Table 4. **Factors relevant to hazards that may affect people's perception**[a]

Perceived as unimportant	*Perceived as serious*
Voluntary	Involuntary
Natural	Man-made
Familiar	Exotic
Not memorable	Memorable
Common	Dread
Chronic	Catastrophic
Controlled by individual	Controlled by others
Fair	Unfair
Morally irrelevant	Morally relevant
Detectable	Undetectable
Visible benefits	No visible benefits
Trusted source	Untrusted source

[a]Reproduced from reference *3* by permission of the authors

Hazard identification

General

Hazard identification determines the hazards that may affect people in a community. This third step in the vulnerability assessment process provides information for further analysis. Hazard identification is not straightforward — people may have quite different perceptions of what constitutes a significant hazard. For this reason seeking the views of a number of people in the community is essential.

A group technique for identifying hazards

Hazard identification should be undertaken by a group of people, such as a planning group, with expertise in the area of work and a commitment to the safety of that area One quick method to determine people's perceptions of the most serious hazards and avoid the pitfalls of "groupthink",[1] is the following

- Each person in the group should be asked to write down the 10 hazards (in the area being investigated) that most concern them, and be given a few minutes to do this
- When they have finished the first task, they should rank, in terms of "seriousness", the hazards they have listed as "high", "medium", and "low" (using their own definition of "seriousness").
- Each person should then say what he or she has written down (without the ranking) and answers should be recorded on a blackboard, whiteboard, or large sheet of paper. Duplications should not be recorded; if very similar hazards are mentioned, planning group members should refine what they mean. Suggestions must not be belittled, but recorded uncritically.
- When each person has contributed, a table similar to Table 5 should be drawn up.
- Group members should be asked about each hazard listed; the numbers of

[1] "Groupthink" is a phenomenon that can occur in highly cohesive groups — to minimize conflict, the members of the group concur and restrict their thinking to the norms of the group No one wishes to be seen as out of place This can limit the range of ideas and views that the group could otherwise generate

Table 5. **Hazard ranking**

	In terms of "seriousness"		
Hazard	*high*	*medium*	*low*
Hazard "a"	2	3	0
Hazard "b"	0	0	1
Hazard "c"	4	0	1
Hazard "d"	0	2	0

people who consider each hazard to be high, medium, or low in seriousness should be recorded.

The numbers recorded in the table indicate how people in the planning group feel about the hazards in the community and may reflect accurate knowledge on their part. The numbers certainly reflect the group's perception of which hazards are a problem. The numbers have no meaning outside the context of the planning group meeting and certainly should not be used for any other purposes

This technique has the following benefits.

- It allows everyone to have their say and avoids some of the problems of "groupthink". If everyone is allowed to contribute, the likelihood of developing a meaningful vulnerability assessment is greater.
- It encourages interaction between people who may not know each other and may encourage all group members to continue contributing.
- It prompts the members of the planning group to think analytically
- It demonstrates to all members of the group that people have divergent points of view concerning hazard and risk and will to some extent validate these different points of view.
- It increases members' commitment to the vulnerability assessment because they have had a chance to contribute

Other techniques for identifying hazards

Other techniques for identifying hazards include.

— researching the history of emergencies in the community, by consulting histories, newspapers, records, and older community members;
— inspecting the community for evidence of previous emergencies, existing hazards, and existing vulnerability,
— examining literature or interviewing people from similar communities;
— requesting information from provincial or national governments

Hazard description

General

Five basic characteristics can be used to describe most hazards·

— intensity (how big, fast, and powerful);
— frequency (the likelihood of a hazard causing an event of a given magnitude),

— extent (the area that a hazard may affect);
— time frame (warning time, duration, time of day, week, year);
— manageability (whether anything can be done about it).

For each hazard, these characteristics may mean different things. In a cyclone, for example, intensity might relate to wind speed, whereas in an earthquake, intensity relates to the number and strength of earth tremors. The example in the following section deals with flooding.

Description of a flood hazard

Flood intensity

Flood intensity may be described by height, class, depth, flow rate, and speed.

Height. Flood height is often described in relation to a fixed marker, such as a post with heights marked on it, often placed in an arbitrary position near the river. Thus, a river height of 4 metres at one point on the river may be a fairly normal height, whereas the same height at a different place will indicate that the river is in flood.

Class. Floods may also be described in terms of classes. Definitions will vary from country to country, but the following are typical:

- Minor flooding — flooding that causes inconveniences, such as the closure of minor roads and the submergence of low-level bridges.
- Moderate flooding — low-lying areas are inundated, requiring the removal of livestock and evacuation of some houses; main traffic bridges may also be submerged.
- Major flooding — extensive rural areas are flooded, with properties and towns isolated; large urban areas are also flooded.

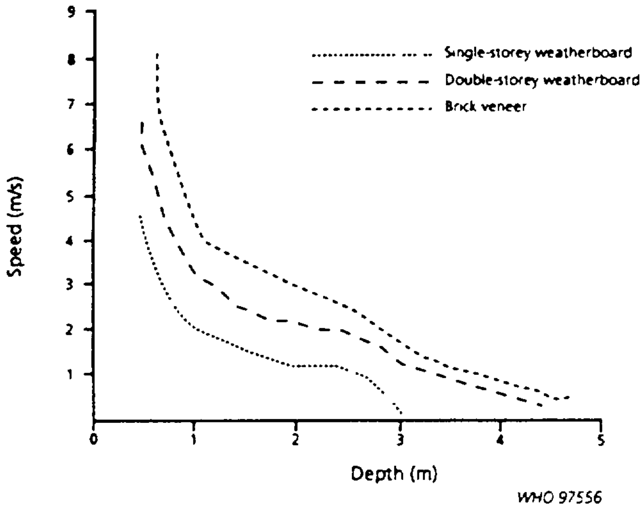
In flood warnings, both the heights and the flood classes are often given for different points on a river; local people who receive the warnings may use their prior experience of either description to decide how to act.

Depth Another way of describing the intensity of floods is to relate flood heights to the floor levels of buildings that may be affected. This gives an idea of depth and is very useful for planning evacuation, land use, and building protection

Flow rate. Flow rate describes the volume of water flowing past a particular point in a given time period, and the units are either cusecs (cubic feet per second) or cumecs (cubic metres per second), where 1 cusec = 0 028 cumecs, and 35 cusecs = 1 cumec. This method of description is often used in relation to dam safety, as a very high flow rate over a dam with insufficient spillway capacity may lead to dam failure.

Speed. Flood intensity may also be described in terms of the speed of the water at a given point. This is a useful measure since speed, coupled with water depth, will indicate the scale of damage of which the moving water is capable Figure 15 shows the speed and depth of flowing water that can cause failure to various building types.

Fig. 15. **Critical flood speed and depth for building failure**[a]



[a] Reproduced from reference *4* by permission of the publisher.

Table 6. **Flood frequency likelihood**

Definitions of average recurrence interval (ARI)	***Definitions of annual exceedance probability (AEP)***
(a) the average or expected value of the period between exceedances of a given discharge	(a) the probability of exceedance of a given discharge within a period of 1 year
(b) the expected time interval (usually in years) between floods of a given level	(b) the probability in any year that a flood of a given level will occur

Floods occurring in flat areas, where the water moves very slowly, are obviously less likely to cause structural damage.

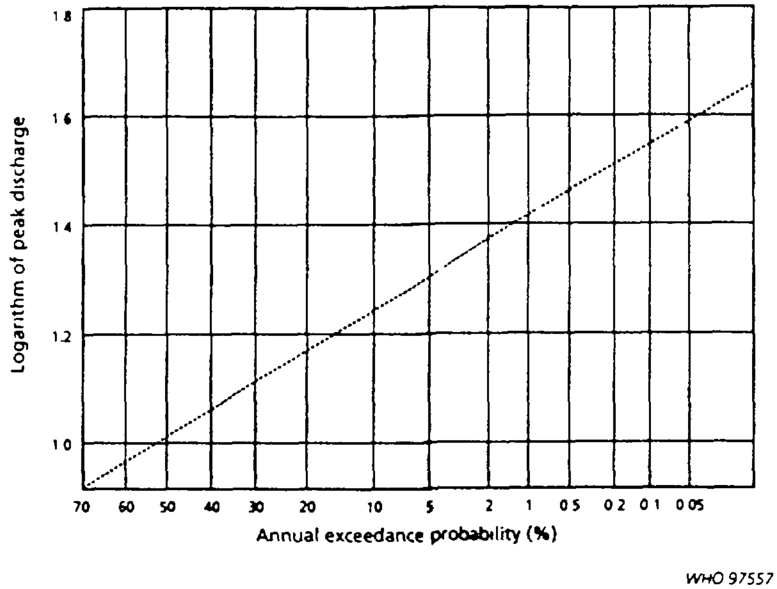
Describing the speed of floodwater also makes it easier to determine when and where rescue boats can be used — boats will not make headway against water that is moving at the normal speed of the boat or faster.

Flood frequency or likelihood

Flood frequency or likelihood is often described in terms of average recurrence interval (ARI) and annual exceedance probability (AEP). These two terms are defined in Table 6 in two ways (a) in strictly correct, engineering terms (*5*), and (b) less formally.

Annual exceedance probability is usually expressed in terms of "1 in 100", "1 in 50", etc. or of 1%, 2%, etc. chance of occurrence in any one year, and rivers may be described using a flood frequency curve, an example of which is shown in Fig. 16.

Fig. 16. **An example of a flood frequency curve**[a]



[a]Reproduced from reference 5 by permission of the publisher.

The horizontal axis of the graph shows the annual exceedance probability as a percentage, and the vertical axis shows the logarithm of the peak flood discharge (in cumecs). The diagonal line is the flood frequency curve, which indicates the estimated or expected probability of a given discharge for this particular river. Taking one point on the curve, the probability of a peak discharge of 10 cumecs (shown as 1.0, i.e. $\log_{10}10$; 100 cumecs would be shown as 2.0, i.e. $\log_{10}100$) is about 50%. The flood frequency curve is based on data from a number of floods over a period of years. It is usual, however, for actual recorded flows or discharges to cluster above and below this line.

The means for describing flood frequency thus includes an element of the description of intensity (in this case, discharge in cumecs).

Flood extent

The extent of a flood is best described using a map. Some flood maps may be used to describe the flood hazard for an entire country, or they may detail particular sections of rivers. The more detailed flood maps should ideally show the following information:

— one or more historical major flood levels;
— the flood levels for a variety of annual exceedance probabilities, typically 5% (1/20), 2% (1/50), and 1% (1/100);
— some of the roads and structures and details of land use in the area;
— flood levels that are considered to represent minor, moderate, and major floods;
— flow rates at particular points in the river for given flood levels.

A table showing the major historical flood events, attached to the flood map, would also provide essential information in describing flood extent.

Flood time-frame

The time-frame of flooding refers to.

- — how much warning time there is (the time-lag between detecting or predicting the flood and disseminating information about it);
- — how much lead time there is (the period between receipt of the warning and action being taken);
- — the time of year when floods are more likely to occur;
- — the length of time over which the flood will continue to cause damage and hamper response efforts.

Flood manageability

Flood manageability is a measure of the degree to which floods can be prevented, prepared for, responded to, and recovered from. This will vary enormously from river to river and from area to area

Conclusion

This description of flooding shows that some hazards can be described reasonably thoroughly. This is not true, however, of all hazards. When the characteristics of intensity, frequency, extent, time-frame, and manageability do not seem to fit a hazard or if they appear incomplete, analysis using an inappropriate model should not be attempted. If these characteristics do not suit the hazard, they should be removed, or new characteristics considered, as necessary. The descriptors used should be the most appropriate for the hazard.

Description of technological hazards

Technological hazards are caused by the processes and materials of life in an industrialized world. They include:

- — the transport of people and materials (by road, rail, air, or sea);
- — the use of heavy or fast-moving machinery;
- — the use of high pressure, high temperature, electricity, etc,
- — the manufacture, storage, use, and disposal of hazardous materials.

The reasons for performing industrial hazard analysis depend on the perspective of those involved, and are summarized in the following paragraphs

The community, including some members of the government, expects industry to be completely "safe" Attitudes towards the safety of industry tend to differ from attitudes towards safety in other activities, such as driving and sports, and are often unrealistic Often, certain industries are targeted, while other less safe ones are ignored. For example, the degree of concern about industries involved in radioactive-related activities may be disproportionate compared with concern about other types of industries

Industries are under increasing pressure from the community and government to minimize the risk of employee accidents and larger hazardous events that could affect the community. One measure that allows them to appear responsible is to perform hazard analysis.

Hazard analysis, coupled with comprehensive safety systems, has the potential to increase the viability of industry. Those industries that are aware of the principles of risk management may have differing degrees of concern about the risks involved in their activities, and may see sufficient benefit from the risks posed to allow them to continue at their current levels, or may consider the cost of reducing the risks to be too high. Industries that are unaware of the degree of risk involved in their activities or of the principles of risk management would probably resist any expenditure on hazard analysis or comprehensive safety systems.

A wide variation in the degree of safety of different types of industry, and in the interest that industrial management would have in performing hazard analysis, may therefore be expected.

Various government agencies may have the following involvement:

- ensuring that industry poses little threat to public safety from fire, explosion, or toxic emissions;
- ensuring that workers' safety is within acceptable limits, with regard largely to minor accidents and injury and chronic toxic effects;
- ensuring that public health is not affected adversely by chronic and acute toxic effects of industry;
- ensuring that damage to the environment (including people) in the form of dust, smoke, noise, odours, gas, and liquid pollutants is minimized;
- ensuring that land-use proposals (concerned with large areas rather than specific industries) involving hazardous industry zoning are appropriate;
- ensuring that emergency planning is appropriate for hazardous industry and surrounding areas.

Quantitative and qualitative hazard analysis

Technological hazards can be analysed and described either quantitatively or qualitatively.

Quantitative analysis (or "quantitative risk assessment") uses statistical, mathematical, and engineering concepts to arrive at the probability of a specific level of harm. For example, the probability of fatality caused by living within 500 metres of the industry may be described as 1×10^{-5} per year.

This form of analysis is useful for making decisions about the siting of hazardous industry, because it provides an estimate of the risk, which can be compared with risk criteria; this is called "risk assessment"). It requires the use of mathematical and statistical techniques, a knowledge of engineering, and familiarity with the particular type of industry. It is not necessary to perform a quantitative hazard analysis of an industry to develop emergency preparedness strategies for that industry and the surrounding community. However, those involved in emergency management should have some knowledge of quantitative hazard analysis if the scope and interpretation of such analyses are to be appropriate.

Qualitative analysis, using techniques such as those described in this chapter, will provide much useful information for emergency preparedness including:

- the types of hazard arising from the industrial activity;
- the nature of those hazards;
- the way in which those hazards may affect the community and the environment;
- the hazards that are the most serious, and should therefore be considered first and most urgently for emergency preparedness.

Because of the importance and widespread use of quantitative industrial hazard analysis, a general description of some of the methods is given below. An example of hazard description, using the qualitative hazard analysis techniques outlined earlier in this section, is also provided.

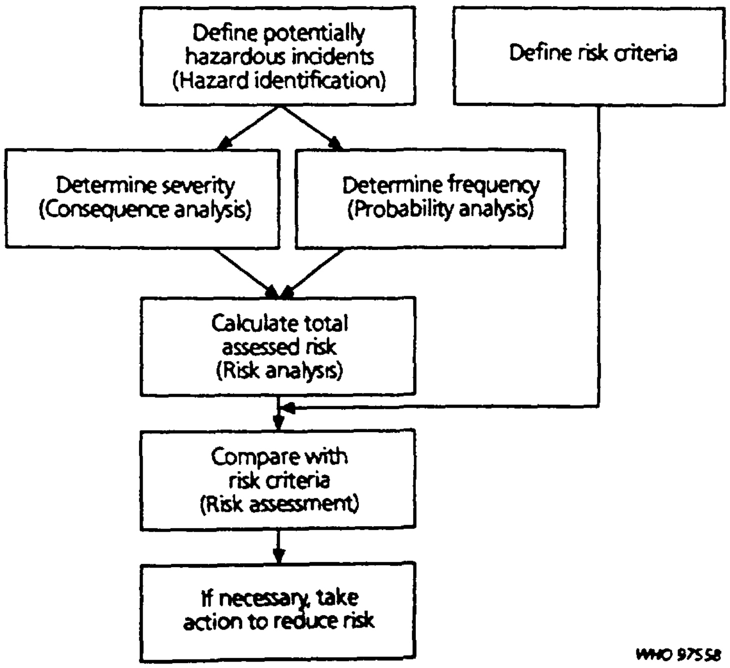
Quantitative industrial hazard analysis methods

Figure 17 shows a quantitative process often used in industrial hazard analysis.

Defining risk criteria

Risk criteria are defined for the industry's possible impact on workers and the community (*6, 7*). These criteria are the minimum acceptable risk levels, and may take five forms:

Fig. 17. A quantitative industrial hazard analysis process



- — individual fatality risk criteria;
- — individual injury risk criteria;
- — societal risk criteria;
- — risk of property damage and accident propagation criteria;
- — biophysical environment risk criteria.

Table 7 shows the individual fatality risk criteria and Table 8 the injury risk criteria accepted in many countries (*7*).

Societal risk criteria combine the probability of a hazardous event with the number of people killed. This takes into account the population density in the vicinity of a hazardous industry, and is otherwise known as an "F–N" curve, the cumulative frequency (F) of killing *n* or more people (N). No limits of acceptability for this criteria have been set in most countries and each case is judged by the individual risk levels and the population density.

Property damage and accident propagation criteria as well as injury risk criteria are based on heat radiation level and explosion overpressure. These criteria are intended to reduce risk to neighbouring structures and activities, particularly those of a hazardous nature, and to people, especially in residential areas. The criteria often used are shown in Table 9 (*7*).

The upper limit for heat radiation in industrial areas is that at which:

- — there is a possibility of fatality from instantaneous exposure;
- — there is spontaneous ignition of wood after long exposure;
- — unprotected steel will reach thermal stress temperatures that can cause failure;
- — pressure vessels need to be relieved to prevent failure.

The upper limit for explosion overpressure is that at which houses would be badly cracked and/or made uninhabitable.

Consideration should also be given to lower-risk events that might generate higher levels of heat radiation and explosion overpressure.

The biophysical environment risk criteria typically dictate that industrial developments should not be sited near sensitive natural environmental areas where:

Table 7. **Individual fatality risk criteria**

Land use or activity	*Individual fatality risk per year*
Hospitals, schools, child-care facilities, old-age housing	0.5×10^{-6}
Residential, hotels, motels, tourist resorts	1×10^{-6}
Commercial developments, including retail centres, offices, and entertainment centres	5×10^{-6}
Sporting complexes and recreation spaces	10×10^{-6}
Industrial	50×10^{-6}

Table 8. **Injury risk criteria**[a]

Cause of damage	*Land use*	*Level*	*Probability per year*
Heat radiation	Residential	4.7 kW/m^2	50×10^{-6}
Explosion overpressure	Residential	7 kPa	50×10^{-6}
Toxic concentrations	Residential	May cause serious injury	10×10^{-6}
		May cause irritation to eyes/throat, coughing, or other acute physiological responses	50×10^{-6}

[a] Reproduced from reference 7 by permission of NSW Department of Urban Affairs and Planning, Australia

Table 9. **Property damage and accident propagation criteria**

Cause of damage	*Land use*	*Level*	*Risk*
Heat radiation	Residential	4.7 kW/m^2	50×10^{-6}
	Industrial	23 kW/m^2	50×10^{-6}
Explosion overpressure	Residential	7 kPa	50×10^{-6}
	Industrial	14 kPa	50×10^{-6}

— the effects of the more likely accidental emissions may threaten the long-term viability of the ecosystem or of any species within it;
— the probability of impacts that may threaten the long-term viability of the ecosystem or of any species within it is not substantially lower than the background level of threat to the ecosystem (7).

Again, these criteria need to be interpreted rather freely and applied on a case-by-case basis.

Defining potentially hazardous incidents

The types of incident usually examined by hazard analysis include:

— fire (including flash fire);
— vapour cloud explosion (confined or unconfined);
— boiling liquid/expanding vapour explosion (BLEVE);
— dust explosion and other types of explosion;
— toxic gas escapes;
— toxic fumes from fires.

Hazards to the biophysical environment, however, have been largely ignored in many studies.

Techniques for hazard identification include:

— past experience (limited to common and known hazards);
— engineering codes and standards (incomplete and generally limited to minor hazards);

— company and historical records (limited by the completeness of databases and to known hazards);
— checklists (limited because they are closed sets and may stifle more rigorous techniques);
— hazard index methods (e.g. Dow Chemical Company Fire and Explosion Index; Mond Fire, Explosion and Toxicity Index; Instantaneous Fractional Annual Loss (IFAL) technique; these methods are also used to determine severity and techniques for loss control);
— failure modes and effects analysis (FMEA);
— hazard and operability study (HAZOP);
— event and fault tree analysis (also used in severity and probability analysis).

FMEA and HAZOP are the recommended analytical techniques (*8*) and are supplemented by the others. HAZOP is briefly described below.

Hazard and operability study. The HAZOP is a form of hazard identification. It involves the study of flow–piping and instrumentation diagrams, section by section, by a team of engineers and technicians who participate in the plant design and will be involved in its operation. The study evaluates deviations from the normal operation of the plant, their consequences, and the efficacy of control systems. The following list of keywords may be used in a HAZOP.

- high flow
- low flow
- high level
- low level
- zero flow, empty
- reverse flow
- high pressure (venting, relief rate)
- low pressure (venting, relief rate)
- high temperature
- low temperature
- impurities (gaseous, liquid, solid)
- change in composition, change in concentration, 2-phase flow, reactions
- testing (equipment, product)
- plant items (operable, maintainable)
- electrical (area classification, isolation, earthing)
- instruments (sufficient for control, too many, correct location)
- toxicity
- services required (air, nitrogen, water, etc.)
- materials of construction (vessels, pipelines, pumps)
- commissioning
- start-up
- shutdown (isolation, purging)
- breakdown (power, failure, air, steam, water, vacuum, fuel, vents, computer, other)
- effluent (gaseous, liquid, solid)
- noise (sources, is it a problem, control measures)
- fire/explosion
- safety equipment (personal, fire detection, fire fighting, means of escape)
- quality and consistency
- output (reliability and bottlenecks)
- efficiency/losses
- simplicity.

Not all keywords apply to a particular section of a process or industry. The keywords, tailored for chemical processes, are intended as a checklist, but also as prompts for investigating possible process deviations HAZOPs can be done only by those with sufficient experience and expertise to understand the plant processes thoroughly.

Determining severity

The method for determining the severity (assessing the effects) of an identified hazard depends on the type of incident, e.g. fire, vapour cloud explosion, BLEVE, dust, explosion, toxic gas escape, or toxic fumes from fires. The following is an example of a typical methodology for fires:

- Identify source, e.g. leak or spill of the product.
- Determine the nature of the fire, e g. a jet flame around a leak or a pool fire.
- Assess the heat of combustion and amount of heat radiated.
- Assess whether the flame is likely to impinge on critical structures or areas.
- Compare heat radiation with tables of effects.
- Determine the need for, and best means of, protection.

The amount of heat radiated may be determined using the *point source method* or *view factor method*. The result from either method is an intensity in kilowatts per square metre (kW/m^2), which can be compared with the effects for different radiant heat levels in Table 10. A more detailed description of the effect of heat radiation on the human body is given in Table 11.

Thus, injury to people, or fatality, is dependent not only on the level (intensity) of radiant heat (in kW/m^2) but also on the duration of exposure. A further factor is the variation of the effects of heat on different people. The sensitivity of individuals in any given population to a harmful effect varies, and can be described using a mathematical model (e.g. probit function).

Severity determination for each type of event has its own techniques, methodologies, and assumptions. The end result of the severity determination step will be an assessment of the degree of damage or harm (often including probability statements regarding the degree of harm) from each identified event.

Table 10. **Effects of heat radiation**

Heat radiation level (kW/m^2)	*Effect*
1.2	Equivalent to heat from summer sun at noon
1.6	Minimum level at which pain can be felt
5	Will cause pain in 15–20 seconds and at least second-degree burns after 30 seconds
6	Probability of person being able to take cover is 50%
12.5	Heats wood to temperature where pilot ignition (e.g. spark) will start fire
13	Probability of person being able to take cover is effectively zero
25	Spontaneous ignition of wood. Thin insulated steel sections can reach a temperature at which thermal stresses cause failure
75	100% fatality — 5 seconds

Table 11. **Effects of heat radiation on humans**[a]

Heat radiation level (kW/m^2)	*Approximate time (in seconds) to:*		
	pain	*1st-degree burns*	*2nd-degree burns*
1.6	150	—	—
3.1	22	—	—
4.7	14	20	30
6.3	9	14	22
9.4	5	8	14
12.6	4	5	8

[a] Reproduced from reference *9* by permission of the publisher.

Determining frequency

The determination of the frequency of events is based on the frequency of causes and is often described using "fault trees". If two causes are required to produce an event, the probability of the event occurring is the product of the probability of the causes. If two causes can produce the same event independently, the probability of each is added. Note that a cause of an event may itself have a cause. In order to attach a probability to any event, the fault trees must be traced back to causes with probabilities that are known or can be estimated. The more complex fault trees will often have the same cause for one or more events, and Boolean algebra is then needed to reduce the chains of cause and effect to an equation.

Data on the probability of occurrence of various events that cause hazardous incidents are highly comprehensive for some processes but non-existent for others. Many companies have databases of these events, which are generally confidential. Where data are not available, educated guesses are made.

Random number simulation analysis (RNSA), also known as the Monte Carlo method, uses a fault tree or similar logical model, but assigns probabilities as ranges, rather than as specific values; this gives more realistic results.

Once the probability of an event has been determined, the probabilities of the various consequences of the event should be determined. "Event trees" are the usual tool for determining the consequence probability. A common method using event trees is the technique for human error rate prediction (THERP), which concentrates on operator error in process control.

Calculating total assessed risk

Calculating the total assessed risk consists of two parts: combining the probability of an event occurring and the probability of its various possible consequences (e.g. an event may have a probability of x, and the probability of fatality of an individual at a given distance may be y — thus the risk of fatality would be the product xy); and combining all the various risks associated with a particular plant or industry, expressed as risk contours, societal risk curves, and total risk of harmful explosion overpressure at given points, etc. The calculations involved in estimating the total risk of a particular industry are normally sufficiently complex and lengthy to require a computer. Their results are expressed in the same terms as risk criteria.

Comparison with risk criteria

The risk analysis results are compared with the risk criteria (risk assessment) to determine the types of actions required to reduce risk.

Limitations and accuracy of quantitative hazard analysis

The outputs of quantitative hazard analysis suggest a degree of accuracy and reliability that they do not have. Furthermore, no two hazard analyses will yield the same answers for a given industry. The reasons for this are many, and include the following:

- *Quality of data on event probability.* The causal events for hazardous incidents are assigned probabilities, based either on experience or on educated guesswork. In either case, these events and their probabilities are central to the probability of occurrence of the hazardous incident, and any inaccuracy in causal event probability can greatly influence the end result.
- *Assumption and conservatism.* At many stages in the calculations and logical techniques used, assumptions must be made as to prevailing or expected conditions. To correct for error in these assumptions, most hazard analysts will be conservative in their estimates. The degree of conservatism will greatly affect the end result.
- *Compounding of errors.* Any error in assumptions or original probabilities of causal events will be compounded in further calculations. Because the calculations tend to contain many steps, each with a known or unknown degree of probable error, and the end results of the calculations are generally combined to give overall risk levels, the final degree of probable error can be very large. For example, a calculated risk of fatality at a given place relative to a hazardous industry can be in error by as much as one or two orders of magnitude (i.e. differ by a factor of 10 or 100).

Qualitative industrial hazard analysis methods

A qualitative analysis will identify hazards, and describe the hazards, the community, and likely effects on people, property, or the environment. Intensity, frequency/likelihood, extent, time-frame, and manageability might be used as hazard descriptors in the analysis.

Intensity

Typically, industrial hazard analysis deals with three intensity aspects of technological hazards: explosion overpressure, heat radiation, and toxicity.

Heat radiation has already been described (see page 49). Explosion overpressure is the blast of compressed air that emanates from an explosion and is expressed in kilopascals (kPa). Toxicity is much more difficult to quantify, as most data are based on estimates of the effects on humans or experimental animals. A number of indicators for toxicity are used, including immediate danger to life and health (IDLH), 50% lethal dose (LD_{50}), and 100% lethal dose (LD_{100}). Toxicity of a substance is also dependent on the effects of a given dose of toxic material on a given individual. This variable effect is often described using a probit function.

Frequency or likelihood

In a qualitative hazard analysis, the frequency or likelihood of an event is described in words such as "highly likely", "likely", "possible", "unlikely", etc. These words may be related to time periods, for example, "highly likely" may be defined as likely to occur once in any given year, where "unlikely" may be defined as once in a lifetime.

Extent

The likely extent of on industrial hazard analysis is a function of consequence and ((consequence × probability) and distance. It can be described in from the industrial site or the likely affected area.

Time-frame

Time-frame refers to:

- — the time of day, week, or year when an emergency is likely to occur;
- — the length of warning time;
- — the length of time for which the surrounding area may be hazardous;
- — the duration of the emergency operation and community recovery.

Manageability

The manageability of an industrial hazard for emergency preparedness purposes indicates what can be done about the hazard in terms of planning, training, and education, and carrying out drills. Regarding prevention, manageability of industrial hazards can be described in terms of the following types of controls, often [illegible]:

elimination (process of material);
- — replacement (process of material);
- — reduction (quantity of material, pressure, temperature, etc.);
- — engineering control (over process or material);
- — separation from people, property, or environment;
- — administrative control;
- — emergency procedures;
- — personal protection.

Other hazard descriptions

Further examples of ways of describing hazards are given in the tables on the modified Mercalli scale, Beaufort scale, tsunami scale, dangerous goods classes, etc. in Annex 2.

Hazard and risk mapping

Maps are among the best ways to present vulnerability assessment results. They provide a familiar spatial dimension, and the characteristics of a given hazard can be overlaid on other types of information, such as features of the environment and a community's relevant characteristics.

Table 12. **Types of map**

Map type	*Information shown*
Hazard map	Shows relevant hazard characteristics, including extent
Risk map	Similar to hazard map, but also shows probability of occurrence of a hazardous event
Vulnerability map	Shows distribution of the elements of the community that may be harmed or damaged

There is some confusion about the terminology associated with hazard maps, with different disciplines using different names for the various types of map. Table 12 shows some of the more common types and indicates the information that may be shown on them. The degree of complexity of these maps varies, as well as the degree of expertise and the time and resources needed to develop them.

The value and use of hazard, risk, and vulnerability maps may be influenced by a number of important factors such as scale (and detail), units of measurement, and sampling (of data). However, provided that these factors are taken into account, hazard mapping is a powerful tool in helping describe the nature of hazards.

Scale

The scale of a map is the proportion that the map bears to the geographical area shown. Small-scale maps show large areas with little detail, large-scale maps show smaller areas and greater detail Small-scale hazard maps that cover a large area, such as a province or country, are valuable for prioritizing areas that may need further analysis or are likely to require emergency planning. They are therefore useful for developing policy and for making decisions on emergency management resourcing. Large-scale hazard maps are of value for detailed emergency management work.

Units of measurement

The units of measurement used on a hazard map should be practical for emergency management purposes. For example, an earthquake hazard map can show the probability of either peak ground acceleration, which is the amount of ground movement, or intensity, in terms of the modified Mercalli scale.

The modified Mercalli scale is more useful for emergency management becauseit indicates what people's reactions might be and the types of damage that may occur. Moreover, given most people's perception of risk and understanding of technical terminology, it is better to express results in a more accessible manner. The modified Mercalli scale is more concrete, and therefore more readily understood. It is also more useful than the Richter scale, since the latter measures the seismic energy released by an earthquake, not the earthquake's effects.

This highlights a general principle of vulnerability assessment, as well as of hazard and risk mapping: the results of a vulnerability assessment should be expressed in terms that are of greatest value to emergency management, and those terms should be concrete and understandable.

Sampling

Sampling refers to both the number of areas from which data have been collected and the period of time over which the data were collected for a given area.

The accuracy of hazard maps is clearly dependent on the extent of the sampling (in terms of area and time span) on which they are based. For example, accurate and scientific earthquake data, particularly for low-intensity earthquakes, have only been gathered during the latter half of the 20th century (although it is possible to infer sources and intensities of earlier earthquakes from historical documents). Since earthquakes of a damaging intensity are relatively infrequent, the analysis of past events and probability predictions of future events should be treated with an appropriate degree of scepticism. That is, areas that are shown on these maps to have a low probability of earthquake may, in fact, have a medium to high probability.

Describing the community

Why describe the community?

The purpose of vulnerability assessment is to describe the interaction between hazards, the community, and the environment in order to develop programmes and strategies for protecting the community and the environment. Without knowledge of the community and environment, it is impossible to describe their vulnerability.

The characteristics shown in Table 13 are among those that can be used to describe a community.

Demography

Demography is the study of the statistics of human populations. Of the large quantities of data often available on the population of any given community, only

Table 13. **Some community characteristics**

Demography	*Culture*	*Economy*	*Infrastructure*	*Environment*
Population and age distribution Mobility Useful skills Hazard awareness Vulnerable groups Health level Education level Sex distribution	Traditions Ethnicity Social values Religion Attitudes to hazards Normal food types Eating habits Power structures	Trade Agriculture/livestock Investments Industries Wealth	Communication networks Transportation networks Essential services Community assets Government structures Resource base	Landforms Geology Waterways Climate Flora and fauna

some are relevant to emergency management. These concern the number of people in the area of study, their distribution across the area, and any concentrations of vulnerable groups. Such groups may be vulnerable because of age (young or old), mobility (availability of transport), or disabilities. However, most people — not just these easily defined groups — are vulnerable to emergencies to some extent.

The following indicators are important as regards the community's capacity for response and recovery:

- Health indicators, which determine how much resistance people can offer to the health effects of an emergency; for example:
  - — infant mortality rate indicates the health service coverage;
  - — vaccination coverage rate indicates the extent and effectiveness of preventive programmes;
  - — disease pattern indicates potential outbreaks of new disease or worsening of existing disease after an emergency,
  - — malnutrition rate indicates how quickly and for how long feeding programmes may be needed.
- Educational indicators, which determine how sophisticated the role of the community can be in participating in response activities and the level and type of public message that can be used; for example:
  - — literacy rate, which is important for assessing the level of community participation and response that can be planned for;
  - — female literacy rate, which is important for the success of health education and public preparedness.

The best way to obtain demographic data on a community is to contact the government organization responsible. Data may be available in printed form or as computer files.

Another aspect of vulnerability is the ability of the community to manage hazards. Those who have a realistic perception of the hazards around them and are aware of the measures necessary to manage those hazards are better able to cope with emergencies. Certain communities will have particular skills that are useful in emergency management. For example, a mining community would probably be better able to cope following storm damage or an earthquake than urban dwellers, owing to the available technical skills, and rural communities would be more resilient than urban communities because of their greater self-sufficiency in normal times.

Culture

A community's culture, including its traditions, ethnicity, and social values, is highly relevant to emergency management. Attitudes towards hazards and vulnerability will be strongly influenced by attitudes towards nature, technology, the causation of accidents and emergencies, and the value of mitigating or contingent actions. Some communities, for example, accept that lives will inevitably be lost in emergencies and may be unwilling to take preventive, preparatory, or response actions.

Economy

The economy of the community requires protection, and the more sensitive and vulnerable sections of the economy require careful consideration in emergency management. It is likely that an emergency that causes considerable structural and environmental damage would devastate the local tourism industry, for example. Investment may also suffer because potential or current investors would regard the risks in the area as too high. Industries and trade might also suffer if disruption to transport and communications were to restrict access to goods and markets. Thus, the wealth of a community may also determine its resilience or its likelihood of sustaining harm.

Infrastructure

The infrastructure (both physical and organizational) of a community is often highly vulnerable to hazards, particularly natural hazards. A vulnerability assessment should consider any possible damage to power generation and distribution systems, water supplies, communications systems, etc. These are often referred to as "lifelines", and relevant considerations include:

- effect of loss of services on the community;
- possible extent of the damage;
- alternative means of supplying the service;
- time required for repairs;
- cost of repairs.

is also important to have a basic description of the government structure, and vice and community organizations, since they will provide the mechanism for emergency management programmes and strategies.

Any other characteristics of a community that are relevant to emergency management should also be considered.

Environment

The environment is an important determinant of settlement patterns and lifestyles of communities; it can be defined as the natural surroundings, including plants and animals, water, air, and soil. Damage to any of these elements may affect other elements of the environment. Many hazards can adversely affect the environment, including chronic (continuous and low-level) or acute (sudden and high-level) pollution by hazardous materials.

Paradoxically, while the environment nurtures the community it can also be the source of some of the greatest natural hazards. Describing the environment in a vulnerability assessment will often identify some hazards that have not yet been considered.

Community and environment mapping

As with hazards, detailed information about a community can be documented effectively with maps. This is particularly true when the characteristics that describe the community vary systematically over a geographical area. The community information that can be mapped includes:

- Population density
- Particularly vulnerable groups — prisons, mental hospitals, orphanages, homes for the disabled, and new and unplanned settlements
- Potential emergency shelter sites
- Community preparedness focal points
- Emergency services — police, fire, ambulance, civil protection, and armed forces
- Residences of essential staff
- Proposed food distribution points
- Water and sanitation information
- Health centres
- Warehouses
- Utility networks and distribution points — electricity, gas, water
- Communication networks
- Essential businesses and factories
- Fuel storage points and distribution sources
- Transport systems and networks
- Road exit points from district
- Ongoing routine maintenance of roads and utilities

Description of effects and vulnerability

How are effects and vulnerability described?

The way in which vulnerability and the effects of hazards are described will depend on the scope of the vulnerability assessment. If a community is assessed, a standard set of parameters to describe the effects (e.g. extent and number of services disrupted, number of homeless persons) can be used. For a hospital, however, other parameters (e.g. effect of loss of service on the community, emergency medical demands on the hospital, effects on staff, and cost of and time required for repairs) would be useful. Table 14 shows some possible parameters for describing community vulnerability and the effects of hazards on a community.

These possible parameters should be discussed with the planning group and modified if necessary. Each hazard should then be examined in detail, parameter by parameter, to estimate the degree of loss in relation to each parameter in the community. The differential vulnerability of parts of the community in respect of these parameters can also be described, and the results of the entire examination should be documented immediately. The planning group should also realize that one emergency may provoke others. There is usually, in fact, a cascade effect, more and different emergencies following the original. These, too should be planned for. There are also specific needs that can be predicted for different types of emergencies (*12*). In addition:

- *Volcanic eruptions.* Possible needs (and secondary effects) are similar to those for earthquakes within the area directly affected by the eruption, there may be population displacements.
- *Tsunamis* (tidal waves caused by earthquakes). Possible needs are similar to those of tropical storms plus floods, with the added complication of contamination of wells and agricultural land by salt water.
- *Epidemics.* Needs usually include specific drugs, transport, surveillance, improvement of water supplies, personal hygiene and sanitation; reinforcement of health service management may also be required.

Table 14. Descriptive parameters for the potential effects of hazards[a]

		Losses	
Effects	***Measure***	***Tangible***	***Intangible***
Deaths	Number of people	Loss of economically active individuals, cost of retrieval and burial	Social and psychological effects on remaining community
Injuries	Number and injury severity	Medical treatment, temporary loss of economic activity by productive individuals, reduced ability of medical facilities in dealing with normal cases	Social and psychological pain and recovery
Social disruption	Number of displaced and homeless persons	Temporary housing, recovery work, economic production	Psychological, social contacts, cohesion, community morale
Disruption of normal services and infrastructure damage	Services disrupted, location, degree of damage, down-time	Inconvenience and harm to service users, replacement and repair costs	Concern over loss of services
Private property damage	Property type, degree of damage, and location	Replacement and repair costs	Cultural losses, decreased self-sufficiency
Disruption to economy	Number of working days lost, volume of production lost, amount of trade lost	Value of lost production	Opportunities, competitiveness, reputation, increased vulnerability
Environmental damage	Scale and severity	Clean-up costs, repair costs	Consequences of poorer environment, health risks, risk of future disaster, increased vulnerability

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