and precipitation (rain and snow). Precipitation occurs primarily along fronts and, on average, is not particularly intense relative to that delivered by tropical cyclones and convective storms. However, when a cyclone is developing, some very heavy precipitation can occur, particularly in a narrow band just to the left (north) of the cyclone track. The band is ordinarily between about 20 and 200 km wide, depending on the scale of the cyclone. In addition, fronts connected to cyclones can sometimes become very slow-moving, remaining over the same location for many hours, and potentially up to 2 days, leading to large rainfall accumulations and potential flooding.

### 3.7.1.3 Tropical cyclones

A tropical cyclone is a rotating storm originating in tropical latitudes, with low surface pressure at its centre. These develop over warm oceans in tropical regions, have a radius in the range of about 100-500 km, and have a lifetime of between a few days and a couple of weeks. They also have a structure in wind, rainfall, temperature, etc., that is relatively axisymmetric (unlike extra-tropical cyclones, the structures of which are not generally axisymmetric). The development and maintenance of tropical cyclones requires that the ocean surface is very warm relative to the air above, and that the air above has high humidity (Emanuel, 2003). The requirement of a warm ocean surface beneath means that tropical cyclones will decay as they move inland. This makes them primarily a hazard for oceanic and coastal regions as well as for small islands.

For historical and cultural reasons, the strongest tropical cyclones are assigned different terminology in different regions of the globe. In the North Atlantic and North-East Pacific, they are called hurricanes; in the North-West Pacific they are called typhoons, and in the Indian Ocean and southern hemisphere they are simply called cyclones. The term hurricane is also sometimes used erroneously by the media to refer to extra-tropical cyclones that have hurricane-strength winds. Tropical cyclones lead to very intense surface winds (notably in a small annulus around the eye), as well as heavy rain and lightning. The most significant threat that they pose is coastal flooding from the associated storm surge.

### 3.7.1.4 Convective systems

Convective storms are produced by a localised rapid ascent of air, which is made buoyant by the heating of air near the Earth’s surface or the cooling of air higher up, with the ascent of the air maintained by heat supplied by condensation of water vapour within it. The rapid ascent of air in convective storms often produces very heavy but relatively short-lived rainfall, thunder and lightning, as well as, potentially, hail, very strong wind gusts and even tornadoes. At their simplest, convective storms consist of a single short-lived convective cell, comprising one ascending and one descending column of air (updraft and downdraft).

Individual cells have diameters ranging from around a few hundred metres up to several kilometres. However, severe convective systems can comprise many cells organised into a larger coherent structure with diameters of up to a few hundred kilometres. These can persist for much longer than the individual cells, as new cells tend to replace old ones within the structure. For example, convective cells may be organised in a linear fashion into squall lines or derecho systems. They may also form part of a rotating system such as a supercell or a large meso-scale convective system. Convective storms mostly occur in the tropics and over land in summer or over the sea in winter in the extra-tropics.

### 3.7.2 Frequency and geographical distribution of severe storm related hazards

#### 3.7.2.1 High winds associated with extra-tropical cyclones

Extra-tropical cyclones account for the majority of recorded high surface winds in Europe. Their capacity to travel inland, and the fact that some cyclones are themselves very large, means that the winds associated with a single storm system can affect large areas. For example, extra-tropical cyclone Kyrill (January 2007) travelled across Europe wind gusts of 25 m/s or more were reported over most of Ireland, the southern United King-
dom, northern France, the Netherlands, Belgium, Germany, Switzerland, Austria, the Czech Republic, Slovenia, Slovakia and Poland (Fink et al., 2009; RAIN, 2016). Cyclone Kyrill caused 46 fatalities (EEA, 2011), created total estimated insured losses of between EUR 4.5 and EUR 4.8 billion (EEA, 2011; AIR Worldwide, 2015) and a total estimated damage of EUR 7.7 billion. An example of a much smaller but much more intense storm system for which the economic losses were about the same was Cyclone Lothar, in December 2009 (Mitchell-Wallace and Mitchell, 2007; Roberts et al., 2014). Lothar affected only a relatively narrow swathe of northern France, south-west Germany and Switzerland, but wind gusts widely exceeded 35 m/s. An important consideration regarding impacts is that damage is typically estimated to vary according to gust strength to the power of 3 (Leckebusch, 2007). Therefore, 35 m/s gusts are much more destructive than 25 m/s gusts.

Understanding of the structure of extra-tropical cyclones has increased considerably in recent decades (see, for example, Browning, 2004; Hewson and Neu, 2015), to the extent that we now have a much clearer picture of related windstorm subtypes. Figure 3.28, for example, shows windstorm footprints for the subtypes Warm Jet (WJ), Cold Jet (CJ) and Sting Jet (SJ). These subtypes are important because they can explain differences in damage levels and the geographical extent of damage between different cyclones. For example, for Cyclone Kyrill, the subtypes were WJ and CJ, while for Cyclone Lothar they were probably WJ and SJ. Moreover, these different subtypes have very different associated predictability levels. WJ is relatively easy to predict, while SJ, the most extreme type, is notoriously difficult.

**Storm systems lead to a variety of hazardous phenomena, including high winds, precipitation and lightning, with the spatial extent and duration of the hazard being strongly dependent on the type of storm.**

Extra-tropical cyclones are ubiquitous in the extra-tropics, occurring at all locations and all year round (although they are more frequent and, on average, more intense in late autumn/winter). Europe is affected by about 10 extra-tropical cyclones per month (based on Hoskins and Hodges, 2002); however, the vast majority of such cyclones do not lead to damaging winds. These cyclones originate from three main sources. The main subtype affecting Europe is Atlantic cyclones, which typically form near the eastern seaboard of the American continent and develop as they cross the Atlantic over the course of several days, although such cyclones can also form over the eastern North Atlantic, closer to Europe. They may also develop over the Mediterranean (Mediterranean cyclones) or in polar regions (polar lows). Within the Mediterranean and in polar regions, cyclones can sometimes have some of the physical characteristics of tropical cyclones (leading to the term ‘medicanes’ in the former case), although such storms are not as long lived and the most extreme cases are much less severe than the most extreme tropical cyclones (Cavicchia et al., 2014). The frequency with which severe cyclones occur is difficult to define because the observational record is not sufficiently long (Della-Marta et al., 2009; Welker et al., 2016) and because current climate models, which could in principle, generate very long synthetic representations of the current climate on which to base an accurate estimate, typically lack the resolution needed to represent severe windstorms (Zappa et al., 2013; Donat, 2011). In addition, if severe cyclones cluster as has been suggested by Pinto et al. (2013) and others, then frequency estimates such as return periods need to be interpreted carefully.

The effect of climate change on the intensity and distribution of extra-tropical cyclones is still very uncertain; however, the IPCC AR5 (IPCC, 2014) states that it is unlikely that the number of cyclones will reduce by more than a few per cent and that there could be a small northward shift in the average tracks of extra-tropical cyclones relative to now. It is also noted that there is little evidence in one set of climate change simulations (CMIP5) of a change in extra-tropical cyclone-related wind strengths.

### 3.7.2.2 High winds associated with tropical cyclones

With the exception of Hurricane Vince in 2005 (Franklin, 2006), tropical cyclones are not known to reach Europe, although they may enter the
region of the jet stream and evolve in structure into extra-tropical cyclones in a process known as extra-tropical transition. Some recent studies have suggested that there may be an increase in these transitioning cases during autumn due to a poleward expansion of the region of tropical cyclone development (Haarsma et al., 2013).

In subtropical coastal regions, tropical cyclones are a major cause of wind damage, particularly in the developing world, where infrastructure is not resilient to the magnitudes of winds that occur. The effect of climate change is likely to be a reduction or no change in the frequency of tropical cyclones, although the average strength of the associated winds is expected to increase (IPCC, 2014).

### 3.7.2.3 High winds associated with convective systems

Winds associated with convective systems can be extreme, the causes being both downbursts and tornados (weak tornados also occur, rarely, in frontal regions in extratropical cyclones). A key difference compared with cyclone-related winds is that convective system winds are relatively short-lived, and so impacts are very localised. Indeed, if plotted on a map similar to that in Figure 3.28, footprints associated with convective systems would be minuscule. Because of their small scale and relatively short lifetime, such events are difficult to observe and, therefore, full knowledge of their frequency and spatial distribution is difficult. Moreover, it is very likely that there is under-reporting, particularly in sparsely populated areas.

In recent decades, approximately 240 tornado sightings have been reported in Europe each year (Antonescu et al., 2016). These were mostly in summer, in mid to late afternoon, when convective activity is highest. The small scale and short lifetime also mean that when they do occur they present a hazard for only a very small area; however, the degree of hazard can be exceptionally high, because of the extreme wind strengths that are possible. The direct measurement of tornado winds is not feasible owing to their destructive nature, although progress has been made with the introduction of mobile Doppler radar, which can make indirect measurements remotely. Occasionally, large convective storm systems can form into squall lines (or derechos), which can cause a swathe of damaging winds over larger areas. One example is the derecho that hit Berlin in 2002 and caused considerable damage and four fatalities (Gatzen, 2004); another is the events of 9 June 2014 in western Germany that killed six (BBC News, 2014). In both such cases, footprints were still no more than about 25% of the size of the red SJ zone in Figure 3.28.

### 3.7.2.4 Precipitation: rain, snow and hail

All storm types are associated with some form of precipitation. The exact nature of this depends strongly on the storm itself. The most frequent type of precipitation is rainfall. This presents a particular hazard when

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**FIGURE 3.28**

Conceptual model of the footprints of windstorms associated with extratropical cyclones.

Source: Hewson and Neu (2015)
accumulations (the total amount of rainfall in a given time) over a local area or river catchment are large. This occurs usually from either severe convective rainfall, especially when the convection persists or is triggered repeatedly over the same location, or just to the left of the track of a rapidly developing extra-tropical cyclone, or on slow-moving fronts associated with such cyclones, or in and just downwind of upslope areas during periods of persistent, strong, moist, low-level flow (orographically enhanced rain). In the last two cases, the rainfall rates themselves may not be very large but the stationarity of the pattern is a key factor. Sometimes even fast-moving supercell storms or organised squall lines can produce flooding simply because of the sheer intensity of the rain.

Heavy snowfall has similar causes to heavy rainfall, as discussed above, but there are two key differences. The first is that, in all instances, the low-level air clearly needs to be sufficiently cold, and this tends to depend primarily on time of year, but also on proximity to coasts and other factors. The second is that extreme convective snow occurs only in certain small areas of certain countries, whereas convective rainfall extremes are much more evenly distributed across the world. Vulnerable areas lie adjacent to bodies of water such as lakes or oceans, which provide both the moisture source for the snow and perpetual triggering of convection, via the elevated surface temperature of the water body. Over the vast majority of the United States, a convective snowfall of 50 cm in 1 day is virtually impossible, but around the Great Lakes, it is not that unusual. Water bodies around Europe (e.g. the Baltic Sea, North Sea and Adriatic Sea) can also trigger extreme localised convective snowfall.

Hail is formed only in strong convective updrafts; the stronger the updraft, the larger the hail can be. Since hailstorms are small scale, it is difficult to get a precise picture of the geographical distribution and frequency of occurrence of hail by size (Hand and Cappelluti, 2011). Pocakal et al. (2009) suggest that the largest hail typically occurs in mountainous regions where updraft strengths can be large owing to the air being forced to rise over terrain. Reports of large hail (diameter of 20 mm or more) within Europe vary between zero and three reports per year per 10 000 km² depending on location; however, inhomogeneities in the observation network mean that confidence in published geographical distributions cannot be very high (see Hand and Cappelluti, 2011).

Lightning strikes usually occur in the presence of convective rainfall associated with convective storms and tropical cyclones, although they may also occur in the frontal regions associated with extra-tropical cyclones. The number of lightning flashes per year is estimated to be of the order of 1-2 billion globally (Mackerras et al., 1998; Christian et al., 2003), with approximately one-fifth of flashes caused by lightning striking the ground and four-fifths caused by lightning between clouds (Mackerras et al., 1998). Over Europe, lightning strikes to the ground are estimated to vary between 0.1 and 4 times per year per square kilometre depending on location (Anderson and Klugmann, 2014). The response of lightning to a changing climate is poorly known, but it is expected to be highly sensitive to increasing global temperatures (Price, 2009).

3.7.2.6 Estimating potential for future severe storm related events

There are a number of ways to estimate ‘potential worst case scenarios’ in the current climate, although these will inevitably have error bars associated with them. For future climate predictions, the problem is much more challenging. For the current climate, one method is to assume that small-scale extreme events, seen in the instrumental record, could by chance have occurred in a nearby location. However, one must have due regard to physical mechanisms, so extreme orographic rainfall, for example, could not have occurred over flat plains situated close to mountains.

A second method is to use a state-of-the-art numerical model to synthesise possible realisations of the current climate. This is relatively common practice within the reinsurance industry, where extreme windstorms are simulated and their output is fed into impact models to estimate potential losses. The companies then position themselves financially to be able to cover such losses should such a storm occur. More recently, the ECMWF has pioneered a method of using operational reforecasts to estimate potential extreme rainfall events in the United Kingdom (Lavers et al., 2016). The main conclusions of this
study were: ‘Across half of the country at least 30% more rainfall is possible. In some places, the potential maximum is substantially higher, up to twice what has occurred’. Such an approach could be extended and expanded, to provide input for strengthening resilience networks.

A third method is to use a stochastic/statistical approach. This approach involves randomly generating a large number of artificial weather events (e.g. windstorm footprints) by, for example, decomposing observed storm structures into base elements using image processing techniques, and recombining these elements with random weighting factors to produce new storm structures. This is also employed in the reinsurance industry.

### 3.7.3 Forecasting and monitoring

#### 3.7.3.1 Current predictive capabilities and future developments

Weather forecasts are produced using large computer models of the atmosphere that propagate the current best estimate of the state of the atmosphere forward in time. The atmosphere is a chaotic system, which means that there are inherent physical limits to how far into the future accurate forecasts can be made. However, over the past few decades, major improvements in forecast accuracy have been achieved through a combination of improved computer power, improved models and improved use and quality of observations (Bauer et al., 2015). Determining the extent to which forecasts can be further improved is a challenging scientific problem, which depends in part on the resolution of computer hardware issues, although there is no clear evidence as yet of any plateauing out of forecast accuracy. No forecast can ever be 100% accurate, but larger scale atmospheric phenomena can be more accurately forecast further into the future than smaller scale physical phenomena (as illustrated by Table 3.2). To quantify the uncertainty, weather forecasts at all lead times are now typically produced using multiple computer forecasts (an ‘ensemble forecast system’) that each use slightly different (but plausible) initial conditions; the degree to which these forecasts differ gives an estimate of the degree of uncertainty in the forecast.

After their initial development, tropical and extra-tropical cyclones are coherent structures that can be tracked in time until they decay. The forecasting problem for such storms can generally be thought of as comprising several components: forecasting the genesis of a storm, forecasting its path and evolution of its structure and forecasting the severity of the associated weather.

Forecasting the genesis of storm systems is one of the most difficult tasks, as storm systems develop from small perturbations in regions of instability. A particularly challenging problem arises when convective cells combine into more organised structures: this includes tropical cyclones (see Majumdar and Torn, 2014), mesoscale convective systems and derecho storms. The formation of tropical cyclones is not completely understood, although several theories exist and some are being actively tested in field campaigns (Montgomery et al., 2012).

Despite a degree of uncertainty in forecasting, it has become more accurate over the past few decades, allowing mitigating actions to be taken and emergency services to be prepared in advance.

Because of their longer lifetimes, the existence of potentially hazardous extra-tropical and tropical cyclones can now be predicted with some confidence up to about 5 days in advance. However, at such leads, uncertainty in the details of a storm’s track, timing and intensity are likely to be very large (Magnussen et al., 2014; Frame et al., 2015). For example, it may often be possible to state with confidence that a strong extra-tropical cyclone will occur, but uncertainty will remain with regard to the path it will take and the strength of winds and precipitation (see third column in Table 3.2). Nonetheless, for some users, having early indications of a very high potential for an extreme event, even if the point probability is only 5%, can still be useful. Some basic mitigating actions can be taken, and emergency services can be placed in a state of readiness (Petroliaagis and Pinson, 2014).

Owing to their small spatial scale and short timescale, unorganised convec-
Effective storms cannot be forecast far into the future (see Table 3.2). The forecast chance of a thunderstorm occurring at a particular location remains negligible, even at lead times of a few hours. However, the background conditions that may give rise to the development of individual storms do have predictive skill (i.e., prediction of the instability in the atmosphere). It is, therefore, sometimes possible to provide a useful probabilistic estimate that convective storms will occur somewhere within a region within a time window. This has motivated a move to short-range local-area ensembles running at ‘convection-permitting resolutions’, requiring horizontal grid spacing of 1-3 km.

For example, the Met Office MOGREPS-UK 12-member ensemble forecast with 2.2-km grid covering the United Kingdom became operational in July 2012; the COSMO-DE 2.8-km ensemble (Gebhardt et al., 2011) became operational in a domain over Germany in May 2012, and the 2.5-km AROME model has been tested in several domains across Europe (Vie et al., 2011; Bouttier et al., 2012; Nuissier et al., 2016).

### 3.7.3.2 Use of observational updates/nowcasting

Although predicting a rapid intensification phase for cyclones can be very problematic, there are nonetheless operational tools available to assist with this. Commonly, forecasters compare imagery signatures, surface pressure measurements and other observations with their equivalent representation in a forecast model output to see if the forecast model is ‘on track’, and if it is not adjustments are made based either on selecting out a suitable ensemble member or on physical understanding and experience. It is of particular importance that forecasts are interpreted with the help of qualified meteorologists and forecasters (Heizenreder et al., 2015).

For convective storms, the high level of uncertainty in the location of storm formation and the short lifetime of storms means that while forecasts can provide initial indications that a severe convective storm is a possibility, much more detailed information is likely to emerge in near real-time as the storm develops. For example, in the United States the average lead time for tornado warnings issued by the National Centre for Environmental Prediction (NCEP) increased from 3 minutes in 1978 to around 14 minutes in 2007 (Wurman et al., 2012), but warnings are still based primarily on the detection of tornados in observational data after tornadogenesis has occurred, and the improvement has been due to better observations and communications (Brotzge and Donner, 2013). Within Europe, recent improvements in radar networks in particular mean that there is greater potential for tracking severe convective events in real time than previously existed. For example, the installation of Doppler and dual polarisation radar give information about winds and more detailed information about droplet size and type within convective storms. Methods are used that project the track of a storm over the next few hours with the assumption that the storm will remain intact and that no new storms will form. These ‘advection nowcasting’ systems can be very useful for the first hour or so, but the rapid evolution of storms can quickly damage performance. In the future, it is expected that convection-permitting numerical models will be run much more frequently (hourly or more often) and combined with advection nowcasting to give the best probabilistic forecast.

### 3.7.3.3 Severe weather warnings

The technical challenge of disseminating information to the general public can increasingly be met through the worldwide web (e.g., meteoalarm.eu and National Meteorological services websites) and the adoption of smartphone applications (e.g., Deutcher Wetterdeinst’s Wetterwarn APP, or weather apps produced by MeteoSwiss, the Met Office and Finnish Meteorological Institute). However, by providing the potential for mass communication to far more individuals and groups than ever before, this technology also creates a greater challenge in maintaining the National Met Service as a ‘single authoritative voice’ in issuing warnings (WMO, 2017) than was previously the case when mass communication was dominated by a small number of media organisations.

Severe weather warnings and guidance pose several other decision-making and communication challenges. Determining what degree of certainty in the forecast is required to for a warning to be issued is a non-trivial problem, which requires balancing the risk of missing the opportunity for early warning with the risk of issuing too many false alarms (Petrolagis and Pinson, 2014). Kox et al. (2015)
Estimated current predictive capabilities in Europe for different hazardous weather phenomena discussed in the text. For this table the maximum lead-time for deterministic predictions (*) is taken to be the point beyond which deterministic forecasts, of threshold exceedance at a point, are more likely to be incorrect than correct (i.e. the 'Deterministic limit', following Hewson, 2006). The maximum lead-time for useful probabilistic predictions (**) is taken here to be the lead time at which one can reliably highlight when the probability of a 1 in 20 year event (for a given day), at a point, exceeds 5 %. For thunderstorms (^), it is difficult to define the meaning of a 1 in 20 year event. Note that lead times quoted are approximate 'best guess values' for current forecasting systems based on forecaster experience and are for illustrative purposes.

<table>
<thead>
<tr>
<th>Storm system</th>
<th>Storm type (weather)</th>
<th>Maximum lead time for accurate “deterministic” predictions *</th>
<th>Maximum lead time for useful ‘probabilistic’ predictions of an exceptional event**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-tropical cyclones (Figure 3.28)</td>
<td>Rainstorm ('left of track')</td>
<td>=24 hours</td>
<td>=72 hours</td>
</tr>
<tr>
<td></td>
<td>Rainstorm ('slow-moving front')</td>
<td>=24 hours</td>
<td>=96 hours</td>
</tr>
<tr>
<td></td>
<td>Rainstorm ('orographic rain')</td>
<td>=48 hours</td>
<td>=144 hours</td>
</tr>
<tr>
<td></td>
<td>Windstorm — CJ</td>
<td>=24 hours</td>
<td>=96 hours</td>
</tr>
<tr>
<td></td>
<td>Extreme windstorm — SJ</td>
<td>=2 hours</td>
<td>=36 hours</td>
</tr>
<tr>
<td></td>
<td>Snowstorm ('left of track')</td>
<td>=12 hours</td>
<td>=48 hours</td>
</tr>
<tr>
<td></td>
<td>Ice storm</td>
<td>=12 hours</td>
<td>=72 hours</td>
</tr>
<tr>
<td>Tropical cyclones</td>
<td>Rainstorm</td>
<td>=72 hours</td>
<td>=120 hours</td>
</tr>
<tr>
<td></td>
<td>Windstorm (broadscale)</td>
<td>=48 hours</td>
<td>=144 hours</td>
</tr>
<tr>
<td></td>
<td>Extreme windstorm (near eye)</td>
<td>=12 hours</td>
<td>=72 hours</td>
</tr>
<tr>
<td></td>
<td>Storm surge</td>
<td>=24 hours</td>
<td>=72 hours</td>
</tr>
<tr>
<td>Convective systems</td>
<td>Rainstorm ('flash floods')</td>
<td>=30 minutes</td>
<td>=48 hours</td>
</tr>
<tr>
<td></td>
<td>Hailstorm</td>
<td>=15 minutes</td>
<td>Not currently possible</td>
</tr>
<tr>
<td></td>
<td>Windstorm (convective gusts)</td>
<td>=15 minutes</td>
<td>Not currently possible</td>
</tr>
<tr>
<td></td>
<td>Tornado</td>
<td>Not currently possible</td>
<td>Not currently possible</td>
</tr>
<tr>
<td></td>
<td>Thunderstorm</td>
<td>15 minutes</td>
<td>N/A^</td>
</tr>
<tr>
<td></td>
<td>Snowstorm (“Lake Effect”)</td>
<td>48 hours</td>
<td>~96 hours</td>
</tr>
</tbody>
</table>
note that, although emergency services in Germany had a good grasp of forecast uncertainty, it was not possible to identify a particular probability threshold at which mitigation measures would begin. However, it was noted that decisions were delayed for low probabilities. Studies suggest that the general public often misunderstand the nature of the hazard from severe weather events; for example, Meyer et al. (2014) found that residents of coastal regions in the United States typically overestimated the probability of their homes being hit by hurricane-force winds, but underestimated the damage that such winds could cause. They also erroneously perceived the greatest threat to come from the wind rather than the storm surge. Since the public response to weather warnings is a key element in their success, determining warning quality necessarily takes forecast verification beyond the traditional quantitative forecast skill measures used so far into the arena of social sciences; for example, the Met Office in the United Kingdom utilises the subjective analysis of data from social media posts among other sources to try to assess the quality of warnings.

### 3.7.4 Impacts

#### 3.7.4.1 Human impact

Direct effects occur during the impact phase of a windstorm, causing death and injury as a result of the force of the wind, and the main dangers include becoming airborne, being struck by flying debris or falling trees and road traffic accidents. Indirect effects, occurring during the pre- and post-impact phases of the storm, include falls, lacerations and puncture wounds, and occur when preparing for, or cleaning up after, a storm. Power outages are a key issue and can lead to electrocution, fires and burns and carbon monoxide poisoning from gasoline-powered electrical generators. In addition, worsening of chronic illnesses owing to lack of access to medical care or medication can occur. Other health impacts include subsequent infections and an increase in insect bites (Goldman et al., 2013).

Owing to their large scale, severe extra-tropical cyclones can expose a very large number of people to hazards, such as injury and loss of life, as can tropical cyclones if landfall is made in densely populated areas.

Severe winds from convective storms have a highly localised and short-lived nature, which means that they frequently occur without any consequence for human health. However, when they occur in certain circumstances they can have severe consequences: for example, an outbreak of convective cells caused downbursts of 29-37 m/s to strike the Pukkelpop music festival in Belgium (18 August 2011), exposing 60 000 people to the associated hazard for approximately 10 minutes. Five people were killed, at least 140 were injured as a concert tent collapsed, and trees, light towers and video screens were blown over. Nearby residences were, however, completely unaffected by the event (De Meutter et al., 2015). Intense long-lived tornadoes (as occur in the United States) can potentially expose a large number of people to hazards due to flying debris. In Europe, tornadoes are generally weaker and much shorter lived than those experienced in the United States; however, it has been estimated that in Europe there are 10-15 tornado-related deaths per year (Groenemeijer and Kühne, 2014).

Storms can lead to a range of direct and indirect impacts on people and on the built and natural environment.

Lightning presents a hazard to humans and infrastructure systems as well as being a major cause of wildfires. Annually, there are approximately three deaths by lightning strike per 10 million of the population in developed countries (Lorenz, 2008; Holle, 2008) and perhaps as many as 60 deaths per 10 million of the population in the developing world (Holle, 2008). These differences are due to the shift in demographics of developed nations from a largely rural population involved in agricultural work to an urban population spending significantly more time indoors, and to the fact that buildings in developed countries mostly now contain conducting elements, such as electrical wiring, telephone cables, or purpose-built lightning conductors, which provide safe charge transfer paths to ground. For example, the risk of death from lightning strike in the United Kingdom has reduced by about 95% over the past century (Elsom, 2015), and data from Elsom and Webb (2014) indicate that changes in
the nature of buildings reduced the proportion of fatal lightning strikes that occurred indoors from 32% in the 1850s, to 5% in 1950s, to 0% during the most recent period (1988-2012). Reductions of a similar order of magnitude have been reported in other developed countries (Holle et al., 2005), but not in developing countries, where the risk of death remains greater (Holle, 2016).

Thunderstorm asthma is a term used to describe an observed increase in acute bronchospasm cases following severe thunderstorms. These asthma events have had significant impacts on both individuals and health services, with a range of different aeroallergens identified (Dabrera et al., 2013). The impact of these rare events can be significant, with many without previous asthma events becoming acutely ill (Murray et al., 1994). Health services can be seriously affected by thunderstorm asthma; for example, during the 24/25 June 1994 thunderstorm asthma episode, hospital emergency departments ran out of asthma-related supplies including nebuliser face masks (5 of 11 departments) and drug therapies (8 of 11) and half of all the regional health authorities in England observed a 6-fold increase in asthma attendances in emergency departments, resulting in difficulty in service provision (Venables et al., 1997).

Large hail has the potential to produce significant head trauma and in extreme cases can result in death. Such extreme cases with multiple deaths have been reported particularly in northern India, Bangladesh and parts of China, but the details of these are difficult to verify. In the United States, only eight deaths from hail were reported in the 70 years prior to 2009 (Changnon et al., 2009), although larger numbers of non-fatal injuries are reported. To the authors’ knowledge, there have been no reported deaths as a direct result of being struck by hail in Europe in recent decades, despite the occurrence of damaging hailstorms such as that in Munich in 1984 (Heimann and Kure, 1985); however, hail has been a contributing factor in fatal traffic accidents.

3.7.4.2 Infrastructure and environment

Damage from high winds associated with extra-tropical cyclones varies according to the wind gust to the power of 3 (or more), so prediction of the correct values is crucial (but still very challenging). This rapid increase in vulnerability with wind strength relates to building regulations that specify resilience to certain standards (e.g. in the United Kingdom and in Eurocodes, 50-year return periods are quoted for some purposes). As winds nominally increase above such thresholds, the building ‘failure rate’ will naturally accelerate rapidly.

Damage to property and crops from hail storms can be very costly: for example, the Munich hailstorm of 1984 (hail diameter 5-6 cm) caused significant damage to vegetation, buildings, automobiles and aircraft, leading to USD 500 million (equivalent to EUR 1.2 billion -USD 1.1 billion- today) of insured losses (Heimann and Kurz, 1985). A more recent hailstorm in Germany in July 2013 caused damage worth USD 5 billion (equivalent to USD 5.2 billion -EUR 4.8 billion- today), part of the explanation for the increase in potential losses being increased use of ‘expensive construction materials and complex building façades’ (MunichRe, 2016).

Regarding damage to environment, more than 130 separate wind storms have been identified as causing noticeable damage to European forests in the last 60 years (~2/year) that, for example, increases the vulnerability of forests to wildfires (see Chapter 3.10). Storms are responsible for more than 50% of all primary abiotic and biotic damage by volume to European forests from catastrophic events (Gardiner et al., 2011; De Rigo et al.; 2016).

3.7.5 Conclusions and key messages

**Partnership**

Collaboration between forecast providers and end users in real time is essential during DRM, since the interpretation of the available information, the uncertainty associated with it and how this changes as new information becomes available should be made in consultation with qualified meteorologists and National Meteorological Services in particular. Information sharing, particularly observational, impact and warning data across national boundaries in real time, is of key importance. Improvements in forecasts will in part be driven by the interaction between fundamental atmosphere and ocean science with operational forecasting, so continued collaboration between forecasting centres and universities and research centres is crucial.
**Knowledge**
A greater understanding of how to interpret, utilise and communicate probabilistic forecasts is required. This is particularly important, since future developments in forecasting systems, particularly short-lead-time, high-resolution forecasts at small spatial scales and long-lead-time global forecasts, lead to forecasts that are inherently probabilistic. Collaboration between physical scientists and social scientists may be important to improve the communication of forecast probabilities.

**Innovation**
Prospects for major extensions of the lead-time thresholds at which we can forecast storms are limited. We should instead expect continued slow but steady extensions of these over the coming years and decades. Improvements in the quality of forecast information for end users will also stem from innovative and improved post-processing of forecast data for the diagnosis of hazardous weather and end user-specific information.
3.8 Meteorological risk: extreme temperatures

Glenn McGregor, Angie Bone, Florian Pappenberger

3.8.1 Temperature extremes in a disaster risk management context

Understanding temperature extremes in a DRM context involves getting to know how often temperature extremes occur, the conditions under which they occur and establishing associated direct and indirect societal impacts.

Knowledge about temperature extremes can inform the development of strategies for managing the risk associated with this type of natural event. That temperature extremes do result in disastrous consequences, in terms of lives lost, is manifest via the observed impacts of a range of extreme temperature events over the last few decades (Table 3.3). Noteworthy is that all top 10 disasters are related to extreme high as opposed to low temperatures.

Temperature extremes, although rare, are important from a DRM perspective as they can lead to a range of substantive direct and indirect impacts on human activity and other systems.

3.8.2 What are temperature extremes?

Temperature extremes can occur over a range of temporal (e.g. daily, monthly, seasonal, annual, decadal) and geographical scales (e.g. local to regional to global). They are usually defined in terms of their position in a distribution of observed temperature values or as a threshold value recorded at a meteorological or climate station.

Temperature extremes can be expressed as a probability of occurrence, or as a return period (e.g. 5% probability or 1 in 20 year return period). Occasionally, the term ‘return period’ is misinterpreted to mean an event of a particular magnitude, so that an event with a return period of 1 in 20 years, having once occurred, will occur again only after 20 years have passed. This is incorrect, as at any one time the occurrence of a particular temperature will have a specific probability associated with it. Given this, it is entirely possible to have two 1 in 20 year events in successive years or indeed in the same year.

A threshold value will be a specific high or low temperature value, above or below which there is a discernible impact. These can be described in terms of percentiles, for example, the 5th or 95th percentile, meaning that for all the temperature observations recorded for a location, the highest or
lowest set of temperatures are considered to fall within the lowest or highest 5% of values. Percentiles are a relative measure of extreme values, as the value associated with a particular percentile will vary from location to location. For example, the 95th percentile value of temperature for a location in southern Europe may be 35°C, while for a northern European location it may be 28°C.

Probabilities, return periods and percentiles are just a few of a wide range of possible measures of temperatures extremes. For example, Table 3.4 lists a set of measures of temperature extremes considered relevant to a range of sectors of the economy and society (Donat et al., 2013). Among these are some that refer to the duration of high or low temperatures over several days. These are often referred to as heat waves or cold waves. Although these terms are applied extensively in a range of fora, there is no standard definition of what a heat wave or cold wave is, despite a number of attempts to develop ‘universal’ heat wave and cold wave definitions (Allen and Sheridan, 2016; Lhotka and Kysely, 2015; Perkins and Alexander, 2013; Robinson, 2001; Tong et al., 2010).

Building a picture of the nature of temperature extremes for a particular location or region is dependent on measurements from daily weather and climate observing stations. Accordingly, a number of daily temperature datasets that can be used for risk analysis have been constructed based on available station data (Klok and Tank, 2009; Menne et al., 2012).

There is a range of temperature extreme metrics. Statistical measures including probabilities, return periods and percentiles can be used to describe their occurrence. Knowledge gaps exist concerning extreme urban temperatures.

In addition to observational data, other sources are increasingly being used to develop extreme temperature climatologies (e.g. assembled via data rescue and reconstruction projects, as well as the analysis of diaries and other historical documents (McGregor, 2015)). Considerable effort has also gone into constructing gridded temperature datasets with a variety of spatial and temporal resolutions (Donat et al., 2013). In the case of data-sparse regions, stochastic weather generators have also been applied to the analysis of temperature extremes (Rahmani et al., 2016; Steinschneider and Brown, 2013; Wilks, 2012). A range of reanalysis products such as the 20th century (100-year) reanalysis dataset produced by the ECMWF (ERA-20C, n.d.) also offer considerable potential for extreme temperature analyses. Because weather and climate stations were originally located to be representative

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**TABLE 3.3**


<table>
<thead>
<tr>
<th>Country</th>
<th>Disaster type</th>
<th>Date</th>
<th>Total number of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Federation</td>
<td>Extreme high temperature</td>
<td>01/06/2010</td>
<td>55 736</td>
</tr>
<tr>
<td>Italy</td>
<td>Extreme high temperature</td>
<td>16/07/2003</td>
<td>20 089</td>
</tr>
<tr>
<td>France</td>
<td>Extreme high temperature</td>
<td>01/08/2003</td>
<td>19 490</td>
</tr>
<tr>
<td>Spain</td>
<td>Extreme high temperature</td>
<td>01/08/2003</td>
<td>15 090</td>
</tr>
<tr>
<td>Germany</td>
<td>Extreme high temperature</td>
<td>01/08/2003</td>
<td>9 355</td>
</tr>
<tr>
<td>France</td>
<td>Extreme high temperature</td>
<td>29/06/2015</td>
<td>3 275</td>
</tr>
<tr>
<td>Portugal</td>
<td>Extreme high temperature</td>
<td>01/08/2003</td>
<td>2 696</td>
</tr>
<tr>
<td>India</td>
<td>Extreme high temperature</td>
<td>26/05/1998</td>
<td>2 541</td>
</tr>
<tr>
<td>India</td>
<td>Extreme high temperature</td>
<td>20/05/2015</td>
<td>2 248</td>
</tr>
</tbody>
</table>
of atmospheric processes over large regions, there are very few long-term urban weather stations. This has constrained the development of a full understanding of the complexities of urban temperature fields and associated extremes (Chen et al., 2012).

Accordingly, attention is now being turned to the development of urban climate networks and information systems (Chapman et al., 2015; Choi et al., 2013; Honjo et al., 2015; Hu et al., 2016; Muller et al., 2013a, b). Furthermore, satellite-based high spatial

### TABLE 3.4

List of the temperature indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) and calculated based on Global Historical Climatology Network (GHCN)-Daily station data. Percentile values used as the threshold for some of the indices are calculated for the base period 1961-90. Source: adopted from Donat et al. (2013)

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Indicator name</th>
<th>Indicator definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>TXx</td>
<td>Hottest day</td>
<td>Monthly maximum value of daily maximum temperature</td>
<td>°C</td>
</tr>
<tr>
<td>TNx</td>
<td>Warmest night</td>
<td>Monthly maximum value of daily minimum temperature</td>
<td>°C</td>
</tr>
<tr>
<td>TXn</td>
<td>Coldest day</td>
<td>Monthly minimum value of daily maximum temperature</td>
<td>°C</td>
</tr>
<tr>
<td>TNn</td>
<td>Coldest night</td>
<td>Monthly minimum value of daily minimum temperature</td>
<td>°C</td>
</tr>
<tr>
<td>TN10p</td>
<td>Cool nights</td>
<td>Percentage of time when daily minimum temperature &lt; 10th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TX10p</td>
<td>Cool days</td>
<td>Percentage of time when daily maximum temperature &lt; 10th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TN90p</td>
<td>Warm nights</td>
<td>Percentage of time when daily minimum temperature &gt; 90th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TX90p</td>
<td>Warm days</td>
<td>Percentage of time when daily maximum temperature &gt; 90th percentile</td>
<td>%</td>
</tr>
<tr>
<td>DTR</td>
<td>Diurnal temperature range</td>
<td>Monthly mean difference between daily maximum and minimum temperature</td>
<td>°C</td>
</tr>
<tr>
<td>GSL</td>
<td>Growing season length</td>
<td>Annual (1 January to 31 December in NH, 1 July to 30 June in SH) count between first span of at least 6 days with TG &gt; 5°C and first span after 1 July (1 January in SH) of 6 days with TG &lt; 5°C. (NH stands for Northern Hemisphere, SH for Southern Hemisphere and TG is daily mean temperature)</td>
<td>Days</td>
</tr>
<tr>
<td>ID</td>
<td>Ice days</td>
<td>Annual count when daily maximum temperature &lt; 0°C</td>
<td>Days</td>
</tr>
<tr>
<td>FD</td>
<td>Frost days</td>
<td>Annual count when daily minimum temperature &lt; 0°C</td>
<td>Days</td>
</tr>
<tr>
<td>SU</td>
<td>Summer days</td>
<td>Annual count when daily maximum temperature &gt; 25°C</td>
<td>Days</td>
</tr>
<tr>
<td>TR</td>
<td>Tropical nights</td>
<td>Annual count when daily minimum temperature &gt; 20°C</td>
<td>Days</td>
</tr>
<tr>
<td>WSDI</td>
<td>Warm spell duration index</td>
<td>Annual count when at least 6 consecutive days of maximum temperature &gt; 90th percentile</td>
<td>Days</td>
</tr>
<tr>
<td>CSDI</td>
<td>Cold spell duration index</td>
<td>Annual count when at least 6 consecutive days of minimum temperature &lt; 10th percentile</td>
<td>Days</td>
</tr>
</tbody>
</table>
resolution surface temperature observations are also being applied in the analysis of urban surface temperature fields (Azevedo et al., 2016; Hu et al., 2015; Jin, 2012) as well as the output from urban climate numerical models (Best and Grimmond, 2015; Loridan and Grimmond, 2012).

3.8.3 Climatic variability and change and temperature extremes

Climatic variability refers to variations in climate conditions from time period to time period (e.g. intra-seasonal, inter-annual, inter-decadal). In general, climatic variability is connected with variations in the state of the atmospheric and ocean circulation and land surface properties (e.g. soil moisture) at the intra-seasonal to inter-decadal timescales. Climate change in contrast refers to a systematic change in the statistical properties of climate (e.g. mean and standard deviation, etc.) over a prolonged period (e.g. several centuries) as manifested by an upward or downward trend in, for example, extreme temperature values. For the majority of the Earth’s climate history, systematic changes in climate have occurred because of natural causes, such as variations in the nature of the Earth’s orbit around the sun or solar output. However, there is now mounting evidence that humans are an important climate agent.

Weather experienced at the surface of the Earth is very much influenced by the atmospheric circulation and the pattern of air and moisture flow above a location or region. Many extreme temperature events can therefore be explained in terms of unusual patterns of atmospheric circulation, such as ‘blocking’, which the term given to a situation in which a high-pressure system becomes ‘stuck’ and does not move for several days. Blocking results in the flow of either very warm or cold air over a region or cloudless skies that enhance heat gain or heat loss from the Earth’s surface. For example, Della-Marta et al. (2007) have shown that heat waves over Europe are related to persistent and large-scale high-pressure systems.

Unusual atmospheric circulation patterns, which are often related to major modes of climatic variability, spawn extreme temperature events. There is mounting evidence that human-related climate change is affecting extreme temperature occurrence.

Alterations to the usual pattern of atmospheric circulation and thus the occurrence of blocking and associated extreme temperature events can often be traced back to interactions between the ocean and atmosphere or modes of climatic variability, such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Donat et al., 2014; Hoy et al., 2013; Scaife et al., 2008). For example, there is evidence that extreme maximum temperatures can be significantly influenced by ENSO for a range of regions across the world (Arblaster and Alexander, 2012; Kenyon and Hegerl, 2008; Parker et al., 2014) as well as by Madden–Julian Oscillation-related anomalies in tropical convection (Cassou et al., 2005; Matsueda and Takaya, 2015). Similarly, the NAO has been found to influence the occurrence of both high- and low-temperature extremes across Europe (Burgess and Klingman, 2015; Hoy et al., 2013; Kenyon and Hegerl, 2008; Moore and Renfrew, 2012; Scaife et al., 2008). Changes in the position of the Inter-Tropic Convergence Zone also seem to alter the possibility of temperature extremes in France and Egypt (Boe et al., 2010).

The IPCC has concluded that there is unequivocal evidence that humans, through a range of activities and an intensification of the greenhouse effect, are having an impact on the Earth’s climate (IPCC, 2013). This is most evident through an increase of the global mean temperature of about 0.8°C since 1880, with two-thirds of that increase occurring since 1975, at a rate of roughly 0.15-0.20°C per decade (NASA, 2016). Understandably, this observed increase and that projected for the next several decades has implications for the occurrence of high- and low-temperature extremes (Russo et al., 2014; Seneviratne et al., 2012). That changing global temperatures appear to be already manifesting themselves in an altered occurrence of temperature extremes and heat and cold waves are evident at a range of geographical scales (Fischer, 2014; Sehar, 2016). Furthermore, there is emerging evidence that a number of recent extreme temperature events
are in part attributable to human-related changes in global temperatures (Easterling et al., 2016, Kim et al., 2015; Mitchell et al., 2016).

### 3.8.4 Health impacts of temperature extremes

Both high and low temperatures, indoors and outdoors, pose substantial risks to human health, including increases in mortality, morbidity and health service use (Ryti et al., 2016; WMO, 2015). In many countries, the health impacts of cold temperatures substantially outweigh those of heat (Gasparrini et al., 2015).

The scale and nature of the health impacts observed depends on the timing, intensity and duration of the temperature event, the level of acclimatisation and adaptation of the local population, infrastructure and institutions to the prevailing climate, as well as the definitions and methodologies used for scientific research. As such, the health effects of temperature extremes and the determinants of vulnerability are, to some extent, context specific.

Population health impacts start to be observed at winter and summer temperatures that are considered moderate for the season and then increase as temperatures become more extreme, in what is variously described as a U-, V- or J-shaped curve. The precise threshold temperatures for health impacts vary by region and country, as does the scale of the health impacts by degree change in temperature, but the overall pattern remains similar wherever it has been studied.

For both heat and cold, the impact of temperature is more marked for deaths than for hospitalisations (Hajat et al., 2016; Linares and Diaz, 2008); this may suggest that individuals die before they reach health care. Temperature extremes may also result in illness that is not sufficiently severe to require hospital attention and that has not been captured by these studies.

For heat, deaths and hospitalisations occur extremely rapidly (same day) and they may be followed by a degree of impact displacement (health impacts in the frail brought forward), which returns to normal within a matter of days (Basu, 2009). The onset of health impacts for cold are slower and persist for longer (up to 4 weeks), with short-term displacement effects not apparent (Analisit et al., 2008).

Longer heat events are associated with greater health effects because of the longer period of exposure (D’Ippoliti et al., 2010), but this has not been consistently observed for cold (Ryti et al., 2016).

Severe heat events that occur towards the beginning of a season have greater health impacts; this is likely to be partly due to loss of the most vulnerable members of the population during the first episode and partly due to population adaptation for subsequent events (Baccini et al., 2008). This pattern is less clear for severe cold, with some authors indicating that cold weather events towards the end of the season are associated with greater mortality (Montero et al., 2010a).

There is some evidence that there has been a reduction in health effects from heat extremes over recent years in some countries, which suggests that there has been some individual and institutional adaptation (Arbuthnott et al., 2016). This is less well established for cold risks.

### 3.8.4.1 Health impacts

Health impacts may be direct (caused by the direct effect of the hazard) or indirect (caused by the consequences of the hazard such as changes in behaviour or impact on services), as shown in detail in Table 3.5.

#### a) Direct impacts

As the ambient temperature changes, the human body’s physiology adapts in order to maintain a stable body temperature. This includes changes to the circulatory, respiratory and nervous systems to allow cooling or to protect vital organs (Ryti et al., 2016; WMO, 2015).

Direct health impacts occur when a stable body temperature cannot be
### TABLE 3.5
Direct and indirect health impacts of temperature extremes

<table>
<thead>
<tr>
<th>Health impacts</th>
<th>Heat</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased risk of classical heat illness:</td>
<td></td>
<td>Increased risk of classical cold illness:</td>
</tr>
<tr>
<td>• dehydration</td>
<td></td>
<td>• hypothermia</td>
</tr>
<tr>
<td>• heat cramps</td>
<td></td>
<td>• frostbite</td>
</tr>
<tr>
<td>• heat exhaustion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• heat stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased risk of death from:</td>
<td></td>
<td>Increased risk of death from:</td>
</tr>
<tr>
<td>• respiratory disease</td>
<td></td>
<td>• cardiovascular disease</td>
</tr>
<tr>
<td>• cardiovascular disease</td>
<td></td>
<td>• respiratory disease</td>
</tr>
<tr>
<td>• other chronic disease (e.g. mental health conditions and renal disease)</td>
<td></td>
<td>• other chronic diseases (e.g. stroke and dementia)</td>
</tr>
<tr>
<td>Increased risk of hospitalisation particularly from:</td>
<td></td>
<td>Increased risk of hospitalisation particularly from:</td>
</tr>
<tr>
<td>• respiratory disease</td>
<td></td>
<td>• respiratory disease</td>
</tr>
<tr>
<td>• diabetes mellitus</td>
<td></td>
<td>• cardiovascular disease</td>
</tr>
<tr>
<td>• renal disease</td>
<td></td>
<td>• stroke</td>
</tr>
<tr>
<td>• stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• mental health conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased risk of poor outcomes in pregnancy</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indirect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on health services including:</td>
<td></td>
<td>Impact on health services including:</td>
</tr>
<tr>
<td>• increased ambulance call-outs and slower response times</td>
<td></td>
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maintained (e.g. when temperatures are too extreme), when clothing or shelter is not suitable or when physiological responses are impaired (e.g. through disease, normal ageing or using certain medications). Moreover, these impacts may be exacerbated when other demands are placed on the body, such as strenuous activity or drug/alcohol use. This produces classical temperature-related disease, such as hypothermia and heat stroke, both of which may have a rapid onset, may not be quickly identified and may be fatal.

However, classical hypothermia and heat stroke are not the major cause of health impacts from temperature extremes; most temperature-related deaths and illness are from chronic diseases such as heart and lung disease (Bunker et al., 2016), which form an important proportion of the background disease burden in European populations. This is because an already impaired physiological system is less able to adapt to the ambient temperature, and the physiological changes needed to regulate temperature may worsen pre-existing disease.

### b) Indirect impacts

Temperature extremes also have indirect impacts on health, for example through impacts on services or changes in individual behaviour as a result of the temperature.

The impact on health services may be mediated through increasing demand for care, direct and indirect impacts on staff, which affect their ability to work, or ambulance response times (Thornes et al., 2014). Temperatures extremes may have impacts on wider infrastructure that is essential for health, such as power, water and transport (USAID, 2013).

Behavioural changes may have inadvertent negative health consequences, replacing one risk with another, which is an important explanation for the increase in injuries associated with hot and cold weather (Bulajic-Kopjar, 2000; Otte et al., 2016).

#### 3.8.4.2 Determinants of vulnerability

The major determinants of vulnerability of a population to temperature extremes relate to the features of the population exposed and their capacity to respond and adapt to the temperature conditions over long and short time frames. Determinants of vulnerability can be broadly categorised by demographic, health, physical, socioeconomic and institutional factors, many of which are inter-related and dynamic.

Temperature extremes rarely occur in isolation and related hazards such as snow/ice, drought/wildfires, poor air quality or other unrelated disasters may coincide in time and geography. Responses to these additional hazards may alter existing vulnerabilities and the capacity to adapt to temperature extremes.

#### a) Demographic determinants

The physiology of older people and the very young renders them more vulnerable to temperature extremes. They may also be less able to adapt their behaviours or environmental conditions and may be more dependent on others (Collins, 1986; Hansen et al., 2011). New migrants or tourists may not understand warnings or how to seek help. Some studies have suggested increased risk by gender (female) and race (black and minority ethnic groups) but this may be explained by alternative factors such as age, income, education, underlying disease and access to health care.

#### b) Health status determinants

Many physical and mental health conditions increase vulnerability to adverse temperatures through a direct effect on the body’s physiology or through the effect of certain medications (Hajat et al., 2007). People with poor health or disability may be less aware of warnings, may be less able to adapt their behaviours or environmental conditions, and may be more dependent on others.

#### c) Physical determinants

People spend approximately 80% of their time indoors, with the elderly or unwell spending longer periods indoors. Buildings (including homes, hospitals, schools and prisons) are not always adapted for temperature extremes and may have insufficient heating/energy efficiency or cooling measures (Conlon et al., 2011; Hansen et al., 2011).

People who have inadequate shelter (e.g. displaced or homeless populations) might be particularly exposed to temperature extremes and often have associated vulnerabilities such as poor health or economic circumstances.

#### d) Socioeconomic determinants

People who are socially isolated are more at risk from temperature extremes because they are less able to
access community support, and may also have additional health or other vulnerabilities (Bouchama et al., 2007; Tod et al., 2012).

Low-income groups may be less able to adapt to their behaviours or environment. Certain occupational groups, such as labourers, may not always be afforded adequate protection from temperature extremes (e.g. undertaking strenuous physical work during very hot periods) (Hanna et al., 2011).

e) Behavioural/cultural determinants

When temperatures become more extreme, most people take some action to adapt to the conditions. However, some factors limit the ability to adapt, such as age, poor health or economic circumstances, and certain belief or value systems may also mean that appropriate action is not taken in response to the temperature conditions (Hansen et al., 2011; Tod et al., 2012). Certain behaviours, intended to be protective, may inadvertently increase health risks (e.g. swimming in unsupervised open waters (Fralick et al., 2013), shovelling snow (Franklin et al., 1996) or using unsafe heating appliances (Ghosh et al., 2016)).

f) Institutional determinants

Health services need robust plans in order to manage the potential disruption and increased demand during and following temperature extremes; their ability to respond influences population vulnerability. This also applies to supporting infrastructure such as power, water, communication and transport systems. Mass gatherings can place additional strains on services, especially if they coincide with temperature extremes (Soomaroo and Murray, 2012).

Employers should take action to ensure that employees are able to take necessary protective actions, such as increasing fluid intake, having access to adequate rest and shade and restricting strenuous activity to cooler parts of the day.

Many countries have formal plans and policies that promote actions to reduce the risk of temperature extremes, such as the Heatwave and Cold Weather Plans for England (see Chapter 3.8.6.2).

3.8.5 Other impacts of temperature extremes

To date, the human health impacts of high and low temperatures have received a great deal of attention in both the academic and technical literature related to DRM compared with ‘other’ impacts. In general, ‘other’ direct and indirect impacts tend to be less well understood than those related to human health. This, however, does not make them less important, as heat- or cold-related impacts may lead to complex disasters, for example those that may arise from the malfunction of energy supply systems, which may lead to the failure of the critical infrastructure necessary to maintain a range of human activity systems and, most importantly, the emergency services. A summary of other impacts arising from low- and high-temperature extremes is given below:

It has been documented that both high and low temperatures have significant effects on plants (Barlow et al., 2015).

Extreme heat stress can reduce plant photosynthetic and transpiration efficiencies and negatively impact plant root development, which acts collectively to reduce the yield of crops. In general, extreme high temperatures during the reproductive stage will affect pollen viability, fertilisation and grain or fruit formation (Hatfield and Prueger, 2015).

Late frosts are particularly damaging to the opening buds of plants. More economic losses in the United States are caused by crops freezing than by any other weather hazard (Snyder and Melo-Abreu, 2005). Even a single night with unusually low temperatures can lead to significant ecological and economic damage (Inouye, 2000). Because of climate change, many plants are now coming out of winter dormancy earlier (Walther et al., 2002), which leaves them even more susceptible to frost damage. Frosts can have lasting effects, as they can cause local extinctions and influence the geographical distribution of some species (Inouye, 2000).

Livestock, such as rabbits, pigs and poultry, are vulnerable to extreme temperatures. Milk production and cattle reproduction decreases during heat waves, and millions of birds have been lost as a result of such events. In extreme cold weather, livestock are also at risk if not protected from the cold (Adams, 1997).
It is a concern that non-health impacts of temperature extremes are not entirely understood, as in combination they possess the potential to create complex disasters and, thus, to have far-reaching societal impacts. Air quality is impacted by both heat waves and low-temperature events. Increased ozone pollution is associated with high temperatures, and nitrogen oxides, SO2 and particulate matter pollution is associated with low temperatures (Hou and Wu, 2016). Heat waves also affect water quality, bringing an increased risk of algal blooms, causing the death of fish in rivers and lakes and the death of other organisms in the water ecosystem (Adams, 1997).

Heat waves can directly impact ecosystems by constraining carbon and nitrogen cycling and reducing water availability, with the result of potentially decreasing production or even causing species mortality. Extreme temperature conditions can shift forest ecosystems from being a net carbon sink to being a net carbon source (IPCC, 2012).

The effects of both high and low temperatures can be exacerbated if combined with water shortages, leading to drought (for a detailed discussion, see Chapter 3.9).

3.8.6 Managing temperature extremes

3.8.6.1 Forecasting

Forecasting extreme temperatures on the medium (more than 3 days) to seasonal (up to 6 month) scale is an important tool for civil protection...
(Mayes, 2012; Ilkka et al., 2012).

However, forecasts on this timescale are uncertain and, therefore, multiple scenarios, known as ensembles, are used. Figure 3.29 shows such a forecast for 15 days for the city of Durham (United Kingdom). This plot clearly shows that the further ahead a forecast is issued, the more uncertain it becomes, with a range of possible values. This poses a challenge for forecasting heat and cold waves beyond the medium timescale.

Heat and cold wave predictability is also linked to a forecast model’s ability to predict transitions between circulation patterns such as blocking and phases of modes of climatic variability such as ENSO and the NAO, as described in Chapter 3.8.3. Because of their low-frequency nature and their teleconnections, modes of climatic variability can exhibit predictability on the subseasonal timescale. A further source of predictability also arises from the effect of soil moisture conditions in the amplification of the temperature anomalies (Quesada et al., 2012). Therefore, accurate skill in predicting persistent large-scale high-pressure systems is fundamental to forecasting heat and cold waves.

The ideal method by which to eval-

FIGURE 3.30

2-metre temperature composites from ERA-Interim weekly mean anomalies for heat wave events: western Europe (left), northern Europe (centre) and Russia (right).
Source: courtesy of authors

FIGURE 3.31

2-metre temperature composites from the ensembles forecast at 12-18 days verifying the same events as in Figure 3.30. Western Europe (left), northern Europe (centre) and Russia (right).
Source: courtesy of authors
uate the skill of an extended range ensemble in predicting heat and cold waves is to use a selection of objective verification measures for probabilistic forecasts. In reality, verification requires a far larger sample than is available. This is typically the case for any investigation that involves extreme events. Here we show the evaluation of individual heat waves, as shown in Figure 3.30, as an example. The 2-metre temperature composites, based on weekly mean anomalies of ensembles forecasts at 12-18 days, are shown in Figure 3.31. Compared with the observations (Figure 3.30), the forecasts (Figure 3.31) generally identify the location of warm anomalies with a certain degree of accuracy, although the amplitude is underestimated. Overall, the successful predictions reflect a persistent anti-cyclonic circulation already present in the initial conditions. This testifies to the critical nature of an extended-range forecast model to represent transitions to anti-cyclonic circulation regimes, which is consistent with the cause of so-called medium-range forecast ‘busts’ (Rodwell et al., 2013).

Careful calibration and judicious combination of ensembles of forecasts from different models into a larger ensemble can give greater accuracy than is obtained from any single model. However, comparing, verifying and testing multimodel combinations from these forecasts and quantifying their uncertainty as well as the handling of such a massive dataset is challenging and is the subject of the ECMWF subseasonal to seasonal (S2S) prediction project. This is a WWRP/THORPEX-WCRP joint research project established to improve fore-

**FIGURE 3.32**

Extreme Forecast Index of 2-metre temperature with a forecast range of 12-18 days verifying the week of 8-14 August 2016. Four different forecast systems are shown. Blue areas indicate a cold spell, while red areas indicate a heat wave (on a weekly average). Ncep is National Centre for Environmental Prediction, ECMWF is the European Centre for Medium Range Weather Forecasting, JMA is Japan Meteorological Agency, UKMO is the United Kingdom Meteorological Office.

Source: courtesy of authors
cast skill and understanding on the S2S timescale, and promote uptake of its forecast products by operational centres and the applications community. Examples of some of S2S’s products can be found at ECMWF (n.d.). The Extreme Forecast Index (EFI) is one such product (Figure 3.32). This is an integral measure of the difference between the ensemble forecast distribution and the model climate distribution. The EFI takes values from $-1$ to $+1$. An EFI of 1 (red) indicates a heat wave, while an EFI of $-1$ (blue) shows a cold spell. Experience suggests that EFI magnitudes of 0.5-0.8 (irrespective of sign) can be generally regarded as signifying that ‘unusual’ weather is likely, while magnitudes above 0.8 usually signify that ‘very unusual’ or extreme weather is likely. Although larger EFI values indicate that an extreme event is more likely, the values do not represent probabilities as such.

### 3.8.6.2 Early warning systems

Early warning systems have been developed for a number of extreme climate events and are gaining traction in the area of temperature extremes (Carmona et al., 2016; Kalkstein et al., 2011; Kovats and Ebi, 2006; Lowe et al., 2016; McGregor et al., 2015). Such warning systems take the output from short- to medium-range forecasting models (Lowe et al., 2016; McGregor et al., 2006), such as described above, and usually use a threshold temperature or some related index to trigger an alert and/or issue a heat or cold warning (Antics et al., 2013; Nairn and Fawcett, 2015; Pascal et al., 2013). More often than not, a weather- or climate-based EWS for heat or cold, which is composed of a number of components, is nested within a wider heat or cold action plan (WHO, 2008, 2011; WMO, 2015) as shown in Figure 3.33.

The normative view regarding heat/cold EWSs is that they should deliver discernible benefits for the management of heat- and cold-related risk across a range of sectors (Fouillet et al., 2008). Given this, heat/cold EWSs are increasingly subject to evaluation that can consider EWS processes and/or outcomes, using a variety of criteria. To date, such evaluations indicate that heat/cold EWSs yield discernible benefits in relation to DRM but, notwithstanding this, there is room for improvement, especially as a successful EWS depends heavily on a well-designed set of risk-mitigating and practical intervention strategies being in place (Bassil and Cole, 2010; Chiu et al., 2014; Ebi, 2007; Hajat et al., 2010; Kalkstein et al., 2011; Montero et al., 2010b; Toloo et al., 2013a, b).

For low-temperature extremes, a range of EWS and forecast products have been developed. Many of these are focused on forecasting snow storms (Nakai et al., 2012; Wang et al., 2013).
and ice storms, with an emphasis on critical infrastructure such as roads (Berrocal et al., 2010; Degaetano et al., 2008; Palin et al., 2016; Riehm and Nordin, 2012) and power lines (Cerruti and Decker, 2012; Nygaard et al., 2015; Roldsgaard et al., 2015).

Although EWSs are considered a plausible DRM tool, developers and users of EWSs should be aware of some of the generic ‘dos and don’ts’ of such systems, as outlined by Glantz (2004).

### 3.8.6.3 Urban design and planning

Cities have received a great deal of attention in the DRM literature because this is where large numbers of people are concentrated; they are, therefore, potentially at risk of heat- and cold-related disasters.

In the case of heat, cities represent a distinct problem because of the so-called urban heat island (UHI) effect which, during periods of high temperatures, can lead to air temperatures in cities being several degrees above those for surrounding rural areas, especially during the nocturnal hours (Arnfield, 2003). This ‘extra’ heat has the potential to place a large number of vulnerable people in cities at risk of heat-related illness (Wolf and McGregor, 2013; Wolf et al., 2014).

The UHI develops because urban materials are efficient at absorbing and storing heat from the sun during the day and releasing that heat back into the urban atmosphere at night, leading to higher nocturnal temperatures in urban areas than in rural areas. A further factor is the low evaporation rates in cities; evaporation is an energy-consuming and thus a cooling process. Significant quantities of so-called anthropogenic heat from air conditioning systems and vehicles can add to the energy available for raising urban air temperatures (Allen et al., 2011; Offerle et al., 2005; Smith et al., 2009). For example, in London, it has been estimated that approximately 80% of the anthropogenic heat goes into heating of the atmosphere (Iamarino et al., 2012), with the greatest contributions from London’s central activity zone, where the service sector is predominant. Given that large cities, such as London, will grow over the coming decades, anthropogenic heat is likely to become an important heat risk management issue for large cities.

Managing temperature extremes can be approached from a number of perspectives, including using forecasting technology, the development of EWSs and heat/cold action plans and urban design and town planning.

Given the processes that generate the UHI, strategies that focus on managing urban heat can range from the scale of the individual building to the city. Examples include controlling for building material absorption and storage of energy from the sun, ensuring that evaporation is promoted through providing moist surfaces and developing green infrastructure and reducing anthropogenic heat release.

While the specific approaches to managing urban heat are potentially wide ranging (Alexander et al., 2016; Eliaisson, 2000; Mills et al., 2010; Phelan et al., 2015), the degree of benefit (the intensity of cooling and improvements to human thermal comfort) arising from urban design- and city planning-related heat mitigation measures (Norton et al., 2015; Sharma et al., 2016; Sun et al., 2016;) depends on considering a multitude of interacting and potentially conflicting factors (Couuttingts et al., 2013; Hamilton et al., 2014). In addition to the scientific challenges (Chen et al., 2012), the actual mainstreaming of urban climate design and adaptation principles into city planning can sometimes become stalled because of a range of institutional barriers (Lenzholzer and Brown, 2011; Reckien et al., 2014; Ugolini et al., 2015; Uittenbroek et al., 2013; Wolf et al., 2015).

Relatively speaking, urban design for low-temperature extremes has received less attention in the recent DRM literature, no doubt as a result of a perception that, in the near future, heat, as opposed to cold, will pose a greater risk management problem. Interestingly, a consequence of the UHI effect, especially the role of anthropogenic heat, may bring some positive benefits in cities that experience harsh winter climates.
3.8.7 Conclusions and key messages

Partnerships
Cooperation between regional, national and international research communities and climate monitoring agencies and citizen scientists is required to construct internally consistent extreme temperature databases and meaningful sector-relevant extreme temperature metrics. This is particularly the case for urban environments where there is an ever-increasing concentration of people who are potentially at risk from temperature extremes as a result of the urban heat island (UHI) effect. A systematic approach at both national and local levels and across all sectors, involving state, private, voluntary and community actors, is required to understand the wider societal impacts of temperature extremes. Partnerships formed between stakeholders in the risk management of temperature extremes should adopt ‘a communities of practice model’ in order to develop integrated heat and cold action plans that transcend vulnerability assessment, weather forecasting, intervention strategies, urban design and city planning.

Knowledge
An enhanced understanding of the physical origins of temperature extremes, as well their changing magnitude and frequency, especially in light of climate change, is required. Where possible, historic non-instrument-based temperature records as captured in diaries and other documents could be used to augment the understanding of the climatology of temperature extremes from the local to the regional level. Long-term observational series need to be sustained through the commitment of resources to climate monitoring. Research should be undertaken to improve our understanding of the effectiveness and cost-effectiveness of extreme temperature-related interventions in a variety of different climatic, socioeconomic and cultural contexts, with learning shared widely. Conceptual risk models of complex disasters related to temperature extremes are required to scope out agendas for knowledge development.

Innovation
In the absence of observed weather station-based temperature data, the use of weather generators for the creation of temperature time series for extreme value analysis and alternative temperature observation platforms such as satellites in addition to the output from urban climate numerical models should be considered as input into DRM analyses. The idea of drawing on multiple sources of information from data networks, as encapsulated by the concept of ‘the internet of things’, offers considerable potential for managing disaster risk related to temperature extremes. High-resolution intra-urban mapping of population vulnerability to heat and cold, integrated with information on building type and air and surface temperature, is an innovation that is likely to yield gains for extreme temperature-related DRM.
3.9 Climatological risk: droughts


3.9.1 Introduction

Drought is one of the most complex and severe weather-related natural disasters and its causes and multifaceted impacts are often not well understood. Droughts can last from a season to multiple years, and even decades, and cover small watersheds to hundreds of thousands of hectares. In Europe, drought is a recurrent phenomenon, affecting extended areas and large populations annually (Vogt and Somma, 2000). Across the world, millions of people are annually exposed to droughts that seriously affect economic development and environment. While fatalities mainly occur in poor economies, even in more prosperous regions many people die as a result of indirect effects (e.g. Tallaksen and Van Lanen, 2004; WMO and GWP, 2014). In Europe, almost 80,000 excess fatalities as a result of heatwaves (see Chapter 3.8) and forest fires (see Chapter 3.10) associated with droughts were reported over the period 1998-2009 (EEA, 2011).

UNESCO notes that drought can have economic consequences that can go far beyond the immediately impacted areas, such as persistent unemployment and threats to food security, regularly leading to forced migration and social instability (WWAP, 2016). The World Economic Forum (2015) labelled the water crisis as first on the list of factors with a risk of severe impacts for the global community. As one of the reasons for this crisis, drought is likely to become more frequent and severe in the 21st century in many regions of the world, especially in already water-scarce and vulnerable areas, including parts of Europe (IPCC, 2012; 2014).

The key challenge is to move from a reactive society fighting impacts to a pro-active society that is resilient and adapted to the drought risk, for example through the adoption of pro-active risk management (WMO and GWP, 2014; Wilhite et al., 2014). This chapter demonstrates that this requires practitioners, policymakers and scientists to collaborate and use a consistent set of definitions and characteristics. Observed and projected trends in drought as a natural hazard need to be understood.

Drought is a recurrent phenomenon that affects extended areas and large populations, putting societies and the environment at risk in many regions of the world.

The hazard has to be connected to its manifold primary and secondary impacts (e.g. on public water supply, food security, energy production, waterborne transport, health, ecosystems). Current, but also future, societal exposure and context-specific vulnerability must be identified to
assess drought risk. If all of these aspects are known, drought risk can be managed through a set of institutional, structural and operational measures, including monitoring and medium-range to seasonal forecasting.

### 3.9.2 Drought definition and characteristics

From a climatic point of view, a drought results from a shortfall in precipitation over an extended period of time, from the inadequate timing of precipitation relative to the needs of the vegetation cover, or from a negative water balance due to an increased potential evapotranspiration caused by high temperatures. This situation may be exacerbated by strong winds, atmospheric blocking patterns and antecedent conditions in soil moisture, reservoirs and aquifers, for example. Droughts can also be triggered in cold climates by temperature anomalies (Van Loon and Van Lanen, 2012; Van Loon et al., 2014). If this situation leads to an unusual and temporary deficit in water availability, it is called a drought. Droughts are to be distinguished from aridity, a permanent climatic feature, and from water scarcity, a situation in which the climatologically available water resources are insufficient to satisfy long-term average water requirements (e.g. Tallaksen and Van Lanen, 2014).

Depending on the prevailing effects on the hydrological system and the resulting impacts on society and environment, drought can be distinguished in terms of meteorological, soil moisture and hydrological factors (groundwater, streamflow, reservoirs) (Figure 3.34 and Box 3.1). The definition of a drought, therefore, will depend on the sector analysed and the related processes and impacts. Finally, the feedbacks between the hydrological cycle and society must be considered (Van Loon et al., 2016). The impacts of drought point to a multitude of drivers that turn lower than average precipitation, limited soil moisture and low water levels into disaster events for vulnerable communities and economies (UNISDR, 2011).

Droughts can be characterised in terms of their onset, duration, severity (accumulated deficit over the entire event) and intensity (total deficit divided by duration).

Standardised indices are used to analyse droughts in different domains of the water cycle (e.g. precipitation, climatic water balance, soil moisture, river flow, groundwater). Among the meteorological indicators, the Standardized Precipitation Index (SPI, McKee et al., 1993) and the Standardized Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010) are the most well-known. The SPI is a probabilistic measure of the severity of a dry event (WMO, 2012). It can be calculated for different rainfall accumulation periods (e.g. 1-48 months) and statistically linked to impacts in different economic and environmental sectors. The SPEI has similar characteristics but includes potential evapotranspiration. Recent studies have shown that including the potential evapotranspiration can provide useful drought early warning indicators (McEvoy et al., 2016).
though some weaknesses occur when the potential evapotranspiration is calculated with temperature-based approaches (e.g. Thornthwaite) in dry, hot regions. Use of SPI and SPEI in cold regions has some limitations, because these indices do not distinguish between rain and snow, which affects the water availability over the year (snow accumulation and melt). Soil moisture-related indicators such as the Soil Moisture-based Drought Severity Index (Cammalleri et al., 2016) or the Palmer Drought Severity Index (Palmer, 1965) aim to characterise the impact on plant water stress; although no specific plant characteristics are included. Hydrological indicators are often based on threshold approaches to quantify the volume of water deficit in rivers and reservoirs (Yevjevich, 1967; Hisdal et al., 2004; Van Loon and Van Lanen, 2012). Finally, combined indicators blend several physical indicators into an indicator of hazard (e.g. US Drought Monitor (Svoboda et al., 2002); Combined Drought Indicator (Sepulcre Canto et al., 2012)).

Drought differs from aridity and water scarcity, and different drought types and associated indices have to be analysed to quantify the multiple drought impacts.

### 3.9.3 Past trends and future projections

Historic trends and future projections of meteorological droughts in Eu-

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**Drought types**

Depending on the effect in the hydrological cycle and the impacts on the society and environment, different drought types are commonly distinguished:

**Meteorological Drought:**
A deficit in precipitation or climatological water balance (i.e. precipitation minus potential evapotranspiration) over a given region and defined period of time with respect to the long-term climatology. It is characterised based on measured and estimated climate variables (e.g. precipitation, temperature, evapotranspiration).

**Soil Moisture or Agricultural Drought:**
Characterised by reduced soil moisture resulting in a deficit in water supply for agricultural crops and natural vegetation and impacts on crop yield and biomass production. A higher risk for forest fires, due to the accumulation of dry biomass, is another important impact.

**Hydrological Drought:**
Characterised by reduced streamflows, lake levels, and groundwater reservoirs. Time-series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts that have, for example, impacts on public water supply, energy production and inland water transport.
Europe have been investigated by Spinoni et al. (2015a,b, 2016a, 2017) using a combination of indicators based on precipitation and temperature from the E-OBS dataset (Haylock et al., 2008). The analysis considers droughts at seasonal and annual timescales and covers the period 1951-2015 (trend analysis) and 2041-2100 (future projections), the latter of which is based on the EURO-CORDEX multimodel ensemble (Jacob et al., 2014) and moderate (RCP4.5) and extreme (RCP8.5) climate scenarios.

Drought frequency increased in southern and western Europe, but decreased in other parts of Europe. However, an increased frequency is projected, particularly in summer, for most of Europe.

Figure 3.35 demonstrates that in the past six and a half decades northern and eastern Europe experienced a decrease in drought frequency and, less prominently, in drought severity (not shown), while southern and western Europe experienced an increase in drought frequency and severity, particularly over the Mediterranean region (see Hoerling et al., 2012; Gudmundsson and Seneviratne, 2015; Stagge et al., 2016). The noted increase in drought frequency and severity is more widespread when analysing the SPEI, which includes the effect of increasing air temperature on potential evapotranspiration (Spinoni et al., 2015b; Touma et al., 2015; Stagge et al., 2016).

With respect to seasonal droughts, the decrease of drought frequency over northern Europe is more evident in winter, while the increase over southern Europe is more evident in summer.

Figure 3.36 shows that the described past drought tendencies are likely to persist in future decades for the winter months, while in the other seasons – especially summer – the whole of Europe (excluding parts of Iceland and Scandinavia) is projected to experience an increase in drought frequency, in particular during the last decades of the 21st century. At annual scale, and according to both climate scenarios, the drying tendencies over southern and western Europe are projected to become even stronger, with the Mediterranean region being particularly strongly affected (Spinoni et al., 2017; Stagge et al., 2015b). The effects of the projected temperature increase on meteorological droughts are likely to outbalance the effects of the projected precipitation increase over northern Europe and partly over eastern Europe, resulting in more frequent droughts for both scenarios in these territories by the end of the 21st century. The combination of these effects is likely to result in more severe droughts over northern Europe according to the extreme scenario (RCP8.5), while according to moderate scenario (RCP4.5), severity is not likely to increase in this region. The projections are considered to be robust with good agreement between the suite of GCM and RCM models.

At the global scale, past changes in drought frequency and severity are still under debate. Sheffield and Wood (2008) and Sheffield et al. (2012) analysed past global and regional trends using a soil moisture-based drought index for the period 1950-2008. Their results indicate that on a global level only small changes in drought occurrence and extent can be detected over the past 60 years. However, on a regional level, significant drying trends can be seen for parts of the Mediterranean and North, West and Central Africa, as well as for parts of East and Northeast Asia, while in the northern hemisphere and in parts of South America and Australia wetting trends are prevailing. These results are largely confirmed by Spinoni et al. (2014) who analysed meteorological drought frequency, duration and severity over the period 1951-2010. Orlowsky and Seneviratne (2013) investigated future meteorological and soil moisture drought around the world using a multimodel set of CMIP5 simulations. Their results hint towards more frequent soil moisture droughts by the end of the 21st century, especially in South Africa and Central America/Mexico and the Mediterranean. While highlighting the aggravating effect of global warming on droughts, Trenberth et al. (2014) underline the importance of reliable precipitation datasets and the data used to determine the evapotranspiration component in order to avoid conflicting results.

Streamflow drought originates from a temporary deficiency in precipitation and/or from temperature anomalies over a large area that can be further aggravated by other climatic factors, like strong winds or low relative humidity (Tallaksen and Van Lanen,
2004). Long-term precipitation reduction may further aggravate streamflow droughts through the depletion of groundwater and the subsequent decrease in baseflow. In addition, anthropogenic drivers, such as intensive water use and poor water management, can exacerbate low-flow conditions in watersheds, leading to a consequent increase in vulnerability to streamflow drought (Vörösmarty et al., 2000; Döll et al., 2009; Wada et al., 2013).

Trends in historic annual river flow in Europe confirm the patterns in meteorological drought with drying trends in southern and eastern regions of Europe, and generally wetting trends elsewhere (Stahl et al., 2010; 2012). They found positive trends (wetter) in the winter months in most catchments. A marked shift towards drying trends was observed in April, gradu-

**FIGURE 3.35**

Drought frequency trends between 1951 and 2015, expressed as the number of events per decade: left to right, winter, summer, annual. In dotted areas trends are significant at the 95 % level
Source: adapted from Spinoni et al. (2017)

**FIGURE 3.36**

Drought frequency differences between the far future (2071-2100) and the recent past (1981-2010), expressed as the number of events per decade: left to right, winter, summer, annual; upper row scenario RCP4.5, bottom row RCP8.5
Source: adapted from Spinoni et al. (2017)
ally spreading across Europe to reach a maximum extent in August. Low flows have decreased in most regions where the lowest mean monthly flow occurs in summer, but vary for catchments that have flow minima in winter. Hannaford et al. (2013) show that trends are sensitive to the selected period (sign may change) owing to decadal climate variability.

Global changes in climate and socioeconomic patterns are expected to affect the development in space and time of river low flows (IPCC, 2012). Many river basins in Europe are likely to be more affected by severe water stress. Projected changes presented in different studies depend on the chosen drought indices (e.g., minimum flow, streamflow deficit), climate scenarios, temporal and spatial resolution of the climate signal and the hydrological representation. However, some coherent patterns emerge. Research studies based on multimodel ensemble climate and hydrological projections show consistent drought intensification both in terms of magnitude and frequency in south-western Europe. The main drivers are reduced precipitation and increased potential evapotranspiration. River low flows in these regions are expected to increase in severity by up to 40% (Feyen and Dankers, 2009; Forzieri et al., 2014; Roudier et al., 2015) and current 100-year events could occur every 2 to 10 years (Lehner et al., 2006). The 20-year event of the river deficit volume is expected to increase by over 50% both in the Mediterranean and European mid-latitudes by the end of the century (Figure 3.37). In contrast, northern regions of Europe will probably experience less severe hydrological droughts as a result of expected increased precipitation, which will outweigh the effects of higher evapotranspiration. In north-eastern Scandinavia and northern Russia, deficit volumes are expected to become more than 50% lower. The projected changes are less clear in a transition zone (Forzieri et al., 2014; Roudier et al., 2015) because of the high climate uncertainty in changes in precipitation patterns.

The spatial drought patterns in Europe are confirmed by global studies
Drought impacts affect almost all parts of the environment and society. Unlike other natural hazards such as floods, earthquakes or hurricanes that result in immediately visible, mostly structural, damage, droughts develop slowly. Frequently, drought conditions remain unnoticed until water shortages become severe and adverse impacts on environment and society become evident. Drought impacts may be influenced by adaptive buffers (e.g. water storage, purchase of livestock feed) or can continue long after precipitation has returned to ‘normal’ (e.g. owing to groundwater or reservoir deficits). The slowly developing nature and long duration of drought, together with a large variety of impacts beyond commonly noticed agricultural losses, typically makes the task of quantifying drought impacts difficult (Wilhite, 2005b).

Quantification is, however, an important task, because, of all weather extremes, droughts have one of the largest impacts on society. Economic damage from drought events can be catastrophic, with a single drought event capable of causing billions of euros of damage (EC, 2007; EEA, 2011).

Drought impacts on society and environment

Drought impacts society and the environment (e.g. public water supply, agriculture, energy production, infrastructure, shipping, forestry, ecosystems and human health). Impact quantification is a prerequisite for drought management and policymaking.

Since droughts affect socioeconomic systems directly or indirectly, their damage may be tangible (market related) or intangible (non-market related). The latter are particularly difficult to quantify as they include, for example, ecosystem degradation or the costs of mitigation and long-term adaptation measures. Impacts of droughts usually cascade. For instance, a lack
of water causing crop losses will subsequently prevent farmers from investing in new machinery, resulting in losses to the farm equipment dealer and producers in the business chain. As a consequence, governments may have to provide aid to the different sectors. As droughts often affect large areas, sometimes over several years, these cascading impacts can affect large parts of society. If drought is severe and widespread, impacts may spread further in the community, as well as to other sectors and regions.

To foster risk management and adaptation strategies, drought impacts and the resulting damage and economic losses must be functionally linked with the monitored drought severity. Gudmundsson et al. (2014), Bachmair et al. (2015), Blauhut et al. (2015 and 2016), Naumann et al. (2015) and Stagge et al. (2015a), among others, have tested modelling approaches that link drought indicators such as SPI, SPEI, soil moisture, streamflow, groundwater, and vegetation-related indicators to reported impacts. All studies conclude that a more quantitative monitoring of impacts and more research towards the quantification of the complex damage caused by drought is needed to improve such estimates. A survey by Bachmair et al. (2016) shows that many providers of Early Warning Systems (EWS) do monitor impacts, but this is not yet done systematically or quantitatively. The variable strength of the relationship between drought severity and recorded damage can often be explained by the sector-specific drought vulnerability and the adaptive capacity of the region affected.

The overall expected damage, estimated by HELIX (2016) and based on the combination of the observed impacts and estimated changes in the recurrence time of severe droughts, are projected to increase in the near future. In some regions such as southern Europe, Southeast Asia, eastern North America and south-east South America, damage could increase from twofold in the near future to tenfold in the far future compared with today (Figure 3.39).

These scenarios suggest that drought risk may increase for many economic sectors and vulnerable regions unless appropriate mitigation and adaptation measures are implemented. Since many regions with high population densities and, often, vulnerable societies relying on local agricultural production show large expected losses in Figure 3.39, they remain a high priority to target better impact monitoring and quantification as a basis for drought management and adaptation.

3.9.4.2 Health impacts

Between 1900 and 2015 drought affected 2.3 billion people worldwide and led to an estimated 11.7 million deaths (EM-DAT, 2009). Drought-associated impacts on people are often linked to health (WHO, n.d.). Health effects can be direct (increased morbidity and mortality) or indirect (economic disruption, infrastructure damage, forced migration). Health
impacts include (1) malnutrition, (2) water-, vector- and air-borne diseases, and (3) mental aspects (WHO, 2012). Population vulnerability may be enhanced by socioeconomic factors, such as poverty, that force people to live on lands with poor soil fertility or in ecosystems at risk of drought.

Malnutrition

The World Health Organization (WHO) ranked malnutrition as the largest global health problem associated with climate change and drought (Campbell-Lendrum et al., 2003; IPCC, 2012). Exposure to drought has been associated with morbidity and mortality owing to the deterioration of people’s nutritional state (Stanke et al., 2013; Friel et al., 2014; Sena et al., 2014). Water shortages may result in reduced food production (crop failure and livestock loss), leading to malnutrition and health risks, such as low birth weight (WHO, 2012). Vulnerable groups, such as pregnant women, children aged < 5 years and people living in shelters are mostly affected (Black et al., 2008; Gitau et al., 2005; Singh et al., 2006a, b; WHO, 1985).

Water-borne diseases

Shortage of water, lack of clean water and inadequate sanitation are typical during a drought. A number of water-borne infectious diseases have been linked to drought (Effler et al., 2001; Brandley et al., 1996). A direct link between drought and the transmission of the pathogens is, however, difficult to observe owing to other concurrent environmental factors and human vulnerability. Drought-induced stress in livestock and livestock use of human water resources may lead to high concentrations of pathogens and increase the risk of human exposure and infection, particularly after heavy rain following a drought. Poor hygiene and poor water quality for human consumption may result in the transmission of diarrheal diseases (WHO, 1985; Sena et al., 2014; Burr et al., 1978; Smoyer-Tomic et al., 2004).

Vector-borne diseases

Pathogens and vectors are sensitive to climatic and other environmental conditions, which is reflected in the characteristic geographic distribution and seasonal variation of vector-borne infectious diseases (Kilpatrick et al., 2012). While increased precipitation may increase mosquito densities owing to new aquatic hab-
Itats, mosquito densities may also increase dramatically following a drought (habitat rewetting) because of the reduced number of competitors and aquatic predators (Chase et al., 2003). Drought may boost the density of birds and mosquitoes around any water sources remaining and thus may accelerate the transmission of pathogens such as West Nile virus (WNV) within these populations, thereby increasing the risk of WNV outbreaks in humans (Shaman et al., 2005; Wang et al., 2010). Mosquitoes, which can efficiently transmit pathogens such as the dengue and chikungunya viruses, may adapt to drought in urban environments and exploit artificial aquatic habitats (e.g. water containers), thus elevating the risk of infection in humans (Brown et al., 2014).

**Airborne diseases**

Drought-related processes can result in atmospheric dust loadings and associated dispersion of microorganisms at various scales, which may have significant implications for human health. The WHO (2015) has identified drought and dust wind activity in sub-Saharan Africa as a risk factor for regional outbreaks of meningococcal meningitis. Dust storms and winds facilitate the transport of microorganisms favouring meningitis seasonality, which can have serious consequences for public health (Griffin, 2007, WHO, 2015; Agier et al., 2012). The mechanisms by which dust and climate may influence meningitis occurrence, along with outbreak location and severity are, however, not fully clear.

An association between respiratory and cardiovascular diseases could be shown in several regions, but little attention has been paid to West Africa, where desert winds and storms may cause more diseases, such as meningococcal meningitis (De Longueville et al., 2013, Garcia-Pando et al., 2014).

**Mental health**

Studies on the association between drought and mental health point to fears and anxieties among the rural population in particular, although suicidal thoughts have been recorded as more critical symptoms. (Polain et al., 2011; Carnie et al., 2011; Hanigan et al., 2012).

In summary, disease incidence is often more pronounced in drought-prone regions and affects more vulnerable population groups, such as children and the elderly, or people with difficult living conditions, which may be caused by poverty, for example. Enhancing drought resilience in regions with high population vulnerability and low adaptation capacity should, therefore, be reflected in relief aid programmes.

**3.9.5.1 Analysing hazard, exposure and vulnerability**

Measuring drought hazard includes estimating the location, duration, intensity and frequency of water deficits over land. Traditionally, drought hazard has been characterised by meteorological indicators, but a simple precipitation shortage often does not translate into immediate concerns and impacts on the ground. Indeed, owing to the multiple-timescale nature of drought, its impacts can continue long after precipitation conditions have returned to ‘normal’ (see Chapter 3.9.4). Therefore, recent scientific developments have focused on combining meteorological indicators with indicators that take into account hydrological processes (e.g. soil moisture, groundwater and river flow), which reflect more closely the impacts felt on the ground.

**3.9.5 Analysing drought risk**

Risk analysis is a major technique for measuring global progress in the implementation of the Sendai Framework for Disaster Risk Reduction (Aitsi-Selmi et al., 2015). Analysing risk is crucial to identify relief, coping and management responses that will reduce drought damage to society. The objective of risk analysis is to determine the underlying causes of drought damages resulting from the combination of drought hazard, drought exposure and drought vulnerability (Table 3.6).

**Interactions between drought hazard, exposure and vulnerability underlie any comprehensive drought risk analysis, which is crucial for drought management and reducing drought impacts.**
agitation across the whole hydrological cycle at different spatial and temporal scales, and (2) the systematic collection of impact data to enable validation and a better understanding of the variety of drought impacts on the ground.

To assess the impacts of drought hazard, the first step is to inventory and analyse the environment that can be damaged (Di Mauro, 2014). In the disaster risk-reduction community, exposure refers to the different types of physical entities that are on the ground and that can be adversely affected by a hazardous event, including built-up assets, infrastructures, agricultural land and the location and density of people (UNODRR, 2015).

Since drought develops slowly and results in a great variety of impacts in most parts of the world, even in wet and humid regions, drought exposure is often measured for distinct water use sectors as a function of the location, timing, duration and amount of a water deficit (Dracup and Lee, 1980; Wilhite and Glantz, 1985). Proxy indicators of drought exposure include, for example, the distribution of crop and livestock farming, industrial and household water withdrawals, and the human population.

Since the location, severity and frequency of droughts are difficult to forecast (see Chapter 3.9.6.2), and since exposure expands as a result of economic and population growth, interventions to reduce drought impacts need to focus on mitigating the vulnerability of human and natural systems. This requires an understanding of who is vulnerable, to which impacts and the reasons for this vulnerability (Gbetibouo and Ringler, 2009).

While tools such as drought management plans are key to deliver a structured and coordinated response when drought hits, drought vulnerability assessments (DVAs) can be used to support the design of mid- and long-term drought preparedness actions to increase structural resilience. As such, they provide a crucial link between drought management and water resources planning, where those actions have to be designed and agreed upon in an integrated way. A broad variety of factors have been used to determine vulnerability to drought (Table 3.7).

Some factors are specific to drought (e.g. the existence of drought management plans or the level of diversification of water sources), while others (e.g. poverty or the quality of social networks) are likely to influence vulnerability to an array of hazards in diverse sociopolitical and geographical contexts (Brooks et al., 2005; Cardona et al., 2012). A recent review of 46 assessments of drought vulnerability (González-Tánago et al., 2016) highlighted that data availability still represents a major constraint in building sound and policy-relevant vulnerability assessments. In particular, it is key to invest in the systematic, high-resolution collection of data on drought impacts, water uses,

### TABLE 3.6

<table>
<thead>
<tr>
<th>Characterisation</th>
<th>Relevant data</th>
<th>Examples of studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hazard</strong></td>
<td>Magnitude of a hydrometeorological deficit</td>
<td>Meteorological, hydrological and/or biophysical indicators</td>
</tr>
<tr>
<td><strong>Exposure</strong></td>
<td>Amount of elements subject to drought hazard</td>
<td>Amount and location of human populations, activities and/or ecosystems</td>
</tr>
<tr>
<td><strong>Vulnerability</strong></td>
<td>Susceptibility of exposed elements to damaging effects of drought hazard</td>
<td>Composite indicators that include environmental, social, economic and/or infrastructural components</td>
</tr>
<tr>
<td><strong>Overall risk</strong></td>
<td>Likelihood of impact</td>
<td>Measured in a probabilistic scale linked to intervention policies</td>
</tr>
</tbody>
</table>
Definitions of risk are commonly probabilistic in nature, referring to the potential impacts or the likelihood of harmful consequences (i.e. environmental, economic, social and/or infrastructural) from a particular hazard to an exposed element in a future time period (Blaikie et al., 1994; Cardona et al., 2012; Cattão et al., 2016). Therefore, the estimation of drought risk requires the development of a model that combines drought hazard with relevant indices or metrics of drought exposure and vulnerability (Government Office for Science, 2012).

An entry point for both understanding and addressing drought risk is to use quantitative measures of historical impacts as proxies for its estimation (Brooks et al., 2005). In particular, historical data relating to socio-economic losses might be used as a retrospective measurement of drought risk to forecast the impacts arising from the interaction of hazard, exposure and vulnerability. For example, Peduzzi et al. (2009) carried out a global assessment of drought risk by fitting the number of human casualties to the determinants of drought risk by means of a generalised linear regression. More recently, Blauhut et al. (2015; 2016) tested the capability of logistic regression to predict the likelihood of drought impacts (LDI) in Europe for different sectors of activity from a set of drought risk determinants. Regression analyses are generally desirable from a risk assessment viewpoint because they may be validated from observed historical data. However, relying on historical impacts has some limitations when estimating current and future drought risk (Government Office for Science, 2012). Foremost, the number of affected people and the types of impacts vary by region, thus hampering consistent broad-scale analyses. For example, drought in developing countries can contribute to malnutrition, famine and loss of human lives, whereas in developed countries it primarily results in economic losses. Second, these analyses do not account for shifts through time in the distribution of exposure or vulnerability.

### 3.9.5.2 Estimating drought risk

<table>
<thead>
<tr>
<th>Sub-dimension</th>
<th>DVAs</th>
<th>Most frequent factors (# of DVAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought characteristics</td>
<td>17</td>
<td>SPI (3), NDVI (4)</td>
</tr>
<tr>
<td>Climatic components: rainfall, evapotranspiration, temperature</td>
<td>20</td>
<td>Average annual precipitation (9)</td>
</tr>
<tr>
<td>Soil characteristics and topographic factors</td>
<td>20</td>
<td>Soil water-holding capacity (10)</td>
</tr>
<tr>
<td>Water resources: runoff storage capacity. Surface and groundwater</td>
<td>19</td>
<td>Status groundwater (12) and surface water (10)</td>
</tr>
<tr>
<td>Water uses</td>
<td>11</td>
<td>Agricultural water use (9)</td>
</tr>
<tr>
<td>Land use</td>
<td>17</td>
<td>Agricultural land uses (9)</td>
</tr>
<tr>
<td>Socio-cultural (demography, education, health, gender, drought awareness, etc.)</td>
<td>29</td>
<td>Population (24) and education (16)</td>
</tr>
<tr>
<td>Economic and financial resources</td>
<td>28</td>
<td>Economic resources (20), agricultural income (17), employment (9)</td>
</tr>
<tr>
<td>Institutional, Policy and Governance (social networks, taxes, governmental programs, participation, etc.)</td>
<td>14</td>
<td>Government presence or programs (9)</td>
</tr>
<tr>
<td>Technical, technological and infrastructural (irrigation, tillage, improved seeds, fertilisers, access to services, etc.)</td>
<td>28</td>
<td>Irrigation (23)</td>
</tr>
<tr>
<td>Others (&quot;Others&quot;)</td>
<td>4</td>
<td>Impacts</td>
</tr>
</tbody>
</table>
indicators are mathematical combinations of risk determinants that have no common unit of measurement (OECD/JRC, 2008). For example, Carrão et al. (2016) used a multivariate and non-parametric linear programming algorithm, a Data Envelopment Analysis (DEA), to aggregate proxy indicators of hazard, exposure and vulnerability into a composite statistic of global drought risk (Figure 3.40). Its values are not an absolute measure of economic losses or damage to human health or the environment, but a relative statistic that provides a regional ranking of potential impacts with which to prioritise actions to reinforce adaptation plans and mitigation activities. Figure 3.40 illustrates that drought risk is generally higher for populated areas and regions extensively exploited for agriculture, such as South-Central Asia, south-east South America, Central Europe and the Midwestern United States. This indicator, while useful for risk assessments in the agricultural sector, may not be adequate for analysing the risk in other sectors, such as energy production (hydropower, cooling of...
nuclear plants), navigation and transportation (waterways), or recreation, which should be part of any comprehensive drought risk management plan.

Composite indicators and impact models represent alternative but complementary ways of approaching drought risk estimation at different scales and coordination levels. Since drought impacts are context specific and vary geographically, regression models are most important for local to national management when preparedness plans and mitigation activities are put in practice, while composite indicators can identify generic leverage points in reducing impacts from drought at the regional to global scales.

3.9.6 Managing drought risk

3.9.6.1 Drought monitoring

Drought monitoring and forecasting systems are an essential component of integrated drought management. They provide the necessary and timely information for stakeholders to analyse drought hazards for use within their decision-making processes (WMO, 2006; Bailey, 2013; Wood et al., 2015). In recent decades, such systems have been developed at different scales and coordination levels. Since drought impacts are context specific and vary geographically, regression models are most important for local to national management when preparedness plans and mitigation activities are put in practice, while composite indicators can identify generic leverage points in reducing impacts from drought at the regional to global scales.

The North American Drought Monitor
Source: NOAA (2017)

http://www.ncdc.noaa.gov/nadm.html

Analysts:
Canada - Trevor Hadwen
Mexico - Minerva Lopez
Reynaldo Pascual
U.S.A. - Brian Fuchs
Richard Hein *

(* Responsible for collecting analysts’ input & assembling the NA-DM map)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for a general summary.

Regions in northern Canada may not be as accurate as other regions due to limited information.
scales from the local or community scale up to the global level, illustrating the broad variety and complexity of users addressed by these systems. Since droughts affect extended regions that frequently cross national borders, it is important to maintain harmonised systems at different scales that provide comparable information and allow for an integrated monitoring of the evolving events. This is even more important with aquifers and river basins that are frequently transboundary and with globally interconnected economies, resulting in primary and secondary impacts that are felt across many countries and even globally.

Available information typically includes meteorological, hydrological and remote sensing-based indicators, allowing for an assessment of the extent and severity of drought events across continents. More specific indicators for water management often become available at the regional to local levels. While the first type of information is targeted at policy and high-end decision-makers in the water management sector and at the general public (i.e. awareness raising indicators), the latter is targeted at water managers and stakeholders at the river basin or sub-basin level (i.e. management indicators).

A well-known example of continental systems is the North American Drought Monitor (NADM), which provides monthly information based on a suite of hydro-meteorological indicators, integrated with expert knowledge into a drought map showing five drought intensity levels, ranging from abnormally dry to exceptional drought. A suite of forecasting products and a seasonal outlook complement the picture. It is based on the concept of the weekly updated US Drought Monitor (USDM, Svoboda et al., 2002) and the US National Drought Information System (NIDIS, Pulwarty and Verdin, 2013), combined with information and expert knowledge from Canada and Mexico (Figure 3.41). Information is provided in the form of maps and analyst reports.

**FIGURE 3.42**

The European Drought Observatory (EDO). Example of the Combined Drought Indicator (CDI) for the period 21 to 30 September 2016. Source: EDO (2017)

Harmonised monitoring and forecasting of a suite of drought indices is crucial in drought management and information interchange across borders. It contributes to a move from reactive to proactive risk management.

In Europe, the European Drought Observatory (EDO) provides maps of 10-day and monthly updates on the hydro-meteorological situation and the occurrence and evolution of drought events, including a 7-day forecast of soil moisture. In addition, a Combined Drought Indicator for agriculture and ecosystem drought analyses the drought propagation from a rainfall deficit through reduced soil moisture to impacts on the photosynthetic activity of the vegetation (Fig-
The goal of such combined indicators is to provide easy to understand sector-specific information for decision-makers in the form of alert levels (Sepulcre-Canto et al., 2012). Like the NADM, the EDO delivers analyst reports during exceptional events, albeit not in a regular manner. The EDO is implemented in a nested manner, allowing for information to be processed and stored at the appropriate levels (i.e. the river basin, country or continental level). To allow for comparability between levels, a set of core indicators are processed following agreed algorithms.

Challenges to drought monitoring and early warning are the continuous availability of indicators covering the various hydro-meteorological components and their combined analysis into usable information for the decision-making process at different levels. Important variables to monitor include precipitation, snow pack and snow water equivalent, temperature, evapotranspiration, river flow, reservoir storage, lake levels, groundwater levels, soil moisture and vegetation vigour, among others. The recently published Handbook of Drought Indicators and Indices (WMO and GWP, 2016) provides a good overview of frequently used indicators.

Cooperation between various entities ensures ownership at all levels, which is important to sustain EWSs. National Meteorological and Hydrological Services (NMHSs), as well as regional and subregional centres, are important partners in this task as they routinely monitor many of the required input variables. This, however, requires the exchange of data and interoperability between systems.

Two other major challenges exist with monitoring and forecasting systems. The first relates to linking drought severity with drought impacts in the variety of economic, social and environmental sectors. Consideration of this challenge is slowly being addressed with several studies in the United States and Europe (Chapter 3.9.5.1) and with systems such as the Global Drought Observatory (GDO), developed by the European Commission JRC for the European Union Emergency Response Coordination Centre (ERCC) and Humanitarian Aid services aim to include sector-specific vulnerabilities for assessing the Likelihood of Drought Impact (LDI). The GDO system shown in Figure 3.43 presents a map of the LDI together with a hierarchical list of all affected countries visible in the map. The second challenge relates to developing an understanding of how decision-makers will use the information being disseminated from monitoring and forecasting systems. That challenge needs to be investigated through social science-based research projects and interactions with key users of the information. An example for such interaction is implemented by the US NIDIS system (Pulwarty and Verdin, 2013).

3.9.6.2 Drought forecasting

Forecasting the onset or likely evolution of an ongoing drought over the weeks and months ahead or over the
season is important to trigger actions for mitigating negative impacts on human activities and environmental processes. Decision-makers and end users require adapted and robust forecast indicators that are capable of informing about the onset, possible duration, intensity and end of drought conditions (Chapter 3.9.6.1). The timescale of this forecast is considered a challenge as it stands between medium-range forecasting, which is strongly related to initial conditions, and the seasonal timescale, which is mainly driven by oceanic variability and large-scale climate features such as the El-Niño phenomenon (Vitart, 2014).

The lead time and duration of drought forecasts should be adapted to the needs of the region. In Europe, where resilience is higher owing to the widespread availability of irrigation systems, needs are more related to the forecast of long-term droughts, although shorter lead times are relevant for water-borne transport. In Africa, where agriculture is mainly rainfed, a short-term deficit of precipitation constitutes a higher risk. In these regions, the forecasts of dry spells (short-term droughts of about 10 days) is also important (Winsemius et al., 2014; 2015).

Studies have demonstrated that droughts can be forecasted using stochastic or neural networks (Kim and Valdes, 2003; Mishra et al., 2007) with a reasonably good agreement and with 1- to 2-month lead times. Linking weather types to drought (Fleig et al., 2011; Kingston et al., 2013) and statistical downscaling methods using weather types can also be used (Lavaysse et al., 2017). Eshel et al. (2000), for example, used the North Atlantic sea level pressure precursors to forecast drought over the eastern Mediterranean. Forecasts of droughts can also be produced using deterministic Numerical Weather Prediction Models. Such forecasts are highly uncertain as a result of the chaotic nature of the atmosphere, which is particularly strong on a subseasonal timescale (Vitart, 2014). In general, the published literature indicates that the skill of the precipitation fields produced by Numerical Weather Predictions over Europe is low (Richardson et al., 2013; Weisheimer and Palmer, 2014). Predictions will be better in regions where precipitation origins are related to large-scale structures, such as synoptic perturbations or oceanic anomalies (e.g. mid-latitudes), while regions with strong local drivers (e.g. West Africa) will record lower scores. However, these analyses tend to be performed from the point of view of weather forecasting and do not incorporate specific properties that are relevant for drought forecasting, such as persistence. Therefore, ensemble prediction systems have been developed that forecast multiple scenarios of future weather. These forecasts become particularly important to assess the risks associated with high-impact and rare weather events such as tropical cyclones or droughts (Hamill et al., 2012; Dutra et al., 2013, 2014). The European Centre for Medium-range Weather Forecast (ECMWF) provides two different types of ensemble forecasts for this time range: an extended range forecast, with lead times of up to 45 days, which is issued twice a week, and a seasonal forecast, with
lead times of up to 13 months, issued once a month. The extended-range forecast incorporates more recent model developments and is usually of higher spatial resolution (Vitart, 2004). The seasonal forecasting system is based on an older model cycle (Molteni et al., 2011), among other significant differences. In the case of droughts, an analysis including both the numerical forecasting skill and the possibilities for binary decisions to issue drought warnings has shown that 40% of droughts can be correctly forecasted 1 month in advance over Europe (Lavaysse et al., 2015). While the performance of these subseasonal forecasts is still behind the current medium-range weather forecasts, the ongoing efforts by academia and operational centres are encouraging. An example of monthly forecasting of the probability of drought occurrence based on the ECMWF ensemble system is shown in Figure 3.44.

Finally, the prediction skill depends on the indicator used. Other studies, for example, analysed the prediction of drought based on soil moisture, groundwater or a multivariate index (e.g. AghaKouchak, 2014; Hao et al., 2014; Mendicino et al., 2008). Depending on the region, results can be better than using meteorological indicators, mainly due to the larger persistency (lower variability) of the variables. However, the corresponding data availability and quality, as well as the skill scores, need to be carefully assessed.

3.9.6.3 Drought management

Most officials at all scales traditionally deal with drought impacts in a reactive fashion when a drought event takes place. This reactive approach, called crisis management, has often been uncoordinated and untimely (GSA, 2007; Wilhite and Pulwarty, 2005). In addition, crisis management places little attention on trying to reduce drought impacts caused by future drought events.

Drought risk management, however, is a paradigm that focuses on trying to reduce future impacts by improving drought monitoring and early warning, planning and mitigation strategies (Wilhite et al., 2005a). It is an approach that is inherently proactive and directed at identifying who and what is at risk, why they are at risk and how individuals respond to events.

The concept of drought risk management is illustrated in Figure 3.45, which demonstrates the Cycle of Disaster Management. Although this cycle applies to all natural hazards, which is why some of the components of the cycle (such as reconstruction) apply better to other hazards, it is also applicable for droughts. The bottom half of the cycle represents crisis management, which will always be necessary in some form to respond to the drought impacts of a current event. However, Figure 3.45 highlights that the actions of monitoring
and prediction, planning and mitigation need to take place in order to reduce future drought impacts. These actions are considered to be a part of a drought risk management approach. Drought monitoring and prediction involves the continuous assessment and anticipation of indicators of drought severity, spatial extent and related impacts. Using this information to elicit response is called ‘early warning’ (Hayes et al., 2012). Because decision-makers require accurate early warning information to implement effective drought policies and response and recovery programmes, drought monitoring and prediction are essential for drought risk management and illustrate an important connection between risk and crisis management (Wilhite and Buchanan-Smith, 2005).

The objective of drought planning, the second component of drought risk management, is to reduce the impacts of drought by identifying the principal activities, groups or regions most at risk and developing strategic actions and programmes that address these risks, as well as response actions that can be taken during a drought event. Drought plans provide an effective and systematic means of assessing drought conditions, developing mitigation strategies that reduce risk in advance of drought, and devising response options that minimise economic stress, environmental losses and social hardships during drought (Wilhite et al., 2005b). This overall emphasis on drought planning is fundamental to drought risk management at any decision-making level. Incorporating planning will help decision-makers to prepare for multiple hazards, including drought and climate change, and will promote sustainability and natural resources management, leading to greater economic and societal security at all levels (GSA, 2007).

The third component of drought risk management is the implementation of appropriate drought mitigation strategies, which are the specific activities taken before a drought occurs that reduce the long-term vulnerability to droughts. According to the United Nations International Strategy for Disaster Reduction (UNISDR, 2006), there are currently a limited number of tested strategies available by which to identify appropriate drought risk-reduction strategies. Furthermore, they concluded that ‘it is essential to identify and demonstrate effective approaches and opportunities for drought mitigation and preparedness, including case studies to show examples of good as well as weak policies. Policymakers, scientists, media, and the public often need to see actions-at-work in order to foster buy-in to similar efforts.’

As drought monitoring systems improve in many locations (see Chapter 3.9.6.1), and as policymakers begin to think about trying to implement drought risk management strategies, such as planning and mitigation, an important feedback loop has emerged whereby better drought management drives the need for improved drought monitoring and, in turn, improved drought monitoring encourages more effective drought management (Hayes et al., 2012). As drought plans become more specific in space and time, the need for information at higher spatial and temporal resolutions increases.

An example of this type of coevolution in drought monitoring and risk management has occurred over the past decade in the United States, whereby improvements in the US Drought Monitor (USDM) (Svoboda et al., 2002) product have led to shifts in national agricultural policies, inspiring additional advancements in the spatio-temporal resolution of drought monitoring to support implementation of these policies at a local scale.

Although progress in drought risk management has been slow, there has been some success around the world (Wilhite et al., 2005a). A great example of this at the global scale occurred with the High-level Meeting on National Drought Policy (HMNDP, March 2013), which was co-organised by the WMO, the Secretariat of the United Nations Convention to Combat Desertification (UNCCD) and the Food and Agriculture Organization of the United Nations (FAO), in collaboration with a number of UN agencies, international and regional organisations.

The Policy Document of the HMNDP (UNCDD, FAO and WMO, 2013) lays out the essential elements of a National Drought Policy, namely:

- Promoting Standard Approaches to Vulnerability and Impact Assessment;
- Implementing Effective Drought Monitoring, Early Warning and Information Systems;
- Enhancing Preparedness and Mitigation Actions; and
These elements are considered to be the key pillars of a National Drought Management Policy. These pillars have been used in many different initiatives including the Integrated Drought Management Programme (IDMP) and the Windhoek Declaration of the African Drought Conference (UNC-CD, 2016). One of the successes of HMNDP is that it has drawn the attention of the international organisations and national governments to focus on proactive policies.

The strong call for a framework in the form of a policy that combines different approaches that have been considered key in moving from a crisis management approach to a risk management approach has led to the launch of the IDMP by the WMO and the GWP at the HMNDP in March 2013. The objective of the IDMP is to support stakeholders at all levels by providing policy and management guidance and by sharing scientific information, knowledge and best practice for an integrated approach to drought management.

The strength of the IDMP is to leverage activities of its various partners to determine the status and needs of countries and to move forward collectively to address these needs. The IDMP also uses the network of NMHSs and related institutions affiliated with the WMO, the United Nations specialised agency for weather, climate and water, and the Regional and Country Water Partnerships of the GWP as the multistakeholder platform to bring together actors from government, civil society, the private sector and academia working on water resources management, agriculture and energy.

Based on one of the tools that has been instrumental in the development of drought preparedness plans in the United States, the ‘National Drought Management Policy Guidelines — A template for action’ (WMO and GWP, 2014) were developed from existing material to focus on a national policy context and to draw on experiences from different countries. The purpose of these guidelines is to provide countries with a template that they can use and modify for their own purposes. Countries should not blindly use the 10-step process. The guidelines should be modified and adapted to local needs and experiences. For example, the Central and Eastern European countries have distinguished seven steps.

### 3.9.7 Conclusions and key messages

The key challenge in reducing drought risk is to move from the prevailing reactive approach, fighting the highly diverse drought impacts, to a proactive society that is resilient and adapted to the risk of drought (i.e. through the adoption and implementation of pro-active risk management). This requires practitioners, policymakers and scientists to use a consistent set of drought definitions and characteristics. Observed and projected trends in drought hazard need to be understood and considered in the management plans. The hazard has to be connected to manifold impacts (e.g. water supply, food security, energy production, transport, health, and ecosystems). Current, as well as future, societal exposure and context-specific vulnerability should be identified to eventually assess the evolving drought risk. Through knowledge of all these aspects, drought risk can be managed through a set of institutional, structural and operational measures, including monitoring and seasonal forecasting. There is, moreover, an ongoing need to consider the institutional aspects of ‘capacity’ and ‘coordination’ at national and local levels, particularly where the required sustained collaborative framework among research, monitoring and decision-making/management is lacking (Pulwarty and Sivakumar, 2014). Central to the above is the development, support and training of a cadre of professionals and policy entrepreneurs who view the role of linking drought science, policy and risk management practices as a core goal over the long term.

Recommendations have been set according to the three pillars of DRM-KC. Links to the various mentioned activities and projects are provided at the end of the chapter (see Web Resources for Chapter 3.9 in References chapter 3 - section III).

### Partnership

In Europe, several drought science partnerships exist: (1) the European Drought Centre (EDC), (2) the European Drought Observatory (EDO), and (3) the Drought Monitor for South Eastern Europe (DMCSEE). On the global level, the WMO/GWP Integrated Drought Management Programme (IDMP) fosters collaboration on drought management in the broad sense. The EDC shares expertise from scientists, water managers and stakeholders, and contains the European Drought Impact Report Inventory (EDII). The EDO and
DMCSEE monitor current drought conditions. The EDO also includes a forecast of drought conditions and up-to-date information on drought in the media. The EDO also performs analyses of past trends and of future projections under different scenarios for the 21st century. The IDMP co-ordinates regional initiatives around the globe (e.g. in Central and Eastern Europe, West Africa, Central America and South Asia), covering a wide range of drought aspects. Professional networks dealing with drought in Europe and beyond are, for example, the UNESCO EURO FRIEND-Water Low Flow and Drought network and the IAHS Panta Rhei Working Group on Drought in the Anthropocene. Further development of and collaboration between these partnerships is important to advance our understanding of drought and to improve our capacity to cope with this important threat to our societies.

Knowledge

Recent EU drought research projects (i.e. DROUGHT-R&SPI, DEWFORA, PESETA) and regional cooperation programmes such as EUROCLIMA, as well as several national initiatives (e.g. Jucar Basin, Spain, Box 3.2), have advanced the knowledge base with better access to information, guidelines and services on: (1) drought monitoring, prediction and early warning, (2) drought impacts and links with the hazard, (3) drought risk assessment, risk reduction and drought response, and (4) policy and planning for drought preparedness and mitigation across sectors. Chapters 3.9.2 to 3.9.6 illustrate progress made in these fields over the last decade. It is likely that the frequency, severity and scale of droughts will increase in multiple regions in Europe and elsewhere, affecting many economic sectors (e.g. agriculture, water-borne transport, energy), the environment (e.g. aquatic ecosystems, biodiversity) and human well-being (health). It is therefore important to improve societal preparedness for the related risks and to adapt to the future challenges resulting from droughts.

Innovation

The European Drought Impact Report Inventory - EDII (Stahl et al., 2016), has created a good base on which to learn more about the multifaceted impacts of drought, but needs to be continuously updated and expanded to cover the whole of Europe. Similar inventories need to be established for other parts of the world. This allows the establishment of improved links between impacts and drought hazard on the one hand, and a better assessment of drought risks and how to manage these across sectors on the other hand. Furthermore, context-specific drought vulnerability profiles for the river basins across Europe that also consider projections need to be elaborated. Scientific innovation is required on seamless drought prediction to address multi-monthly and seasonal forecasting, as well as drought projections for the intermediate and far future. Drought management should be put in a multihazard setting, which requires land and water management that integrates policies and measures for the different hazards (droughts, floods, wildfires and heat waves). A follow-up of the past EU working group on Water Scarcity and Drought is required to effectively disseminate progress on drought, including guidelines and good practices among EU Member States and beyond.
Jucar Basin Case Study
Proactive and participatory drought planning and management in a semi-arid water-scarce system

The Jucar Basin District (JBD) (42,989 km²) is located near Valencia in eastern Spain. Most of the area can be classified as semi-arid, and precipitation is highly variable in space and time.

Multiyear droughts are common, as illustrated by the Standardized Inflow Index for the naturalised flow into the Tous Reservoir (lower JBD) (Figure 3.46). The most significant water use is attributable to (1) irrigated agriculture (400,000 ha, 80% of water demand), (2) urban areas (4.3 million inhabitants) and (3) industry (including hydroelectricity production and nuclear plant cooling). The water exploitation index (water demand / natural renewable resources) is approximately 86%. Water scarcity is acute, resulting in high environmental stress and water quality deterioration.

In the JBD, water has been intensively exploited over centuries and adaptation to drought has been a common feature. Institutional and legal developments (e.g. irrigation district associations and water tribunals) were fostered centuries ago and are still working. However, while many measures (e.g. building infrastructure) were taken to decrease vulnerability, drought response remained mainly reactive. In 1936, the participative JB Public-Private Partnership (JBPPP) was founded, and nowadays it includes many stakeholders (e.g. national, regional and local administrations, water users and environmental non-governmental organisations (NGOs)).

The JBPPP does the basin administration, enforces decisions and recovers costs of infrastructures building, operation and maintenance. It provides a very good framework for governance, as well as a good forum for conflict resolution, which is fundamental in drought management. Within the JBPPP, there has been an improvement in knowledge of water resources management since the 1980s through the use of models and collaborations with scientists. Initially the focus was on individual basin components, but in the 1990s an integrative decision support systems (DSS) at the basin scale was designed for basin planning, with an emphasis on water allocation and drought vulnerability assessment (Andreu et al., 1996). To ensure that approved plans provided acceptable levels of drought vulnerability, indicators and criteria about acceptable and unacceptable values were agreed in a participative process since 2004.

In parallel, from the year 2000, the JBPPP adopted a clearly proactive approach by developing a Special Drought Management Plan (SDP) (Estrela and Vargas, 2012). A Composite Drought Operative Index (CDOI) (Ortega et al., 2015) was introduced to monitor drought states (normal, pre-alert, alert and emergency). CDOI maps are published regularly (Figure 3.46) and serve as early warning to trigger predefined anticipation and mitigation measures attached to each drought state. The final DSS, which has been regularly updated, was accepted by all parties as a reliable tool for planning scenarios (Andreu et al., 2009). It includes a probabilistic approach (Andreu and Solera, 2006) to obtain more specific risk assessments (e.g. probabilities of deficits and reservoir...
voir states at short and medium timescales, the impact of anticipation and mitigation measures (Andreu et al., 2013). Anticipation and mitigation measures include: (1) more efficient water use, (2) water saving, (3) conjunctive use of surface and groundwater, (4) financial compensation for giving up water use, (5) water rights purchase for environmental protection, (6) irrigation sluice water recirculation, (7) reuse of waste water, (8) enhanced control of water use, water quality and the ecological status of water bodies, and (9) revision of actions and post analysis. In the alert and emergency state, the JBPPP Participatory Permanent Drought Commission (PDC) has special powers, for example to override water rights and priorities, to further improve governance aspects, thereby facilitating consensus for equitable decisions.

The JBPPP PDC demonstrated its relevance during the severe 2004-2008 drought (Andreu et al., 2013). The governance body had 28 sessions with successful results, as recognised by its own stakeholders (Urquijo et al., 2016). It provided transparency and credibility to the decision and policymaking processes. Drought management and planning in the JBD is internationally recognised as exemplary (e.g. Schwabe et al., 2013; Kampragou et al., 2015; Wolters et al., 2015).

Nevertheless, improvements can still be made, for instance through: (1) refinement of monitoring of indicators and real-time data gathering, (2) the consolidation of measures, (3) further enhancement of institutional and legal aspects, (4) demand and supply management, and (5) the use of additional economic instruments (e.g. insurance for irrigated agriculture). Finally, major challenges have been maintaining the personal commitment of individuals in all sectors (knowledge brokering, policymaking, NGOs, stakeholders in general) and incorporating the comprehensive interaction in the regular functioning and procedures of the institutions and other bodies involved.

**FIGURE 3.46**

The Jucar Basin (south-east Spain). Standardised Inflow Index for the JBD (left), and CDOI maps corresponding to March 2006, January 2007 and March 2009 (right, from left to right).

Source: self-elaboration from public domain information.
3.10 Climatological risk: wildfires

Jesus San Miguel, Emilio Chuvieco, John Handmer, Andy Moffat, Cristina Montiel-Molina, Leif Sandahl, Domingos Viegas

3.10.1 Introduction – wildfires in the context of natural and man-made hazards

About 4 % of the global vegetated area is burnt every year by fires (Giglio et al., 2013; Hantson et al., 2015). Wildfires have significant impacts on humans and on the natural environment. They affect human lives and livelihoods (Finlay et al., 2012) and result in high social and economic costs, associated not only with the damages, but also with the prevention and suppression measures put in place every year (Birot, 2009). Fires cause large increases of atmospheric emissions and pollutants (Carvalho et al., 2011), cause soil erosion (González-Pérez et al., 2004), reduce the provision of goods and services by forests (Mavsar et al., 2013), and change land cover patterns and landscape ecosystem dynamics (Moreira et al., 2011; San-Miguel-Ayanz et al., 2012).

Wildfires, which are often caused by humans, have a large impact on human assets and the natural environment, contributing to atmospheric pollution and reducing the provision of goods and services from forests and other ecosystems.

Wildfires are commonly considered natural phenomena for many ecosystems, as wildfire ignition and spread are greatly driven by vegetation and meteorological conditions. However, humans have used fire for land use management and hunting for at least the past 100 000 years (Bowman and Panton, 1993). Nowadays, human-caused wildfires have become a major hazard for the environment and human assets globally. An analysis of fire causality in Europe shows that more than 95 % of the fires in this region are caused by negligence or arson (Ganteaume et al., 2013). Likewise, an analysis of fire causality worldwide shows that most wildfires are caused by humans (Krawchuck and Moritz, 2011).

However, although wildfires are most often initiated by human actions, their intensity and their effects are mainly driven by fuel condition and availability, vegetation structure (González-Olabarria and Pukkalaet, 2011) and prevalent meteorological and topographic conditions. In the context of this subchapter, wildfires are considered a natural hazard, regardless of their ignition source.

3.10.2 Wildfires – definitions
Definitions of wildfire vary according to the scientific or operational context in which the issue is discussed. Until recently, in Europe, the most commonly used term to define and discuss wildfires that are not the result of a controlled human activity (these would usually be called 'prescribed fires') was ‘forest fire’.

The definition of risk used by the IPCC’s special report Managing the risks of extreme events and disasters to advance climate change adaptation (2012) is that risk is a function of hazard, exposure and vulnerability. This subchapter uses these terms as key components of the wildfire risk. In other fields, such as the prediction of droughts or earthquakes, risk is often considered as the conjunction of two factors, namely the hazard, or potential threat to humans and their welfare, and the vulnerability, or exposure and susceptibility to losses.

Traditionally, wildfire risk has been assessed at national or local scales using individual data sources and methodologies. This has led to local or national indices that are not comparable either across Europe or worldwide. In addition, there are differences of opinion over the definition of fire risk. According to the FAO’s terminology (FAO, 1986), forest fire risk is ‘the chance of a fire starting as determined by the presence and activity of any causative agent’. The Vocabulary of Forest Fire Terms compiled by the DELFI forum (1999) supports this definition, stating that fire risk is ‘the probability of fire initiation’. Other approaches consider wildfire risk as ‘the potential number of ignition sources’ (Hardy, 2005). It should be noted that fire ignition is not the same as fire initiation, since not every ignition outbreak develops into a fire.

Other authors suggest wildfire risk to be the probability of wildfire occurring at a specified location, and under specific circumstances, together with its expected effects (San-Miguel-Ayanz et al., 2003). Wildfire risk has also been defined as ‘the probability of a fire to happen and its conse-

3.10.3 Wildfire risk

3.10.3.1 Definition

The definition of risk used by the IPCC’s special report Managing the
Fire hazard can be defined as the combination of the presence of ignition sources, fuel availability and conditions for fire ignition and spread (fire behaviour) (Oliveira et al., 2014). It thus refers to the conditions under which an ignition can result in a wildfire, as a result of the availability of fuels and their condition, and the prevalent meteorological conditions. Vulnerability refers to the susceptibility of suffering damage. This term is often associated with exposure, as vulnerability exists if a series of assets (such as lives or property) are exposed to damage by wildfires (Galí- na-Martín and Karlsson, 2012). This approach is consistent with the ISO 31000 standard.

Wildfires are a recurrent phenomenon, and their importance in the earth system is widely recognised (Dwyer et al., 1999; Bowman et al., 2009; Flannigan et al., 2009; Scott et al., 2016). Wildfires affect many regions in the world and their impacts are evident in natural systems and human society.

Owing to the many factors that affect fire risk, the issue of scale is highly relevant in the assessment and management of risk. At local to national scales, the assessment of wildfire risk is accompanied by mitigation measures aimed at reducing fire risk by increasing prevention and preparedness. At the supranational and global scales, assessment aims to reduce the negative impacts of wildfire by establishing international guidelines and agreements for best practice among the wildfire management organisations. Organisations such as UNISDR seek to establish common nomenclatures and methods for the assessment of risks. At the European level, an initiative to compile information on National Risk Assessment good practice is currently ongoing. An analysis of the resulting data will provide guidelines on good practices for the assessment of wildfire risk in Europe and, probably, at the global scale.

Although there is a vast knowledge of wildfire risk-related issues, information varies according to the scale at which risk is assessed, varying notably from local to regional or global scales.

Therefore, the involvement of so many organisations in fire management, from national to local level, means that clear definitions of authority, functions, tasks and responsibilities, together with an effective coordination of their inputs is essential. The influence of the multilevel governance structure is a key issue in wildfire management (Aguilar and Montiel, 2011).

The international standard on risk management, ISO 31000, defines risk as the ‘effect of uncertainty on objectives’. For this definition of risk, there needs to be a clear objective, for example, avoiding significant human impacts from wildfires. Recent studies at the local and global levels describe wildfire risk as being derived from the interaction of two components, fire danger and vulnerability. In this case, fire danger is equivalent to fire hazard (see Figure 3.47).

### 3.10.4 Existing knowledge and the issue of scale in fire risk assessment

Wildfire risk is derived from the combination of fire hazard and fire vulnerability, namely hazards related to the presence of fuels and ignition sources, and vulnerability related to the assets at risk.
3.10.5 Wildfire information systems: regional, national, global

Often, fire management is the responsibility of local to regional agencies within a country, although these operations are commonly supported by national governments. In developed countries, the increase in the number of human-caused fires and the large economic losses caused by them have triggered forest fire prevention and, in particular, firefighting programmes.

A range of infrastructural components including hard infrastructure (e.g. control centres), plus education and awareness raising (strategic as well as tactical or responsive) are part of permanent programmes. Moreover, expenditure in firefighting equipment and operations has escalated in recent decades, especially with the increasing use of aerial firefighting.

As technology has evolved in the last decade, modern methods for the analysis of fire risk components and the evaluation of fire effects have found their place in national, regional and global organisations. Accordingly, wildfire information systems often include modules for the dynamic evaluation of fire danger and the frequent update of fire risk components such as fuel distribution, structure and moisture content. Satellite technology and Geographic Information Systems permit the integration of spatial layers of information to analyse spatial patterns of fire occurrence and to derive fire risk at different scales. National fire information systems to assess and quantify fire risk exist in nearly all European countries, although they differ in approach. Regional initiatives of wildfire information systems are the European Commission’s European Forest Fire Information System (EF-FIS) and the recent Group on Earth Observations (GEO) initiative to establish a Global Wildfire Information System (GWIS) (see Figure 3.48).

FIGURE 3.48

Global Wildfire Information System (GWIS) initiative of the GEO and Copernicus programmes
Source: GWIS (2017)
Both initiatives are currently under the umbrella of the EU Copernicus Regulation. These systems benefit from other initiatives aimed at deriving relevant information, such as the Climate Change Initiative of the European Space Agency (ESA).

### 3.10.6 Wildfire management: prevention, preparedness, impact assessment, restoration

The wildfire policies adopted by most European countries over the last century have been based on fire exclusion regardless of their specific context. Nowadays, this approach is widely recognised as being neither ecologically desirable nor economically feasible. Total fire exclusion policies have significant consequences for the magnitude and frequency of wildfires, through an increase of fuel accumulation, the loss of resilience to fire and the alteration of fire regimes. New approaches to wildfire defence are required to improve the strategies of prevention and suppression (Montiel and San-Miguel, 2009). A further step is given by the concept of integrated fire management (Sande Silva et al., 2010). It involves the consideration of the various aspects of fire in suppression and prevention as well as the use of fire as a tool for management practices.

An integrated system for wildfire management must consider the different phases of the fire cycle. According to the definition of fire risk in the sections above, wildfire management requires the monitoring of all the factors that affect fire ignition, spread and impact. It also requires action to prevent and mitigate fire impacts. Fire prevention must target the reduction of fire ignitions as well as the management of fuels, as these are the only factors affecting fire propagation upon which we can act. Whenever the fire exclusion policy is predominant, this fuel management is commonly restricted to reducing fuel spatial continuity, by fuel breaks, or fuel amount using grazing or mechanical means. Those fuel reduction operations can be eventually used for the generation of biomass energy. In many regions, the result of the fire exclusion policy is often the continuous accumulation of fuel, which, when ignited, can result in uncontrollable wildfires (San-Miguel-Ayanz et al., 2013; Viegas et al., 2009). However, prescribed burning is not widely accepted in many countries, particularly because of potential accidents and negative public perception. Policy conflict between different government departments occurs in other areas, for example in the conversion of land for certain forms of wildlife habitat such as heathland, and housing development on land surrounded by vegetation at significant risk of ignition. It is important that these conflicts are worked through and resolved.

Wildfire management comprises the totality of the fire cycle, before the events in the prevention and preparedness phases and the post-fire assessments that lead to the implementation of restoration measures.

Preparedness refers specifically to activities in the period immediately before fire initiation, notably at times of the year when fire hazard is greatest. Modern technologies for the assessment of vegetation dynamics and meteorological weather prediction systems allow forecasting of fire danger conditions, resulting in enhanced preparation for firefighting. The use of remote sensing techniques has be-
come common among forestry and civil protection organisations. Remote sensing permits the near-real-time assessment of fire spread, which can be used in decision-making for the deployment of firefighting crews and equipment during large wildfire events. Remote sensed information is also used to assess fire effects at a very low cost, which complements necessary field campaigns for the in situ assessment of damage and the planning of restoration measures.

### 3.10.7 Other hazards such as windstorms and pests and their relationship to wildfire risk

Other natural hazards that worsen the conditions for wildfire management often result in an increase in the levels of fire risk.

Prolonged droughts (see Chapter 3.9) and heatwaves (see Chapter 3.8) dry out fuels and help to create the conditions for uncontrollable wildfires (Gower et al., 2015). Examples of these are the fires that occurred in 2003 in Portugal and southern France, and in 2007 in Greece. Windstorms can result in the sudden accumulation of large amounts of fuel, which are often difficult to manage or extract. Furthermore, the difficult arrangement of fuels on the ground hinders the effective implementation of fire prevention measures and hampers firefighting operations. Examples of these situations occurred in the areas affected by Storm Gudrum in Denmark and Sweden (2004), which resulted in the world’s largest stockpile of wood (de Rigo et al., 2016), and Storm Klaus (2012) in France.

In Europe, heavy attacks by insects and phytopathogens can have major impacts on forests, resulting in reduced forest health and, sometimes, widespread tree death (FOREST EUROPE, 2015). Standing dead timber poses an increased risk of wildfire. The loss of economic value may induce lack of fuel management and increase the fire risk. The accumulation of dead and fallen woody fuel following windstorms (see Chapter 3.7) also makes these forest areas more prone to attacks by insect pests and further increases their vulnerability to wildfire.

#### Other hazards, such as pest outbreaks or windstorms, may increase wildfire risk and hamper wildfire prevention measures.

However, wildfires can also influence other hazards. They are particularly shaping the flood scenarios in the fragile Mediterranean-type ecosystems, where the peak flood and the suspended material load of water streams increase significantly in post-fire conditions, inducing soil erosion, floods and landslides.

### 3.10.8 Harmful effects of wildfires on human population and health

The effects of wildfires include damage to land cover, which encompasses the loss or degradation of natural values and the decrease or failure of provision of ecosystem services in the affected areas, which can be temporary or permanent. These include, among other things, soil protection, water purification, recreation, tourism, etc.

In addition, wildfires emit large volumes of gases that affect the human populations in the areas affected by them. Wildfire emissions contribute considerably to the total global atmospheric carbon emissions and are a concern from local to global scales. At the global scale, assessment of emissions is compiled in the Global Fire Emissions Database - GFED (Randerson et al., 2015).

#### In addition to economic and environmental damage, wildfires pose a serious threat to human populations, producing negative effects on human health and increasing death tolls.

At the local scale, wildfire emissions can have harmful effects on the local population (Finlay et al., 2012; Bow-
man and Johnston, 2005). The effects of atmospheric pollution by wildfires include the aggravation of respiratory problems in the population and can result in the deaths of more susceptible individuals. Serious problems to human health were recorded in many critical fires during the last decade; possibly the most noted events were those in Indonesia and Russia in 2010 and Indonesia in 2015. The Indonesian fire event in 1997 resulted in an estimated 45 000 km² of forest and land being burnt on the islands of Sumatra and Kalimantan, releasing between 0.81 and 2.57 Gt of carbon to the atmosphere, equivalent to 13–40 % of the mean annual global carbon emissions from fossil fuels. As a result of this fire, an estimated 20 million people in Indonesia suffered from respiratory problems, with 19,800-48,100 premature mortalities (IFFN, 2000). Russia reported a death toll of about 700 people daily in connection with the smoke problems caused by peat fires in the Moscow region in 2010 (The Guardian, 2010). Less well known is the significant psychological effect that some people can experience after close contact with wildfire (Eisenman et al., 2015).

### 3.10.9 Contextual factors affecting wildfire risk

#### 3.10.9.1 Climate change

Currently, an average of 400 million ha of natural areas are burnt annually at the global level (FAO, 2015: 245). Many organisations, including the IPCC (2014) contribute to the assessment of the relationship between climate change and fire occurrence, supporting wildfire prevention in the context of global change. A number of researchers have highlighted the potential changes in fire climate regimes in different parts of the world, which may result in increased fire risk and exacerbation of the effects of wildfires, especially in the Boreal and Mediterranean climatic regions (Barbero et al., 2015). Climate studies in Sweden show that more fires, especially in south-east Sweden, with a fire season that is about two times longer than the current fire season, is expected, with attendant climate change scenarios (Sandahl, 2016).

The effect of climate change in the United States (Westerling et al., 2006) has already led to an increase in large-fire activity in the western United States, with longer wildfire duration and longer wildfire seasons. Likewise, climate change is associated with an increased fire danger and consequent larger burnt areas in the EU Mediterranean region by the end of the century (Amatulli et al., 2013; Khabarov, et al., 2014). The increase in fire activity and burnt areas will consequently lead to an increase in fire emissions in Europe and globally (Jolly et al., 2015). The economic impact of climate change, including the effects of wildfires, has recently been assessed in the context of the Peseta II project of the JRC (Ciscar et al., 2013).

#### 3.10.9.2 Socio-spatial factors of wildfires: population, land cover and land use change, and landscape dynamics

Socio-spatial factors have a major role in the management of wildfire risk. As noted in the literature, there is a proven relationship between ignitions and human populations (Bowman et al., 2011). Furthermore, the increase in the intensity of wildfires results every year in a number of human casualties and large economic losses due to the destruction of human assets (San-Miguel-Ayanz et al., 2013; Viegas, et al., 2009; EM-DAT, 2009). The expansion of the so-called Wildland Urban Interface (WUI) leads to an increase in wildfire risk and to the much more difficult management of wildfires. Often, fire-fighting crews must protect human assets and disregard the fighting of wildfires, limiting their intervention to the protection of human lives and properties.

Wildfire risk is affected by contextual factors. The main factors are climate change and socio-spatial factors such as population, land cover and land use change, and landscape dynamics. The changes in land cover and land use patterns due to the movement of population from rural areas to urban centres in many parts of the world, and the consequent decline in fuel management in these areas, leads to an increase in fire risk and higher intensity of wildfires (San-Miguel-Ayanz et al., 2012). Wildfires are a complex socio-spatial...
issue. However, both systemic components – space and society – have usually been dealt with separately. The spatial patterns of wildfires have been analysed at the regional scale, using the available data and employing methods of comparative analysis for producing an overview of fire occurrence in Europe (Chas-Amil et al., 2015; Montiel and Herrero, 2010; Salis et al., 2014). Interesting literature on the spatial distribution of fire occurrence has also been developed at the municipal level (Fernandes, 2016; Martínez-Fernández et al., 2013). The social aspects, which are basically related to community-based fire management and community wildfire relations beyond wildland fire causes and wildland fire defence organisation, are less well known.

The temporal patterns and the evolution of the spatial patterns through history have also been less studied, owing to data limitations. The temporal dimension of wildland fires has been mainly explored in the short term, considering the different periods of the existing statistical series, although some studies have analysed fire history on the basis of lake charcoal deposits from the last 12,000 years (Whitlock and Larsen, 2012). The interactions between environment factors, the social context and the fire regime over the long term, as well as changing fire behaviour spatial patterns, resulting in the creation of new territories at risk, are still largely unknown. Furthermore, it is essential to take into account the territorial contextual factors (land cover and land use, meteorological factors, land tenure, cultural and organisational aspects, public policies) that interact and influence fire occurrence to better understand wildland fire causes (Beilin and Reid, 2015; Montiel and Galiana-Martín, 2016).

The interactive evolution of spatial and human issues is defining different land-type fire scenarios at various scales. The concept of fire scenario (Montiel and Galiana-Martín, 2016) has provided an important conceptual foundation by which to understand connections between landscape patterns and dynamics and fire behaviour (propagation patterns). The use of fire scenarios is thus useful to establish fire-design management strategies at the landscape level (Costa et al., 2011; Moreira et al., 2011) that increase social and ecological resilience and reduce territorial vulnerability to fire risk. Figure 3.49 shows a fire-resilient Mediterranean landscape in Sierra de Gata (Spain), in which diversified land management and fuel discontinuity prevent high-intensity wildfires.

FIGURE 3.49
Wildfire-resilient Mediterranean landscape in Sierra de Gata, Spain. Source: photo courtesy of C. Montiel

3.10.10 Innovation for better understanding and wildfire management

Innovation in wildfire management comes from two main sources: (1) operational experience, in a lessons learning process, and (2) scientific research. Such knowledge and innovations are incorporated in the management activities through, for example, the advancement in methods to quantify and map fire risk components and the incorporation of human factors in the management of wildfires through education campaigns, rural
programmes and a better consciousness of human society on the impacts of wildfires. However, there remains a lack of agreement with national and regional fire administrations on the implementation of a common wildfire risk assessment at the European or global levels.

Relevant progress has been made in the implementation of common methodologies to assess fire danger at the European level in the context of EFFIS. At the global level, there are initiatives to promote the production of information that forms the basis of wildfire risk assessment (GWIS, FIREGLOBE, 2008), such as global fuel maps (Pettinari and Chuvieco, 2016), global fire ignition sources datasets, global fire vulnerability (Chuvieco et al., 2014), as well as global burnt area maps (Chuvieco et al., 2016). In addition, global data on fire ignitions and burnt areas are provided by the National Aeronautics and Space Administration FIRMS activity and fed into regional and global systems (e.g. AFIS, INPE, GWIS).

Innovation in wildfire management involves the adoption of new technologies for the assessment of wildfire risk and the incorporation of the human component in the implementation of prevention measures.

Some of the areas in which innovation can be further developed are as follows:

- Increased use of fire spread models, coupled with portable, handheld devices to make decisions on site during firefighting (SCION, 2009).
- Increased use of digital technologies and social media to reach relevant stakeholders and lay communities at times of heightened fire risk; use of these platforms to get early warnings of wildfire outbreaks (two-way knowledge exchange).
- Increased synergy between different agencies and departments with responsibility for disaster management. Economies of scale and greater effectiveness in bringing relevant parties/actors together when it matters. This is important for countries such as the United Kingdom, where the risk of storm and flood damage is currently much greater than the risk of wildfires. Working together is likely to engender a better understanding of the impending wildfire problems that climate change is already bringing about — a significant form of preparedness.
- A better integration of the four ‘R’s (risk reduction, readiness, response, recovery) with shared responsibilities between land managers/owners and the civil contingency community.
- A better understanding that prevention is better than cure (e.g. Firewise (NFPA, 2016)), especially in times of recession when government agencies are being cut back. Hence, land managers are being brought into the risk management process via wildfire fora, projects and other forms of communication. Government financial incentives for forest management (grants) are also manipulated to ensure that applicants understand the need to embrace wildfire risk-reduction policy and practice (GOV UK, n.d.).
- Increased rooting of government policy in a risk-based framework (HM Treasury, 2013), driven by climate change and other national risks (e.g. in a National Risk Register (Cabinet Office, 2015)). Better understanding that poor handling of a disaster can be politically damaging in a digital environment when blame can be ascribed with some confidence (Gasper and Reeves, 2011).
- Increased use of the ecosystem framework (e.g. Millennium Ecosystem Assessment - MEA, Mapping and Assessment of Ecosystems and their Services - MAES) to contextualise ecosystems, their goods and services and their values (e.g. via Natural Capital Accounting (BISE, n.d.)), and thus the potential loss from wildfire; e.g. the ecosystem approach has been used to evaluate potential loss from wildfire in a study in the United Kingdom (KWFW, 2014).
- Disaster Management degree (BSc, MSc) courses will help to embed risk analysis in the mainstream.

3.10.11 Research gap

Although innovation provides a better assessment of fire risk components, and research demonstrates the applicability of research methods in pilot projects, there is still a lack of proof-of-concept at an operational level.
Few of the research advances in projects are adopted or implemented by regional or national administrations. This is often due to the complexity in the use of new tools and the inertia of these administrations to change the use of long-established methods, which are well known by staff.

Basic research on the social aspects of wildland fire is very limited. The existing literature is mainly applied research, in particular case-studies of certain aspects of the social dimensions of wildland fires (wildfire human causes and influencing factors; fire laws/policies/regulations; fire management; socioeconomic impacts of wildfire risk; social awareness/vulnerability/resilience to wildfire risk, etc.).

Although progress has been made in the assessment of fire risk components, there is still a need for research on, inter alia, fire risk and behaviour models as well as policy, social and economic aspects.

In general, these scientific publications are analytical descriptions used to assess a specific issue of wildland fire factors or impacts at the local or regional level, instead of the community one which is closer to the social approach because this is the scale at which people organise and interact.

Research is needed in both technical and social spheres. It is easy to predict that developments in wildfire risk management will follow the increase in sophistication and use of digital technologies. These largely support the readiness, response and recovery phases in disaster management. However, it is less easy to be sure that reduction via a decrease in ignition events can take place without significant changes in human behaviour for which social research will be valuable.

The following are a few areas of research that could be prioritised (not in order of importance):

• Refinement of risk models (continual process), based on developments in fire science and better parameterisation, for example based on increased knowledge of vegetation, its phenology and flammability. This will be achieved through basic experimental research, monitoring and modelling.

• Modelling of wildfire risk in the context of predicted land-use change, which is affected by a range of social, economic and environmental (e.g. climate change) drivers. Foresight analysis is very important.

• Gaining a better understanding of wildfire behaviour to support fire prevention and fire suppression activities and to improve fire safety. The development of more advanced fire suppression methods to cope with very high-intensity fires that are becoming more common.

• Economic analysis of wildfire consequences, including all elements of risk management (reduction, readiness, response, recovery) at a regional or national scale in order to evaluate cost-effectiveness of investment in each of these elements. This must include the value of loss of the full range of ecosystem goods and services.

• Land use/cover analysis (both current and future projections) that would better characterise the impacts of landscape structure in fire propagation.

• Policy analysis to understand at national/international levels how wildfire policy can work synergistically with existing agricultural, forestry, urban and habitats/biodiversity policies instead of conflicting with them. Use of ecosystems frameworks to explore trade-offs and provide possible ways forward.

• Social research to understand the perceptions of wildfire risk in the different land management sectors and the constraints to adopting a more realistic approach to it. In other words, why do we still experience so much negligent behaviour? Research to find ways to overcome such obstacles should be undertaken.

• More social research to understand why people commit intentional fires, and how to reduce these motivations and to have a larger involvement of the population in the fire prevention and risk-reduction activities. A better understanding of the interactions between physical and human factors affecting fire ignition is needed.
3.10.12 
Partnerships and networks, international collaboration in wildfire management

International collaboration in wildfire management exists in different fora. There are networks that have collaborated to establish common wildfire management practices among countries. For instance, the Voluntary Guidelines: Principles and Strategic Actions of the FAO provide a series of recommended practices for wildfire management (FAO, 2006). These have been adopted by many countries, including most EU Member States.

There are bilateral agreements among many EU Member States for fire prevention and, in particular, for firefighting. In addition, at the European level a general agreement for collaboration exist between countries to share firefighting resources during fire campaigns. This agreement is established under the so-called Union Civil Protection Mechanism (UCPM) and is coordinated by the European Commission’s ERCC.

At the global level, one of the most long-lasting initiatives aimed at building and retrieving information on wildfires is that of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) Fire Implementation Team. This brings together researchers and regional networks to generate and analyse information on wildfires at different spatial scales, as well as to develop new methods for wildfire monitoring, management and policy decision-making. The synergies between this network and the GEO Global Initiative on establishing a GWIS may result in improved access to wildfire management information globally.

Regarding community-based cooperation, organised groups of local stakeholders are emerging, especially in Mediterranean countries. These groups contribute to fire management as a result of instrumental motivation, or self-interest (Aguilar and Montiel, 2011).

3.10.13 
Conclusions and key messages

There is a vast amount of information on wildfires at local, regional and global scales. However, problems remain at different scales in terms of harmonising or standardising practices for the assessment and management of wildfire risk.

Resilience theory is providing a suitable framework by which to explain abrupt changes in socioecological systems. The importance of community participation and building social capital through collective learning and governance mechanisms has been highlighted as a required basis for building disaster resilience (Aldunce et al., 2015; Aldunce et al., 2016; Montiel and Kraus, 2010; O’Brien et al., 2010). Nowadays, one of the most important factors that affect wildfire impacts (and adds risk to humans) is the expansion of the WUI. Considering that the developments in fire policy, in terms of environmental politics, depend on the social construction of fire problems (Hajer, 2000), the social perception of fire risk and fire culture are crucial components by which to understand and enhance support for specific management strategies (Czaja and Cottrell, 2014). This is one of the bases of social prevention programmes for reducing unwanted ignitions, including the promotion of good practices of fire use (Montiel and Kraus, 2010).

The following recommendations would help to enhance fire risk management from local to global scales in relation to three aspects, namely partnership, knowledge and innovation.

Partnership

Engaging the wildfire community with other involved groups in other areas of disaster management or emergency response in order to build on synergies and best practice methodologies.
Engage the lay public and land management sectors, as a unified and non-contradictory ‘voice’ is vital — confusion always leads to disinterest and failure of communication.

The exchange of research outputs, models, best practice and experience between countries should be encouraged through the continuation of existing international forums and other mechanisms (e.g. Marie Curie and Erasmus programmes in the EU); this is especially important for countries with less experience of wildfires to learn from those with more experience, particularly in the context of climate change.

Wildfire governance schemes are urgently needed in order to obtain consensus between the different stakeholders to create collective willingness and favour the effectiveness of wildfire management systems. It is important to identify the institutions/administrations that are relevant for the implementation of actions related to wildfire risk assessment/mitigation.

Cooperation between the competent authorities and rural communities for wildfire preparedness and damage mitigation should be enhanced through organisation assistance, equipment supply and training sessions for locals. Good governance in wildland fire management requires the conscious regulation of fire use practices and the establishment of an action protocol to arrange cooperation for pre-extinction measures and emergency responses between the different stakeholders.

The wildfire community should engage with world-changing agencies such as the IPCC to ensure that its voice is heard, and that planning for the future takes wildfire risk fully into account. It may be that there are currently too many competing international wildfire bodies, which need to find ways of integrating together as individually they are too small. The IPCC is an example of what can be achieved using a good platform.

Knowledge
Harmonisation or standardisation of practices for the assessment and management of wildfire risk across Europe or at global scale has merit. However, it is more important to reach a common scientific understanding and to facilitate individual countries to deploy such knowledge/wisdom in the best way for the particular needs of the country.

It is necessary to identify if harmonisation is possible for all European countries, or if this would be appropriate only for countries with similar climatic conditions. The same approach should be considered worldwide.

When dealing with harmonisation/standardisation, it is important to identify what needs to be harmonised. This is possible for example for the definition of wildfire and wildfire risk, information systems, actions to take for wildfire management, capacitation of resources, education and information messages during fire campaigns.

Social education and prevention programmes, which aim to increase knowledge of wildfires and to reduce unwanted ignitions, are essential where fire is a traditional land use and resource management tool.

Innovation
Technical research is important but, using current knowledge to the fullest effect, effort must be put into engagement with politicians and senior decision-makers in order to ensure that wildfire management is given strategic support and is resourced appropriately.

Integrated fire management is an innovative concept to reduce damage and maximise the benefits of fire. It includes a combination of prevention and suppression strategies and techniques that integrate the use of technical fire and regulate traditional burning.

Fire scenarios are a new tool for integrating fire management and land use planning to reduce the vulnerability of territories and societies to wildfires. The concept of a fire scenario is useful when confronted with the need to coexist with fire but this requires an understanding of societal discourses and risk constructs at the landscape scale. This innovative approach to fire management provides arguments for adapting land use and forestry practices to the changing fire hazard.
3.11 Biological risk: epidemics

3.11.1 Introduction

An epidemic is the widespread, and often rapidly extending, occurrence of an infectious disease in a community or population at a particular time (CCDM, 2008). A pandemic is the extension of an epidemic to many populations worldwide or over a very wide area, crossing many international boundaries and affecting a large number of people (Last et al., 2001). Both epidemics and pandemics can be hugely disruptive to lives, livelihoods, and the political and socioeconomic stability of affected communities. As a result of this capacity for disruption, they constitute a class of disaster, which like other types of disaster, presents risks that can be ameliorated or reduced through risk management. As a class of disaster, epidemics and pandemics possess some unique characteristics. Infectious disease pathogens continue to circulate, extend and evolve during an event and thus present ongoing and changing challenges in regard to assessment, impact and persistence, further complicating risk management, control and recovery (Floret et al., 2006). For example, the emergence of antimicrobial resistance may thwart efforts to effectively treat infectious disease, resulting in more costly health care as well as prolonged illness and mortality.

Unless detected and controlled at a very early stage (when this is possible), epidemics are prolonged, and pandemics more so. Robust and sensitive systems for detection and surveillance therefore form the backbone of risk management strategies.

While many endemic or routine infections have been controlled in developed countries by immunisation, antimicrobials and improved standards of health and nutrition, they may still pose major hazards in developing countries with weaker health systems, fewer resources to devote to health and limited access to care. Such health systems are also poorly equipped to withstand epidemics of emerging infectious diseases, which may be sporadic and far more difficult to predict, and often involve diseases for which there is no cure (Jones et al., 2008). The existing routine surveillance systems may not be able to detect early signs of outbreaks. As many of the severe emerging diseases (such as Ebola, West Nile, Rift Valley fever) are zoonoses, the first signs of such events may not manifest in humans but rather in wildlife or livestock, indicating the importance of strong surveillance in the veterinary sectors, and the critical value of strong linkages between human and animal health surveillance in a One Health approach (CDC, 2016a).

Disease surveillance, preparedness and response mechanisms are essential to enable any health system to respond.
Droughts, floods and other natural hazards such as earthquakes can all contribute to the initiation of outbreaks. Outbreaks of plague can follow earthquakes, as the rodents that carry plague-infected fleas are displaced from their customary habitats and food sources, and come into closer contact with human environments (Ivers and Ryan, 2006). Epidemics of Rift Valley fever often commence when a period of drought is followed by flooding or intense rainfall, so climate perturbations such as the El Niño-Southern Oscillation may herald an increased risk of outbreaks in at-risk regions, and indicate the initiation of preventive measures, such as immunisation of livestock to prevent epizootics, and heightened surveillance for early detection of outbreaks in animals and in humans (Anyamba, et al., 2001). Disruption of water and sanitation infrastructure from earthquakes, storms and floods can lead to outbreaks of water- and food-borne pathogens such as cholera (Ivers and Ryan, 2006). The extractive industries, with their attendant ecosystem disturbance, land-use and demographic changes, have been associated with precipitating outbreaks of severe emerging diseases, including Marburg haemorrhagic fever (Le Guennno, 1997). A recent study identified the top five drivers of infectious disease outbreak: the care of patients (to alleviate disease and suffering) and the epidemiological investigation of an outbreak to facilitate the response (Ferguson et al., 2006). For both patient care and the epidemiological investigation and response, the laboratory testing of human (and/or animal/vector/environmental) samples for evidence of the pathogen is important to ensure that the correct intervention strategies are employed. The magnitude of testing may be overwhelming for laboratories with specialised testing services (Kumar and Henrickson, 2012), so plans to access such laboratories should be in place before an outbreak.

The response to an emerging infection disease outbreak may initially be largely dependent on the local public health workforce but the response may soon be directly reliant on the capacity of other health departments and agencies. Again, cross-sectoral collaborative arrangements and planning for surge capacity play a fundamental role. Public health risk communication, which is effective in engaging the communities at risk and cognisant of societal and cultural values, is key to ensuring implementation and compliance with recommended public health controls. Psychosocial as well as physical consequences may also occur in epidemic response and recovery and, therefore, plans must address the management of related psychological distress and mental illness (Moore et al., 2007).

The Sendai Framework (UNISDR, 2015) states that:

“more dedicated action needs to be focused on tackling underlying disaster risk drivers, such as the consequences of poverty and inequality, climate change and variability, unplanned and rapid urbanization, poor land management and compounding factors such as demographic change, weak institutional arrangements, non-risk-informed policies, lack of regulation and incentives for private disaster risk reduction investment, complex supply chains, limited availability of technology, unsustainable uses of natural resources, declining ecosystems, pandemics and epidemics”

The framework goes on to advocate the promotion of ‘transboundary cooperation to enable policy and planning for the implementation of ecosystem-based approaches with regard to shared resources, such as within river basins and along coastlines, to build resilience and reduce disaster risk, including epidemic and displacement risk’ (UNISDR, 2015).

Of note, the Sendai Framework states the global target need to ‘Substantially increase the availability of and access to multihazard early warning systems and disaster risk information and assessments to people by 2030’ (UNISDR, 2015). The framework goes on to state that to achieve this it is important ‘To enhance cooperation between
The scope of this subchapter has been limited to viral and bacterial infectious diseases only. A series of well-documented disease epidemics are summarised to demonstrate the complexity of DRM. The value of using the International Health Regulations (IHR) and pandemic preparedness approaches to disaster risk reduction on a global scale is demonstrated, innovations in Early Warning Systems (EWSs) and surveillance are discussed, and the conclusions summarise the key points and recommendations.

3.11.2 Diseases of contention

3.11.2.1 Severe acute respiratory syndrome (SARS)

The first cases of SARS occurred in China in November 2002 (Christian et al., 2004), and the disease eventually spread to 37 countries, with 8 273 confirmed cases (Chinese SARS Molecular Epidemiology Consortium, 2004). The disease caused major outbreaks in Asia and the Americas, with smaller outbreaks in Europe, illustrating how globalisation can contribute to the rapid amplification of disease spread (Coleman and Frieman, 2014). While the overall estimated case fatality rate was estimated at 15%, the rate increased significantly with age (Chan et al., 2003). Transmission was also amplified between health workers; nosocomial transmission accounted for 72% of cases in Toronto (Booth et al., 2003) and 55% of cases in Taiwan (CDC, 2003).

Before the SARS epidemic, coronaviruses were believed to primarily cause minor upper respiratory tract illness in humans (Myint, 1995). With SARS, illness usually begins with a high fever associated with chills and rigors, headache and malaise, followed by respiratory impairment, which, on becoming severe, requires mechanical ventilation (Peiris et al., 2003).

During the early stage of the epidemic, the non-specific presenting symptoms and the lack of access to reliable diagnostic tests made it difficult for clinicians and public health authorities to accurately ascertain cases. Furthermore, the uncertainty around the population health impacts of SARS generated considerable public fear. The need to follow up many thousands of contacts of confirmed cases to check for the development of illness placed an enormous burden on already overstretched public health services. Examples of issues identified included:

- governments investing in highly visible public health activities such as temperature testing at entry to buildings in order to provide a degree of public reassurance, with a major investment made in entry-screening at airports, even though these measures were not evidence based (Bitar et al., 2009);
- the reintroduction of enforced quarantine and isolation practices to prevent transmission, raising ethical and legal questions around the balance between public health measures and individual rights, as well as questions about the effectiveness of such measures and challenges in implementing them at scale (Huang, 2004);
- a lack of availability of hospital negative pressure isolation rooms in countries at the start of the SARS epidemic, which are required to treat ill patients safely (Gamage et al., 2005).

Severe acute respiratory syndrome (SARS) demonstrated the need for systems for early detection and global information-sharing.

In its wake, the health-care and national economic systems of some countries were seriously disrupt-
ed. The dramatic reconfiguration of health systems in response to the epidemic, as well as the amplification of transmission in high-technology settings, caused significant disruption to normal service delivery (Wenzel and Edmond, 2003). Trade and tourism were also significantly affected, with the global cost to economies estimated to be in the region of EUR 38 billion (McKibbin and Lee, 2004). However, the basic strategy that eventually controlled SARS outbreaks worldwide was effective surveillance and containment.

### 3.11.2.2 Ebola

Ebola Virus Disease (EVD) is a severe haemorrhagic fever caused by viruses belonging to the genus Ebola-virus in the family Filoviridae (Gatherer, 2014). Bats are thought to be the hosts of Ebola viruses in nature, from which other wild animals such as chimpanzees and monkeys become infected (Reddy, 2015). Ebola is introduced into the human population through close contact with infected animals. It then spreads through human-to-human transmission via direct contact with the blood, secretions, organs or other bodily fluids of infected people (Feldmann and Geisbert, 2011).

Symptomatic patients experience a sudden onset of fever, muscle pain and chills accompanied by vomiting and diarrhoea, which in approximately one-fifth of cases is followed by haemorrhagic complications. In severe cases, multiple organ failure may lead to death (Hartman et al., 2010). Transmission can be interrupted through early diagnosis and the institution of effective public health measures, such as patient isolation and care, contact tracing and safe burial practices (Bausch et al., 2007).

Since 1976 when Ebola was first identified, more than 25 Ebola outbreaks have occurred in sub-Saharan Africa (Gostin et al., 2014). The recent West African Ebola epidemic (2013-16) in Guinea, Liberia, Nigeria, Senegal and Sierra Leone was the most widespread outbreak of EVD in history, resulting in 28 616 cases, of which 11 310 are reported to have resulted in death (CDC, 2016). Owing to the collapse in the ability to deliver other essential health care, a significant rise in mortality due to other, normally treatable, disease was also observed.

On 8 August 2014, the WHO declared the epidemic a ‘public health emergency of international concern’ (PHEIC) (WHO, 2014a). Despite an understanding of the control measures required to limit the spread of the outbreak, the initial response was slow, which allowed the epidemic to gain momentum. Reasons for the slow response included the wide geographical spread of cases, the weak local health infrastructure and poor laboratory capacity to diagnose infection, the lack of expertise in containing the epidemic and treating those infected (Bell, 2016), and the delay of political leaders in calling on international assistance early on for fear of creating panic and disrupting economic activity (Moon et al., 2015). Italy, the United Kingdom and Spain were the only European countries to have imported cases of Ebola linked to the West African outbreak (WHO, 2016a).

Lessons identified from the outbreak included:
- the need for stronger event-based surveillance systems in developing countries for early detection and response, to detect and stop infectious disease threats;
- the importance of engaging local communities in the response;
- the need for stronger international surge capacity and the mobilisation of rapid assistance when countries are overwhelmed by an outbreak;
- strengthening infection prevention and control in health-care settings.

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**FIGURE 3.51**

*Ebola*

Source: PHE EDAM
given their potential to become ‘amplification points’ for spread of EVD, placing health workers at significant risk (Bell, 2016; Gostin et al., 2014).

The epidemic also highlighted the need to fast-track the development of effective tests, vaccines and medicines. The final results of a trial have just been published, confirming the protective efficacy of an Ebola vaccine, which may prevent future Ebola outbreaks from having as devastating consequences (WHO, 2016b). A new WHO initiative, the blue print to accelerate Research and Development (R and D) for severe emerging diseases with no or insufficient control measures, has been established. Furthermore, the Coalition for Epidemic Preparedness Innovations has recently been established with an initial investment of EUR 431 million from the governments of Germany, Japan and Norway, and from the Bill and Melinda Gates Foundation and the Wellcome Trust in the United Kingdom. This alliance aims to finance and coordinate the development of new vaccines to prevent and contain infectious disease epidemics.

3.11.2.3 Zika

Zika is caused by a flavivirus, from the group of viruses that cause dengue, yellow fever, WNV and Japanese encephalitis. The main vectors of Zika are Aedes aegypti mosquitoes, which are common in dwellings and carry other viral infections. Zika virus was first recognised as a cause of human disease in 1953, but only usually produced a mild and self-limiting illness without lasting consequence (Macnabara, 1954). However, in December 2015, reports were emerging of an epidemic of microcephaly in Brazil (ECDC, 2015a).

![Distribution of Zika virus](image)

Source: WHO

**FIGURE 3.52**

Countries, territories and areas showing the distribution of Zika virus, 2013 - 2016
Microcephaly is a severe neurodevelopmental disorder caused by a failure of the brain to grow normally in the foetus, leading to an abnormally small head and impaired development (PAHO/WHO, 2015). The epidemic was confirmed to be caused by the Zika virus, which was new to Brazil (Campos et al., 2015). In addition to microcephaly, Zika causes a range of neurological and other congenital abnormalities in the developing foetus (WHO, 2016c), and severe neurological complications have also been observed in some adults and children, including Guillain-Barré Syndrome, which requires specialised intensive support (Oehler et al., 2014). Zika was declared a PHEIC under the International Health Regulations in February 2016 (WHO, 2016d).

The social consequences of the severe complications of Zika are formidable. The congenital abnormalities are a cause of fear and anxiety among women who are, or may become, pregnant. In some cultures, women who have children with abnormalities are isolated or stigmatised in their communities (WHO, 2016e). Family planning services may be weak, difficult to access or not culturally acceptable in some areas, and many countries do not allow abortion even for medical reasons, so the impact on affected women and their families, and the need for longer-term social provision and disability services, must be addressed (WHO, 2016f).

Zika requires urgent prevention investment and control measures, which will take time to fully develop.

Zika is now spreading in the Americas to several other countries in South America, Central America and North America, and imported cases have been recorded in Europe (ECDC, 2015a, 2015b, 2016; Hennessey et al., 2016). Although in November 2016, it no longer had the status of a PHEIC, questions remain unanswered on the best means of controlling the virus and its impacts. The disease is spread by mosquitoes, which are very difficult to control using conventional vector control methods (Yakob and Walker, 2016). This has required a major investment into accelerating novel vector control strategies, which will require years of intensive testing, evaluation and regulatory oversight (Daudens-Vaysse et al., 2016). Work is under way to speed up the development of vaccines, which will have to be safe for pregnant women and women of child-bearing age, effective with one dose, cheap and scalable to large volumes of production (Maurice, 2016).

Human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS) provides an example of the problems in managing a pandemic when early detection is poor.

HIV was first identified in 1983 and was definitively linked to AIDS patients in 1984 (Blattner et al., 1988). A reluctance to address the common transmission factors directly through effective social engagement may have impeded early efforts to limit the extension of the epidemic, which is now a pandemic. To date, approximately 75 million people have been infected with HIV and it is considered that 36 million people have died from HIV-related causes (WHO, 2016h). Despite the predominance of HIV/AIDS cases in sub-Saharan Africa, recent reports state that eight out of 12 countries in Eastern Europe and Central Asia have experienced increases in new cases of HIV infections (UNAIDS, 2016).
Even with extensive education programmes, the social, economic, political and environmental structural factors that increase susceptibility to HIV infection and undermine prevention and treatment efforts continue to pose challenges (Seeley et al., 2012).

HIV infection risks include men who have sex with men, unprotected sex outside a stable relationship and injecting drug use. Safe infection control practices are crucial to prevent transmission in health-care settings. Fear of stigmatisation and discrimination can prohibit access to health services (Mahajan et al., 2008). Women are also particularly vulnerable in cultures where they have little power over their sexual behaviour (Tsasis and Nirupama, 2008). Conditions correlated with safe behaviours include knowing an individual's HIV status, possessing skills for implementing safe sex, perceiving risk accurately and having peer support to build safer behaviours (Coates et al., 1988).

The economic impact of HIV is also significant. Although no definitive figures for Europe have been found, it is estimated that, on average, the epidemic causes a reduction in GDP of 2-4 percentage points across affected African countries (UNDESA, 2001). Annual HIV/AIDS mortality has reduced from 2.3 million in 2005 to 1.5 million in 2013 as a result of the introduction of highly active antiretroviral therapy (Granich et al., 2015). This effective treatment increases survival by up to 25 years following infection (Poorolajal et al., 2016). Global treatment coverage reached 46 % at the end of 2015. However, in Eastern Europe and Central Asia, only 21 % of those living with HIV are receiving treatment, owing to a lack of resources and political will (UNAIDS, 2016). Further work has been proposed by the United Nations General Assembly High-Level Meeting on Ending AIDS to terminate the AIDS epidemic by 2030. Intensified efforts are required to reach this target, including the strengthening of HIV therapy with pre-exposure prophylaxis, ensuring that people with HIV know their status, filling the treatment gap and reaching and protecting vulnerable groups such as women and children through an improved surveillance system (WHO, 2016i). Increased efforts should also be directed at strengthening human rights and combatting stigma and discrimination against people with HIV infection.

**FIGURE 3.53**

HIV virus
Source: PHE EDAM

3.11.3 The International Health Regulations and pandemic preparedness

Currently, there are two international mechanisms that have been created by the WHO to respond rapidly to international health emergencies: the Global Outbreak and Response Network (GOARN) and the International Health Regulations IHR (2005).

The Global Outbreak and Response Network GOARN has its secretariat in the WHO and is a worldwide partnership of agencies, institutions and networks, with expertise to support the response to epidemics wherever they may occur. Since 2000, it has co-
ordinated over 130 international public health operations (WHO, 2015).

The International Health Regulations (2005) is an international legal instrument which is key to the Sendai Framework for DRR and its implementation and provide a comprehensive framework of definitions, principles and responsibilities that are ‘designed to prevent the international spread of disease’ (WHO, 2005). The IHR set out State Party obligations to develop certain minimum core public health capacities in surveillance and response at the local and national levels. Within the European Union, the European Centre for Disease Prevention and Control (ECDC) is responsible for identifying, assessing and communicating current and emerging threats to human health posed by infectious diseases. WHO Europe and the ECDC work together to develop a single European reporting and response system, and the ECDC assists EU Member States in certain aspects of IHR implementation, via Decision 1082/2013/EU.

The IHR also specify procedures for the determination by the Director-General of a PHEIC and the issuance of corresponding temporary recommendations (WHO, 2005). In the case that a potential PHEIC is notified, the IHR sets out the procedure for the establishment of an Emergency Committee of relevant experts selected by the Director General that will provide views on whether the event constitutes a PHEIC (and when it ceases to be) and on recommendations to be given on health measures to prevent or reduce the international spread of disease and avoid unnecessary interference with international traffic (WHO, 2005). During a PHEIC or any other public health event, countries may require and request assistance with the management of the epidemic. However, the overall capacity to control and prevent the occurrence of epidemics or a pandemic is only as good as the weakest link in the chain and, similarly, the effectiveness of an international alert system will only be as good as its implementation.

The 2009 H1N1 flu virus pandemic marked the first use of the IHR 2005 to address a global public health emergency (Katz and Fischer, 2010). Although this pandemic saw significantly fewer fatalities than the 1918 ‘Spanish flu’ pandemic (Morens and Fauci, 2007), it still resulted in significant pressures on responding organisations (particularly health systems), coordinating governments and the public (Girard et al., 2009).

Pandemic influenza differs from the more routine epidemics of seasonal influenza that populations face on a regular basis in a number of ways:

• a pandemic is, by definition, a global epidemic, affecting all countries across the world at the same time (Cox et al., 2003);
• a pandemic can occur at any time of the year, unlike the more predictable seasonal epidemics (Lipsitch et al., 2009);
• most of the population will be susceptible to the pandemic influenza virus owing to the novelty of the virus compared with previous circulating strains, rather than the typical at-risk groups of those at extremes of age or with known clinical risk factors (Cox et al., 2003);
• a pandemic could occur in multiple waves (Ngyuen-Van-Tam and Penttinen, 2016).

Pandemic preparedness varies across states and is influenced by many underlying factors. These include the resources available to plan for and respond to something as unknowable as a pandemic, where limited resources are understandably targeted towards known immediate challenges such as childhood immunisations, HIV/AIDS or clean water (Nicoll et al., 2016; Oshitaniet al., 2008). Even if a country is developing robust pandemic preparedness arrangements, ad hoc or unexpected events can cause activity to be derailed, postponed or abandoned, such as an outbreak of another disease or a major natural disaster (Campigotto and Mubareka, 2015; CCDM, 2008).
Pandemic preparedness and response goes much wider than health-care systems. While the link with social care is easily recognised, maintaining the business continuity of other essential services (such as emergency services, schools, fuel, power, education, prisons, etc.) is necessary to mitigate any further unintended or unanticipated impacts on the health response. On account of the need for cross-sectoral involvement, and the potential broad disruption that a severe pandemic might generate, pandemic planning may be considered a model for large-scale disaster planning.

While all sectors of society are involved in pandemic preparedness and response, the national government is the natural leader for overall coordination and communication efforts. Public perceptions of the state can therefore influence the success of the response; during the 2009 H1N1 pandemic, health authorities were viewed as trustworthy in the United Kingdom, while in Spain, there was public speculation that the vaccine was driven by the economic interests of the pharmaceutical industry, which led to poor vaccine uptake (Henrich and Holmes, 2011; Prieto et al., 2012).

As in all disaster preparedness scenarios, there are a number of key essential elements that underpin robust pandemic planning (CCDM, 2008; Fineberg, 2014; WHO, 2009):

- having national, subnational and local strategic, tactical and operational plans;
- working across multi-agency partnerships, including the private and voluntary sector organisations;
- planning for a risk-based and flexible response;
- testing and exercising plans, and ensuring that staff are appropriately trained;
- using routine surveillance to ensure early warning of pandemic arrival in the country;
- ensuring that communication routes are effective for a range of audiences (including the public, health-care workers and politicians);
- providing access to effective and appropriate clinical counter measures;
- providing access to appropriate personal protective equipment for health-care workers;
- ensuring that essential services and business have considered their business continuity arrangements;
- planning for special groups and settings (such as the justice setting, migrants and persons in transit, and hard-to-reach populations);
- planning to cooperate with international partners, and how to manage any border issues;
- planning for recovery.

Responding to a severe influenza pandemic is potentially one of the biggest challenges for the health sector, as well as wider society. Even if a severe pandemic never occurs, all the planning and discussion around some of the potential issues can help to inform responses to other incidents.

### 3.11.4 Innovative approaches for early warning and surveillance

As advances in technology and communications have increased the opportunities for international travel and trade, both of which are recognised drivers of the emergence and re-emergence of human pathogens (Suk et al., 2008), so have they increased the opportunities for surveillance to enable the rapid detection and assessment of threats, and the sharing of intelligence across international borders. Key advances that have improved surveillance capacities include:

- increases in computing power and storage capacity, enabling the rapid analysis of large disease incidence datasets;
- developments in electronic communications systems and information standards enabling machine-to-machine data transfer and rapid sharing of information, nationally and internationally (Guglielmetti et al., 2005);
- internet-based search and retrieval applications that scan for media and other informal reports that might indicate the emergence of an infectious disease epidemic (Keller et al., 2009; Anema et al., 2016);
- Geographic Information Systems (GISs) that enable the analysis and display of information that can assist in identifying clusters or assessing environmental determinants of exposure (Freifeld et al., 2008).

Infectious disease modelling that integrates data on environmental variables with health and disease data may also help to anticipate future disease threats, thereby providing support tools for decision-makers (Suk et al., 2014; Semenza et al., 2013). The emergence of the field of digital epidemiology, which is the science of conducting epidemiological studies using data...
from digital tools and data sources from the internet such as social media, is already having an immediate impact on the operational activities of public health agencies worldwide (Salathe et al., 2012). There are, however, considerable challenges, such as filtering large volumes of unstructured data, and ethical issues around data-sharing and use (Brownstein et al., 2008).

Informal sources for event-based surveillance can provide very early signals of significant health events, sometimes before they are detected through official indicator-based channels.

An important innovation in the 2005 revision of the IHR was to change the focus of the regulations from one limited to specific diseases to one applicable to health risks, irrespective of their origin or source (WHO, 2005). This has a number of key benefits in terms of the early detection of epidemic threats, including not only the broadening of the scope of infections (and other potential causes of PHEICs) covered, but also removing a dependency on awaiting definitive (laboratory) confirmation of the aetiology of a detected case or incident of potential international concern before reporting. As a consequence, monitoring of the evolution of diseases and factors affecting their emergence and transmission can occur at an earlier stage than in the past.

### 3.11.5 Conclusions and key messages

Epidemics and pandemics are types of disasters that are capable of overwhelming health systems, disrupting communities and challenging political leadership, and that often have devastating societal, economic and psychological impacts. Infectious diseases can behave unpredictably and have a capacity to evolve and adapt to exploit population susceptibilities, thus posing a perpetual challenge in the context of DRR and DRM.

The recommendations below have been structured according to the pillars of the DRMKC, namely partnership, knowledge and innovation. The DRMKC has been developed in order to support the translation of complex scientific data and analyses into usable information, providing science-based advice for DRM policies, as well as timely and reliable scientific-based analyses for emergency preparedness and coordinated response activities.

#### Partnership

Multidisciplinary working is essential in order to reduce the impacts of epidemics and pandemics. Information-sharing between sectors (e.g. animal health, veterinary, transport, environmental health, food, water and sanitation) is key to preventing the spread of infection and assessing evolving risk through surveillance, particularly as many emerging infections are zoonoses and may first manifest in livestock. As infectious diseases do not respect borders, strong collaboration and coordination between national and international structures is fundamental to limiting morbidity, mortality and societal disruption. Comprehensive preparedness planning involving multi-agency partnerships can also make the transition from disaster to recovery more effective.

#### Knowledge

Control measures should be evidenced-based when possible, and preparedness plans should be clear, flexible and regularly tested in order to provide a timely, appropriate and effective response. Countries should also be supported to comply with the International Health Regulations which set out the core competencies that countries should have with respect to their national surveillance and response, and their obligation to report events that constitute a PHEIC.

#### Innovation

Syndromic surveillance and the use of innovative methods to collect event-based data, for example through the internet, may assist in the early detection of disease outbreaks. In the absence of existing effective treatment or preventive measures, investment is required into research to develop new preventive and/or therapeutic strategies; two recent examples of this are the WHO blueprint for accelerating Research and Development and the evaluation of an effective vaccine against Ebola, and the formation of the Coalition for Epidemic Preparedness Innovations.
Recommendations

A set of recommendations relating to the hazards has been identified and is based on the three pillars of the DRMKC:

**Partnership**

**Recommendation 1:** multidisciplinary working and information-sharing is essential to reduce the impacts of these hazards. Collaboration and partnerships are necessary both between institutions and disciplines, and need to occur at the local, national and international levels. For example, with respect to institutions and disciplines, improvements in the forecasts of storms will in part be driven by the interaction between fundamental atmosphere and ocean science with operational forecasting, so continued collaboration between forecasting centres and universities and research centres is of key importance. Between the local and national levels, a systematic approach across all sectors involving state, private, voluntary and community actors is required to understand the wider societal impacts of temperature extremes. In relation to international alerting and response, countries are now legally bound by the International Health Regulations to report on potential transboundary risks of hazards such as infectious diseases, allowing the determination (if required) of a PHEIC. This has led to the overarching implementation across government and all sectors of the Sendai framework.

**Knowledge**

**Recommendation 2:** it is recommended that an enhanced understanding of the origin, behaviour and evolution of these hazards to facilitate local, national and regional risk assessment is needed. This is consistent with priority one of the Sendai framework, which states: Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be leveraged for the purpose of pre-disaster risk assessment, for prevention and mitigation and for the development and implementation of appropriate preparedness and effective response to disasters. For instance, climate change is predicted to exacerbate the frequency and severity of droughts; therefore, observed and projected trends in drought hazard need to be understood and considered in management plans.

**Recommendation 3:** the generation of knowledge and evidence to address research gaps around risk will enable a shift towards a more pro-active approach as opposed to the prevailing reactive approach. The influence of different socioeconomic and cultural contexts on risk and response should also be studied. With respect to wildfires, although there is a vast knowledge of wildfire risk, information varies according to the scale at which risk is assessed.
and differs from local to regional or global scales. There is also a need to use standardised event documentation to enhance risk assessment where feasible.

**Recommendation 4**: EWSs often entail the collection, integration and analysis of different types of data, and so it is recommended to improve the interoperability of systems and exchange of data. Challenges to drought monitoring are the continuous availability of indicators covering the various hydro-meteorological components and their combined analysis into usable information for decision-making. In the context of storms, a greater understanding of how to interpret, use and communicate probabilistic forecasts is required.

**Recommendation 5**: preparedness plans should be clear, flexible and regularly tested in order to provide a timely, appropriate and effective response. Comprehensive preparedness planning involving multi-agency partnerships can also make the transition from disaster to recovery more effective. Managing temperature extremes can be approached from a number of perspectives, including using forecasting technology, the development of heat and cold plans, and urban design and town planning. The key essential elements that underpin robust epidemic and pandemic planning provide a useful example.

**Recommendation 6**: of critical importance is building knowledge on how to strengthen community resilience to hazards. For example, enhancing drought resilience in regions with high population vulnerability and low adaptive capacity should be reflected in relief aid programming, and knowledge of epidemics and pandemics should be used where possible to facilitate support and to implement population immunisation with relevant strains of vaccines.

**Innovation**

**Recommendation 7**: investment in research is needed in order for innovation to continue. For all the discussed hazards, new technologies are emerging that better assess their risk. Disasters can also act as a catalyst for innovation. The West African Ebola outbreak highlighted the need to fast-track the development of effective tests, vaccines and medicines. The final results of the targeted trial for the population at risk have just been published and confirm the protective efficacy of an Ebola vaccine, which may prevent future Ebola outbreaks from having such devastating consequences.

**Recommendation 8**: the internet revolution has significantly contributed to innovation; for example, syndromic surveillance to collect event-based data through social media, for instance, may assist in the early detection of disease outbreaks. The ability to draw on multiple sources of information from data networks, as encapsulated by the concept of ‘the internet of things’, also offers considerable potential for managing disaster risk related to temperature extremes.
3.7 Meteorological risk: extratropical storms, tropical cyclones


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3.8 Meteorological risk: extreme temperatures


3.9 Climatological risk: droughts


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