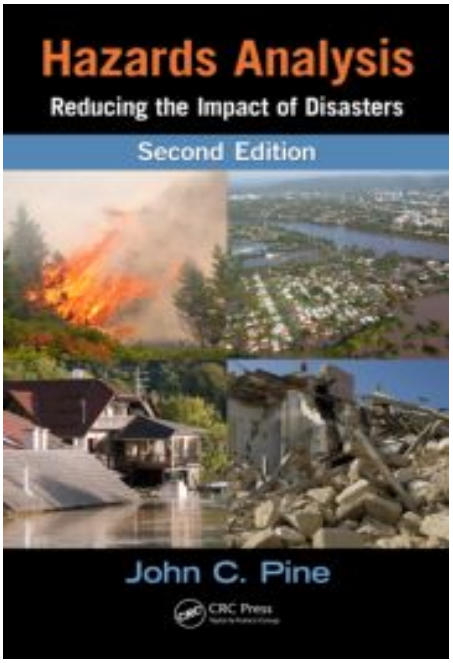
Chapter 5 Risk Analysis: Assessing the Risks of Hazards.

Kevin L. Shirley and John C. Pine



To cite this chapter:
Shirley, Kevin L. and Pine, John C. (2014). “Risk Analysis: Assessing the Risks of Hazards.” In *Hazards Analysis: Reducing the Impact of Disasters*. 2nd. Edition. CRC Press, Taylor Francis Group. Pages 113 – 154.

For additional information on this publication see:
http://www.crcpress.com/product/isbn/9781482228915

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

International Standard Book Number-13-978-1-4822-2891-5 (Hardback)

Taylor & Francis Web site at: http://www.taylorandfrancis.com

And the CRC Press Web site at: http://www.crcpress.com

CHAPTER 5

Title: RISK ANALYSIS: Assessing the Risks of Hazards

Kevin L. Shirley, Appalachian State University
John Pine, Appalachian State University

Objectives

1. Explain the process of Risk Analysis
2. Explain what is risk
3. Compare and contrast quantitative and qualitative approaches to risk analysis
4. Identify and discuss related to using historical data in determining risk
5. Explain the concept of uncertainty and how it impacts risk analysis
6. Discuss the concept of acceptable risk and how we determine it
7. Explain how we describe the likelihood and consequences of risks

Key Terms

Risk
Quantitative Analyses
Qualitative Analyses
Acceptable Risk
Voluntary risks Involuntary Risks
Flood Flow Frequency Flood Discharge Uncertainty
Vulnerability
Hazard Models
Logic Tree
Monte Carlo Method

Introduction

Risk analysis is the determination of the likelihood of a disaster and possible consequences. In order to begin this analysis, the hazards affecting a community must be identified. After identification, data is collected in order to prepare a community hazards profile that will characterize the nature and extent of these hazards. Finally, we do an analysis of the risks present. This analysis includes identifying community vulnerability indicators and the probability of the hazard occurring. From this information, we explore the likely impact of the hazards on the community. This exploration may include the use of hazard models and software such as GIS. This analysis should provide useful and accurate information for decision-makers working in risk management or responsible for community hazard mitigation initiatives. Our goal is to provide decision-makers with the right information, at the right level of complexity and detail at the right time.

The Process of Risk Analysis

We are all vulnerable to some hazard. A community may be vulnerable to natural hazards because it is located on a coastline and subject to hurricane winds or storm surge while another community located in the mountains may be vulnerable to fire and floods. Some organizations may be constrained in the location of their business. For example, a business may need to be located near a major transportation route. As a result, it may be necessary to locate their operation in a floodplain or near a coast. By utilizing risk analysis, the community or organization can make informed decisions about their exposure to the local hazards. The risk analysis process is used to assess this vulnerability.

The process of risk analysis examines the nature of the risk from a hazard, when and where it might occur, potential intensity, and the potential impact on people and property. The level of risk for a disaster of any scale is expressed as a likelihood of the occurrence or frequency times its consequences. Hence risk analysis must begin with hazard identification. With each hazard identified the probability or frequency of occurrence of the hazard event and the consequences if the event should occur is explored. The consequences could be loss of life, the socio-cultural impact, or economic, recovery, and environmental costs of a disaster. Once the analysis is completed, the results of the risk analysis can be used in the problem solving and decision-making process to adopt strategies to reduce organizational or community vulnerability.

In light of the inevitability of facing risk, individual families, organizations and communities must make conscious choices about what is an “acceptable risk.” Hazard reduction policies can be made with an understanding of what choices are possible and the consequences for any option. The level of risk may be very limited so that nothing needs to be done to address it. Other hazards may be more likely to occur and have the potential to cause extensive damage. The fact is that some organizations and communities may be willing to live with a specific risk or not willing to expend the resources necessary to reduce the adverse consequences that come with it (Waugh 2000). In order to assist in this decision making process, relevant analysis is conducted. This analysis might include mapping the hazard to determine the spatial distribution of risk, such as the risk associated with a gas or chemical leak. In the case of an area vulnerable to landslide, this analysis could include the collection of data on the frequency and intensity of past landslides and the local areas most vulnerable to future landslides. In many cases, especially when data is lacking or needs to be interpreted, judgments are made concerning specific risk factors (i.e., factors that may significantly increase or decrease the risk of disaster or the threat to life and property), and the vulnerability of the people and property within the risk area. The analysis stemming from the available data and expertise as well as the use of judgment are part of the hazards analysis process.

Risk managers consider the likelihood and consequence of all (identified) hazards faced by their jurisdiction, and they rank them according to priority. However, to understand the likelihood component of the risk analysis, one needs to understand probability. It is the probability of an occurrence that informs a risk manager whether or not they should expect a hazard to affect their community. Jardine and Hrudley suggest that a classical or frequency concept of probability be used and focus on discrete events which examine all possible outcomes and the numerical relationships among the chances of these outcomes (1997). In the real world, however, such complete information is seldom, if ever, available. Therefore, risk analyses must include subjective information along with detailed historical information.

What is Risk?

Risk is the product of likelihood or probability of a hazard occurring and the adverse consequences from the event and viewed by many as our exposure to hazards. Figure 5-1 provides a model for defining risk.

RISK= {LIKELIHOOD or PROBABILITY} X CONSEQUENCE

Figure 5-1: Defining Risk

This approach is based on the Royal Society Study Group (1992) defining risk as “the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge” (1992, p. 2). The Society provides a basis for an analysis of risks associated with hazards by measuring the likelihood and consequence of hazards in the community. How one perceives the adverse impacts of risk either from an individual, organizational or societal perspective certainly influences strategies to address the risk of natural hazards. Also, the process used in the analysis will help to shape the individual and institutional approaches in addressing risk. Although individuals, organizations and public policy positions may be viewed differently, an open analysis of hazards is constructive in preparing a sound hazard risk management policy and community hazard mitigation plans.

Risks may be viewed as voluntary where we agree to participate in activities that increase our chances of harm or injury including driving fast or participating in high risk sporting events. Other risks that we do not choose to participate in are classified as involuntary risks where we unknowingly or unwittingly are exposed to harm. For involuntary risks, one may be exposed simply because the nature of the risk has changed as in a potential for wild-land fire or a hazardous material spill. Some communities may not appreciate the actual risk from some hazards because they have adjusted to the threat presented by the hazard and not examined alternatives that would reduce their vulnerability.

The Royal Society Study Group acknowledges that risk management as a concept involves making decisions concerning risks and that this concerns both hazard identification and risk analysis. Our use of the term risk analysis fits within this context and reflects our determination to understand the likelihood of a hazard event and the consequences of the disaster on a community, region or for an organization (1992). This definition of risk analysis comprises the identification of the outcomes and estimations of the magnitude of the consequences and the probability of those outcomes. Finally, organizations use the outcomes of risk analysis to determine what is an acceptable level of risk and if anything can be done to reduce the adverse effects of the risk of a specific hazard. The determination of risk reduction measures at an organizational level is regarded as hazards risk management.

Quantitative Analysis of Risk

There are predominantly two categories of analysis: Quantitative Analyses and Qualitative Analyses. Quantitative analysis uses statistical measures to derive numerical references of risk. Qualitative analysis uses categorical variables in describing the likelihood and consequences of risk. Quantitative analysis uses specific measurable indicators (whether dollars, probability, frequency, or number of injuries/fatalities) while qualitative analysis uses qualifiers to represent a range of possibilities.

Quantitative Analysis of Likelihood

Quantitative analysis of the likelihood component of risk seeks to find the numerical statistical probability of the occurrence of a hazard causing a disaster. These analyses tend to be based upon historical data. A standard for the numerical measurement for this likelihood of occurrence must be established. One of the most commonly used quantitative measures of likelihood is the number of times a particular hazard causes a disaster per year. For example, a measure indicating the frequency of a hazard occurrence is 3 per year (3/year), would indicate an historical average of 3 hazard events occurring annually. Other time frames may also be used such as 1/decade or 10/week. An alternative technique for a quantitative measure of likelihood is to express the frequency per time frame as a probability that reflects the same data, but expresses the outcome as percentage between 0% and 100%. For example, a 100-year flood has a 1/100 chance of occurring in any given year, or expressed as a probability 1% or 0.01, while a hazard that occurs 1/decade has a 10% or 0.1 chance of occurring in a given year. We interpret these probabilities based upon how close they are to 0%, 50%, or 100%. For example, a 0% chance for occurrence indicates the hazard will not occur and a 100% chance for occurrence indicates the hazard is certain to occur in the specified time. The closer the percentage is to 100% the more likely it is to occur, while a 50% chance indicates the hazard is equally likely to occur as to not occur.

Quantitative Analysis of Consequence

As was true with the likelihood component of risk, the consequences of risk can also be described according to quantitative or qualitative reporting methods. The quantitative representation of consequence can be represented by the number of deaths or injuries or by estimating actual damages from various events. For example, the final death toll for Hurricane Katrina was 1,836 and caused $81 Billion in property damage (Zimmermann 2012). These quantitative measures are sometimes used to rank and compare disaster events, such as the deadliest or most expensive. Figure 5-3 (NOAA, NWS NHS 47) shows the deadliest hurricanes on record to hit the United States.

Hurricane	Year	Category	Deaths
Great Galveston Hurricane	1900	4	8000-12000
Okeechobee Hurricane	1928	4	2500-3000
Hurricane Katrina	2005	3	1500+
Louisiana Hurricane	1893	4	1100-1400
S. Carolina / Georgia	1893	3	1000-2000

Figure 5-2: Deadliest U.S. Hurricanes

Qualitative Analysis of Risk

Qualitative Analysis of Likelihood

Qualitative representation of likelihood uses words to describe the chance of an occurrence. Each word, or phrase, will have a designated range of possibilities attached to it as illustrated in the categories in Figure 5-3.

	Chance of occurring in a given year
Certain	>99%
Likely	50-99%
Possible	5-49%
Unlikely	2-5%
Rare	1-2%
Extremely rare	<1%

Figure 5-3: Qualitative Representation of Likelihood

Individuals determine the risk of a specific hazard by making a judgment among these alternatives. We base these judgments on many factors, which could include our recent experience, how hazards have affected others, information provided by the media and or community meetings that may have addressed potential hazards. We may also convert a calculated quantitative measure to a qualitative variable. For example, if it is calculated that there is a 1.5% chance of a wildfire in a specific area, then we would assign the categorical variable rare to this event according to Figure 5-3.

Qualitative Analysis of Consequence

As was true with the qualitative representation of likelihood, words or phrases that have associated meanings are used to describe the effects of a past disaster or the anticipated effects of a future one. These measurements can be assigned to deaths, injuries, or costs (oftentimes, the qualitative measurement of fatalities and injuries are combined). Figure 5-4 provides an illustration of the subjective ranges to help quantify the measurement indicator associated with injuries and fatalities.

	Injuries	Fatalities
Insignificant	none	none
Minor	small number first aid treatment required	none
Moderate	medical treatment required some hospitalization required	none
Major	extensive injuries significant fatalities	some
Catastrophic	large number of severe injuries*	some

*EMA, 2000

Figure 5-4: Qualitative Consequence Indicators

Critical Thinking: We attempt to understand risk using both quantitative and qualitative tools that allow us to examine hazards and their impacts using both the physical and social sciences. Not only is an understanding of risk shaped on an individual basis by the individual's familiarity with local hazards (Slovic 1991) but also from elements of local culture that includes how hazards have been viewed locally over time. For example, residents in the northeast seemed relatively unprepared when hurricane Sandy struck the northeastern states in 2012. However, just one year after Sandy struck 49% of the residents surveyed in New York and New Jersey believed that Sandy made them more urgent and thorough in their hurricane preparedness (Breslin 2013). For hazards that are possible in your area, what influences your view of risk?

Views of Risk

Rejeski (1993) notes that discussions of risk have included three primary groups including scientists who form their opinions through a rational process, policy makers who establish their perspectives based on multiple sources of information including quantitative and qualitative data, and finally the public whose perceptions and judgments of risk are formed from their own perspectives in some circumstances despite data provided by the other two major groups. He observes that environmental risks and risk are full of ambiguities that may not be resolved especially when interested groups have such different perspectives on the issues. He believes that a common view of risk can only be obtained when groups agree to share their perceptions and basis for their positions. He stresses that there is a great difference between uncertainty and ambiguity. For ambiguity, there are intrinsic elements of public policy that separate risk management strategies from the risk analysis process. One of the key elements in debates concerning risk and uncertainty is the relative level of trust that is established between the three groups, scientists, policy makers and the public. One possible option that may lead to a consensus is to encourage a more participatory process and open dialogue. Utilizing tools to visualize the data and scientific results concerning a hazard can provide a point of access into this meaningful discussion. As an example, GIS provides a tool for examining both hazards and risk. It can be used to visualize the nature and extent of a risk zone as shown in Figure 5-5. Three risk zones are displayed in this simulation of a hazardous spill release as well as an additional zone reflecting uncertainty. Unfortunately, this tool cannot solve the problem of disagreement but it may enable those interested in the risks of hazards with the means of building a consensus.

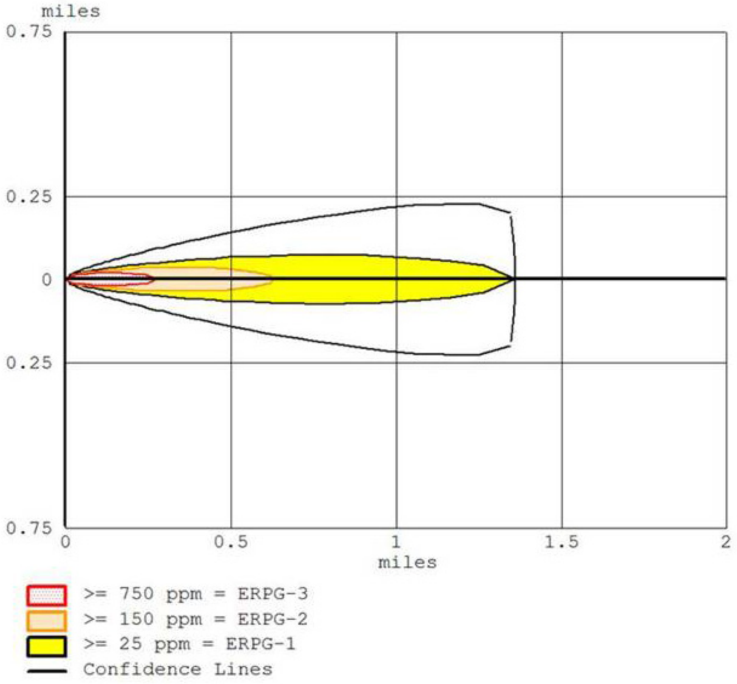


Figure 5-5: Hazard Risk Zones representing alternative exposure limit

To examine how hazard models and spatial analysis tools may address some issues, let's scrutinize the GIS example more closely. Figure 5-5 provides an estimate of an accidental release of Ammonia on a cool cloudy February day at 10 AM, the wind is assumed from the east at 10 MPH. The release is assumed to occur near a hospital when a 600-pound tank drops from a truck unloading a shipment of various cylinders. The model output provides three estimates of risk using alternative exposure limits of 25 ppm, 150 ppm, and 750 ppm. The model shows areas most vulnerable and provides an estimate of the exposure limits within these areas. This zoning helps to clarify the spatial uncertainty inherent in such a disaster. The goal then is to more fully understand the limitations of our hazard model and the data that is used in the spatial analysis indicating the area of vulnerability.

The three exposure limits for the scenario in Figure 5-5 were drawn from Emergency Response Planning Guidelines (ERPGs) which are used in the ALOHA chemical dispersion model to predict the area where a toxic gas concentration might be high enough to harm people. A committee of the American Industrial Hygiene Association developed three sets of exposure limits to toxic chemicals for use as planning guidelines and to anticipate human adverse health effects caused by exposure. The three-tiered guideline, Figure 5-6, uses a one-hour direct exposure duration. Each guideline identifies the substance, its chemical and structural properties, animal toxicology data, human experience, existing exposure guidelines, the rationale behind the selected value, and a list of references.

Understanding the limitations inherent in the model and guidelines described above is useful in their application. First, the categories in these guidelines do not protect everyone. Very sensitive individuals, including younger children and the elderly, might suffer adverse reactions to concentrations far below those suggested in the guidelines. Further, these exposure limits are primarily based on animal studies and not human studies. In addition, the exposure limits are based on a one hour time period and do not account for any personal safety measures that might be taken to reduce our exposure. The fact is that we might experience exposure for a period longer than one hour but seek shelter at the initial signal of the release, thus subjecting ourselves to less toxicity or harm than assumed in the guidelines.

Critical Thinking: The question that the scenario of the accidental ammonia release presents centers on our risk of harm for a specific exposure limit in a chemical release. The question of risk in this case is not simple and depends on many factors such as where we are in the risk zone (are we close or further away from the actual release), if we are inside a building or are exposed in the outside environment, our individual health and if we suffer from asthma or other breathing handicap, our age and physical size. How aware of potential risks in your area are you? If you see the sign in Figure 5-7 : NFPA Hazmat Diamond on the side of the building next to you, how would you interpret it? Who it is meant to inform?
See http://www.compliancesigns.com/nfpadiamonds.shtml

ERPG 1

The maximum airborne concentration below which it is believed that
nearly all individuals could be exposed for up to 1 hour
without experiencing other than
mild transient adverse health effects
or perceiving a clearly defined, objectionable odor.

ERPG 2

The maximum airborne concentration below which it is believed that
nearly all individuals could be exposed for up to 1 hour
without experiencing or developing
irreversible or other serious health effects
or symptoms which could impair an individual's ability to take protective action.

ERPG 3

The maximum airborne concentration below which it is believed that
nearly all individuals could be exposed for up to 1 hour
without experiencing or developing
life-threatening health effects.

Figure 5-6: Emergency Planning Guide Exposure Guidelines

Figure 5-7: NFPA HAZMAT Diamond

Using Historical Data in Determining Risk

Whether we are determining parameter values for a hazard model or just trying to get a fix on the vulnerability of a community to a specific hazard, risk experts turn to historical data to gain insight and understanding. Complete data is normally not available as methods and resources for collecting data have changed over time. However, even when it is known that a data set is accurate, care must be taken when it is used. For example, losses following a disaster are often measured in U.S. dollars. However, dollars in one country may have a different value than dollars in a different country making comparisons between the impacts of disasters in different countries problematic.

Over time, our ability and the methods used to collect information on disasters have changed. Scientific instruments are more sensitive and accurate than in the past. New technologies such as satellites provide opportunities for collecting data that previously did not exist. Indeed, our capacity to detect and accurately classify disasters since satellites have been in use means that the frequency data since the 1960's may be far more accurate than the frequency data sets of the early 20th Century. As an example, our ability to accurately detect and classify earthquakes or tropical cyclones today is far greater than ever before. Hence we have observed a dramatic increase in disaster frequency in many data sets over the past twenty years.

Numerous data sets reflecting the frequency of disasters and their consequences worldwide are now available. These data sets may come from governing bodies, such as the United Nations, or private companies such as Munich Reinsurance Company. The Centre for Research on the Epidemiology of Disasters (CRED) at the University of Louvain, Belgium maintains one of the largest datasets relating to disasters, Emergency Events Database (EM-DAT). The EM-DAT data covers both natural and human caused disasters since 1900. These data sets may be of value in establishing a benchmark for a specific type of hazard that in turn may be adjusted for the same hazard in a specific part of the world. For example, parameters established from landslide data taken from communities in central Europe may need to be adjusted to specific soil layers and building codes when applied to analyzing landslides in Africa. Weather related data obtained from domestic sources such as the National Weather Service or NOAA may provide a more accurate determination of specific risks of hazards in a specific part of the U.S.

Figure 5-8 shows centers for major natural hazard data sources. For the United States, the National Climatic Data Center (NCDC) serves as a national resource for climate information. As a climate resource, the NCDC works with scientists and researchers world-wide. They provide both national and global data sets for weather and climate information. In addition to the NDCD, the USGS Center for the Integration of Natural Disaster Information is a clearinghouse for disaster information and provides links to disaster data distributed by other agencies (Thomas 2001). The U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation (DOT) provide information on accidental releases of hazardous chemicals. The DOT focuses its data collection on transportation accidental releases while EPA focuses its attention on fixed site releases. Thomas (2001) notes that there has been some integration of hazard event data within a single agency such as the National Weather Service (NWS), although he acknowledges that "a true systematic integration of multiple types of hazard data currently does not exist (p. 64).

Hazard	Agency	Time Covered
Tornadoes	Storm Prediction Center Norman, IL	1959-present
Thunderstorm wind	Storm Prediction Center Norman, IL	1959-present
Hail	Storm Prediction Center Norman, IL	1959-present
Lightning	National Climatic Data Center Asheville, NC	1959-present
Storm data*	National Climatic Data Center Asheville, NC	1959-present
Hurricanes	National Hurricane Center Colorado State University	1886-1996
Floods	National Weather Service	1903-present
Earthquakes	Council of National Seismic Systems	1970-present
	National Geophysical Data Center	2150 b.c.-1994
	Earthquake Research Institute University of Tokyo, Japan	3000 b.c.-1994
Volcanoes	Global Volcanism Program Smithsonian Institution	8000 b.c.-present

*Meteorological events including wind, hail, lightning, water hazards, tornadoes, flooding, drought, landslides, hurricanes, wildfires and thunderstorms

Figure 5-8: Natural Hazard Data Sources with Time Covered

The Need for Complete Accurate Data for Decision Making

In order to reduce the adverse impacts of disasters, those involved in the hazards analysis process must have accurate and timely information to support effective decision making. Information that results from our hazard modeling exists to support this decision making process. Transparency with regard to the information normally promotes confidence in the information and those who provide it by the user. Showing transparency, includes revealing the sources of the data relied upon, any errors found in the data, data that the expert chose to omit and why, and whether the data was complete or incomplete.

Since the data is used as input to hazard models or to find parameter values used in these models, understanding its quality and accuracy is important. Inaccurate data or data with a large amount of measurement uncertainty will result in an inaccurate model result or a large amount of uncertainty in the model result. The saying among experts is “trash in, trash out.” Hence it is important for the end user, the decision makers in this case, to know how much they should rely upon the information given them. In the end, the information coming from this rather technical report or complex hazard model must fit into a framework established for dealing with the hazard. The data requirements for supporting the emergency management process will vary both for the type of hazard as well as how the outputs will be utilized in supporting decision making (Cutter 2001). For example, suppose a village is seeking to mitigate and manage the affects of frequent landslides that plague the region. Accurate elevation, soil and water flow data is needed to show high-risk areas, as well as identifying past landslide areas. Community leaders may use this data to write regulations indicating where building is prohibited and building codes for areas where it is allowed. Inaccurate data could lead to regulations that do not provide sufficient protection for businesses or families or possibly too much regulation that becomes an economic hardship for expansion.

Using Technical Data in Decision-Making

The description and categorization of hazard areas, critical infrastructure, and disaster zones is greatly facilitated by the use of geospatial technologies and hazard models. The use of scientific data from hazard models and risk analysis requires that decision makers fully understand the limitations of these tools and how to communicate information. An informed user of complex data is critical to minimizing legal challenges and law suits. Hazard models can provide different results with just small changes in data inputs. Clarifying the model sensitivity to the inputs and the limitations of the data used in the model will help to avoid challenges to the use of these models in emergency management.

Also, there may be a discrepancy between an objective assessment of risk by the hazards analysis team and the public (Kirkwood 1994). An objective view of risk by a knowledgeable professional who understands the nature and limitations of hazard modeling and how it is described, may not be shared by the public. An objective evaluation of risk must be non-judgmental and explained in a way that the public or other stakeholders can understand.

The discrepancy between risk analysts and the public in their view of risk has been changing for many hazards. For example, with satellite imagery, a storm can be tracked over long periods of time and distances providing ample warning to those in its path. The radar image of the storm and its motion through time provides a concrete way that experts can use to communicate the hazard information to the public. However, when hazards occur infrequently, such as in the case of volcanic eruptions, both experts and the public may be caught off its guard (USGS 2012). In 1982, the eruption of El Chichón in Chiapas Mexico became North America's most deadly volcano, killing 2,000 within a radius of 10 km. Its last eruption had been about 500 years earlier. Its peak appeared frosted and calm for dozens of generations. Even though there were seismic precursors, hazard analysis for volcanic eruptions was and is still in its infancy. According to Marzocchi and Woo (2009), since the 1982 eruption volcanic risk has been quantitatively defined but not effectively measured. Their paper proposes a framework for volcanic risk metrics (VRM) in an attempt to provide rules to local authorities for managing this risk. As challenging as it will be to develop effective volcanic eruption risk management measurements, communicating this risk to authorities and local inhabitants in the face of a peak that has been frosted for generations will be even more difficult.

Analysts and decision-makers can find ways to leverage the increased power in modern technology. As technology has increased and the speed and memory capacities of computers grown, information can be stored and accessed more easily than in the past. Systems supporting decision- making activities from technical data have evolved. Today, decision support systems (DSS) allow the software and the user to interact in a way to solve problems and make decisions with the warehoused technical data. Indeed, Wallace and Balogh (1985) stress the need for decision support systems (DSS) for using technical data. They stress a DSS must address the following:

- Provide support to decision makers and their stakeholders;
- Evolve as the users become more familiar with the technology;
- Be interactive and controllable;
- Recognize their non-routine, but consequential use; and
- Adapt to the idiosyncrasies that are inherent in human decision making.

Indicators of Direct and Indirect Losses

We measure the consequences of disasters using indicators of disaster impacts. They could include social disruption, economic disruption or environmental impacts. Social disruption measures include the number of people displaced or made homeless and incident rates of crime (murders, arrests for civil disorder, or fighting). Economic disruption measures include unemployment rates, days of work lost, production volume lost, and decrease in sales or tax income. Environmental impacts can be valued at total cleanup costs, costs of repair or restoration of water or sewerage systems, the number of days of unhealthy air, or the number of warnings involving fish consumption or restrictions on recreational use of a water feature. Direct tangible losses such as fatalities, injuries, cost of repair, loss of inventory, response costs by a business or community, or relocation costs are first order consequences that occur immediately after an event (Smith 2004). Indirect losses associated with a disaster evolve after the event and include loss of income by displaced employees, sales that did not occur, increased costs for skilled employees, losses in productivity of employees, employee sickness, increases in disruptive behavior (fights) at schools or crime in a neighborhood.

The indicators for social, economic or environmental impacts may be based on historical data and collection of data after a disaster event or modeling techniques. To estimate the impact on the population in a disaster zone using historical data, one would determine from past disasters the number of injuries, fatalities, displaced persons, and those requiring shelter or left unemployed. In order to measure the relative impact of the disaster, the population size and economic data need to be known before and after the event. For example, a rate comparing the number of injuries for the total population would provide a means of comparing injuries at different disaster events allowing for population changes over time.

Allowing for population changes over time does not account for other related changes that could impact injuries, fatalities and indicators for disaster impacts. Significant errors can result when projecting past disaster consequences forward based solely upon projected population changes. The impacts from more recent disaster events may reflect legal changes (code requirements or flood plain management programs), changes in development patterns, or cultural and social changes causing movement in populated areas.

The use of measurable indicators to help understand risks could be enhanced if all of the indicators used the same units of measure or the same reference points. An example would be to quantify deaths, injuries, and damages in a common measure such as U.S. dollars. Unfortunately, it may be impossible to associate a dollar amount to some indicators. The alternative is to use measurable indicators that may be compared over time. As an example, consider the indicators used when assessing population vulnerability to disasters. It is often the case that countries with high poverty levels show increased vulnerability to many natural hazards. This increased vulnerability can by attributed to lack of resources for planning and reduced government enforcement of codes and restrictions. The World Bank classifies each national economy by its gross national income (GNI) per capita, to reveal low income, middle income and high-income countries (ISDR Secretariat 2003). A more complex measure of population vulnerability is provided by the United Nations in its Human Development Index (HDI) that uses life expectancy, educational attainment and income as indicators of sustainability.

Intangible losses are those that cannot be expressed in universally accepted financial terms and are not generally included in damage assessments or predictions. Despite the difficulty in associating some intangible losses to specific indicators, we may want to identify some type of indicator that reflects the losses associated with cultural changes, individual and family stress, mental illness, sentimental value and environmental losses. We need to identify appropriate measures of both tangible and intangible losses associated with disasters. It is not uncommon for the intangible impacts to exceed the tangible ones in terms of the overall effect they have on a community (UNDP 2006).

As we examine potential losses from disasters, we may find that the community or business organization actually has gains. Though it is extremely rare for gains to be included in the assessment of past disasters or the prediction of future ones, it is undeniable that benefits can exist in the aftermath of disaster events. Gains could be observed in increases in employment, business volume, tax collections, or the number of residents, or decreases in the volume of traffic or crime rates. Post Hurricane Katrina data shows that many cities within a 100 mile distance of the City of New Orleans had positive gains from the displacement of the metropolitan New Orleans population. Although the impacts were temporary, some gains remained even years after the disaster.

Critical Thinking: How might you measure the intangible losses related to the impact of a disaster in an education system that has to accommodate an increase of 25% more students or increases in traffic in a community that absorbed 40% more residents who have been displaced?

Issues in Risk Analysis

Changes in Disaster Frequency

Changes in disaster frequency may be the natural result of climatic variations that occur over a long time intervals or from changes in factors that impact the frequency or severity of an environmental change such as an increase in human activity where the hazard already exists. The number of hurricanes that enter the Gulf of Mexico varies over a long period, especially with the rise or fall of sea surface temperatures or wind patterns from an El Niño. Flooding or hurricane storm surge might cause more physical damage because of increased development in coastal areas (Smith 2004). The trend in population shifts to high hazard coastal zones will likely result in higher losses from tropical cyclones. Environmental changes resulting in natural system degradation may also increase the severity of hazards. As infrastructure is added and more buildings are constructed, the potential for hazard impacts increases. With changes in technology, people expect to have access to a certain level of services, including availability of water, electricity, and easy long-distance transportation. As these systems expand and develop they become more vulnerable to hazards. Major blackouts, the spread of computer viruses, or communication of terrorist threats have occurred worldwide in the past and will likely occur in the future. The Interdependence of our societies globally contributes to our increasing vulnerability to epidemics and disease. This interdependence also increases our economic vulnerability. For example, when Greece defaulted on its government debt in 2012, there were major political and economic ramifications within and outside of the European Union. Natural resources such as oil, water, and air quality are increasingly being recognized as threatened from human activity. To understand these changes in disaster severity and frequency and its causes trends may need to be examined over longer periods of time than the current data reflect. Hence, the continued measurement and collection of data is needed to help risk experts understand the natural variation of specific hazards and the impacts they will have in an increasingly complex and interdependent society.

Availability of Essential Data

The availability of essential data for modeling hazards and determining the frequency of occurrence is critical in a valid risk analysis. This essential data comes from both historical data, as previously discussed, as well as measurements and data taken in real time. Examining the management of flood hazards illustrates how the availability of historical and real time data is used when attempting to understand the nature of the risk presented by a natural hazard.

The National Flood Insurance Program (NFIP) was established in 1968 and made affordable flood insurance rates to individuals through participating local communities such as towns, cities, counties or parishes. In 1983 a common standard for risk assessment and management of flood hazards was adopted by federal agencies and known as the 100 year event or one percent annual chance of flood as the standard for floodplain management. This standard was considered to represent a degree of risk and damage worth protecting against, but was not considered to impose excessive burdens or cost to property owners. The 100‐year event standard represents a compromise between minor floods and the greatest flood likely to occur in a given area. In many cases the 100‐year flood level is less than the highest recorded flood.

As part of its role in floodplain management, this 1‐percent annual chance of flood is used to determine the need for flood insurance. Further, the development of flood models and flood maps was considered by the NFIP as a primary means of reducing flood hazards. The flood maps would provide a basis for managing the development and use of flood prone areas and lead to a better understanding of the magnitude and likelihood of large flows. As federal agencies enhanced their efforts to assist in flood mapping for communities joining the NFIP, information on water feature flow frequencies grew in importance. In 2002, The U.S. Water Resources Council published a report describing flood regionalization techniques used in the National Flood Frequency Program (NFF), (Ries and Crouse 2002; Benson 1967). These techniques were adopted by USWRC for use in all Federal planning involving water and related land resources.

All flood modeling programs that are used to create flood maps for local communities need a discharge value for a water feature, such as a stream, canal, lake, or reservoir. The discharge value is determined by measuring flow rates directly by the USGS through a river gage or indirectly by statistical methods. A USGS River Gage Station measures a water feature's discharge at particular site. Figure 5-9 shows the locations of the gage stations. For these stations, data is collected on a real‐time basis by automated instrumentation and analyzed quickly enough to influence a decision that affects the monitored system. The discharge measured at the gaged sites characterizes the volume of water passing a point of the river gage station and is commonly expressed in a hydrologic unit per unit of time, such as cubic feet per second, million gallons per day, gallons per minute, or seconds per minute per day.

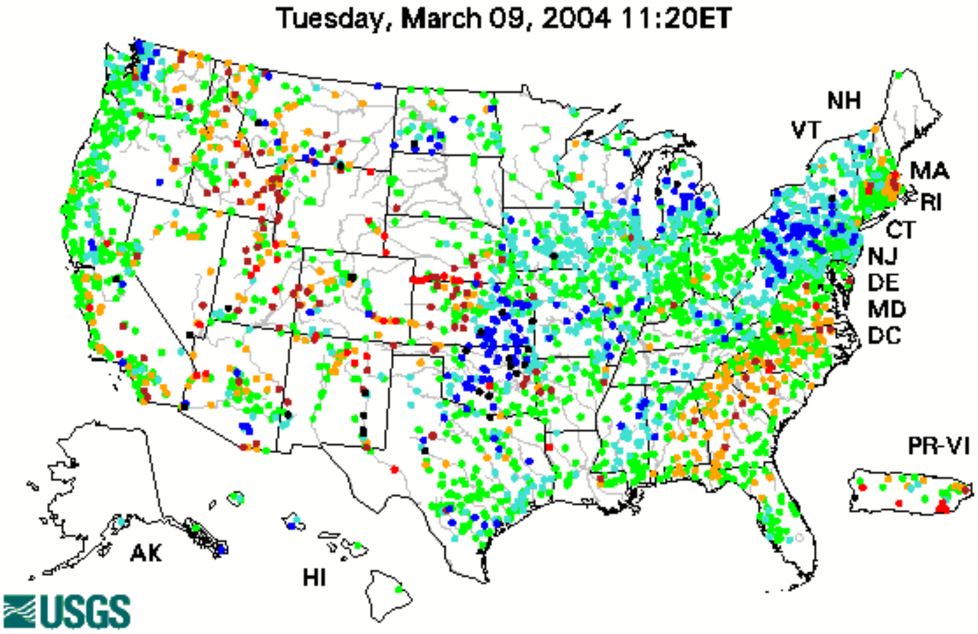


Figure 5-9: USGS River Gauges in the U.S.

Go to http://water.usgs.gov/waterwatch to review active state stations

The table or graphical representation of the discharge data over a specific time period is called a hydrograph. It provides real time and historical values. Figure 5-10: USGS Hydrograph for a water feature provides an example of a hydrograph at a site that has a USGS river gage. For examples of real time hydrographs see the following USGS Internet site: http://cfpub.epa.gov/surf/locate/index.cfm. For ungaged areas, the NFF program produces estimates of the magnitude and frequency of flood-peak discharges as well as the corresponding flood runoff hydrographs. The estimates for ungaged areas are based upon statistical methods using regression equations. The estimates are used in flood-plain management, flood-control and the design of different structures used in these areas. (Ries and Crouse 2002)

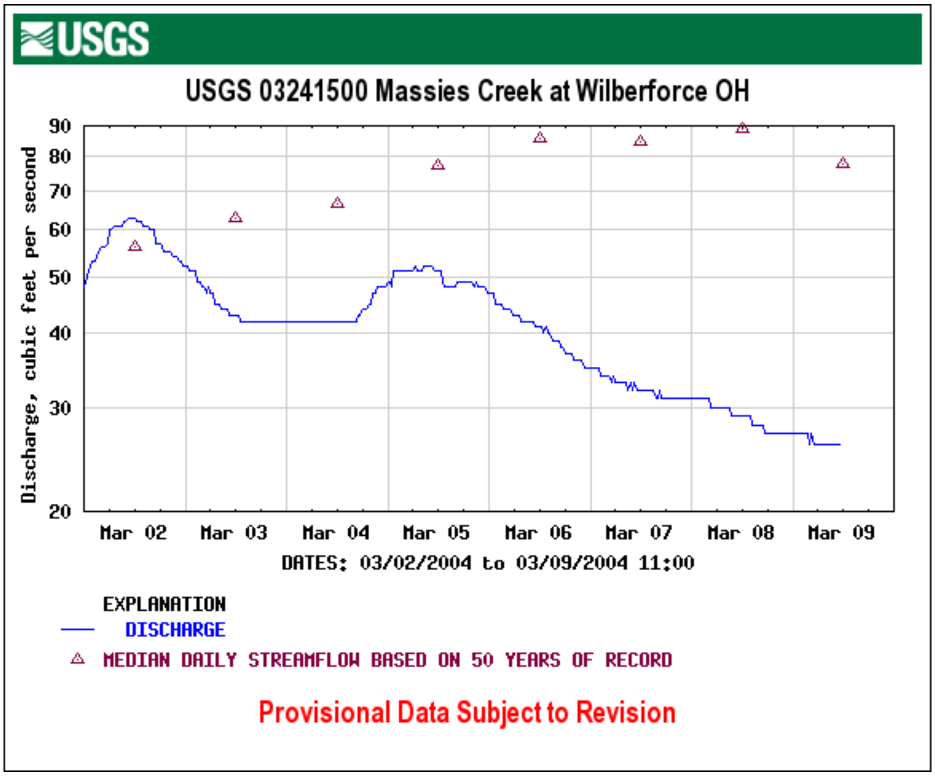


Figure 5-10: USGS Hydrograph for a water feature.

Depth of Analysis

Each hazard that is analyzed must be considered according to the range of possible intensities that could be exhibited by the particular hazard. Depending on the hazard, we may need to examine it based on its intensity since the frequency of occurrence is so rare.

We generally see that lower intensity hazard events occur more often than more severe ones as in the case of a hurricane or an earthquake. More hazard events provide more data that can be broken down into more classes. This increased granularity allows for a more comprehensive assessment. We can thus determine a broad based frequency by calculating the likelihood of each identified hazard broken down by magnitude or intensity, if appropriate. Likewise, the consequences that are expected to occur for each hazard can be calculated and broken down by magnitude or intensity if appropriate. Finally, a locally tailored qualitative system for each hazard identified as threatening to the community can be produced. The qualitative measures may be determined from the quantitative calculations as described above or at least should reflect them.

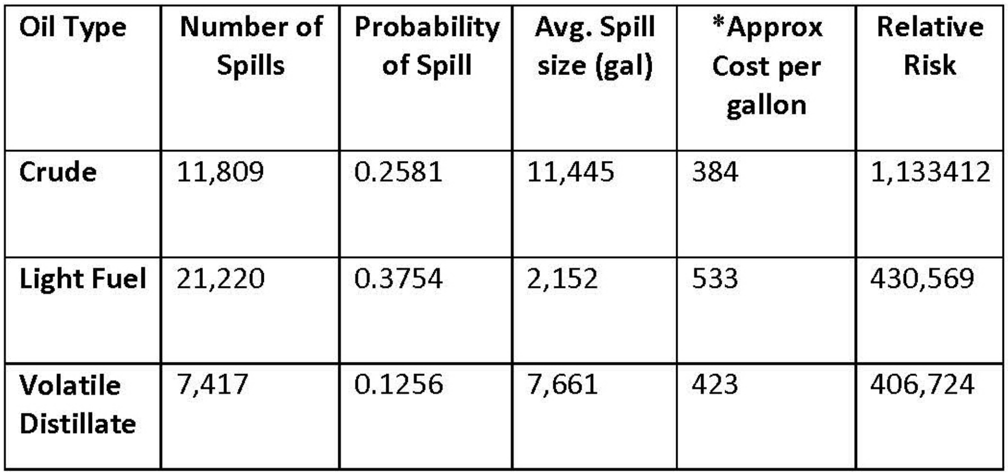
In calculating the consequences as described above, damage resulting from past major disaster events may form the basis for examining the impacts of future disasters. The massive floods of 1993 or hurricanes such as Andrew (1992) or Katrina (2005) could provide a basis for estimating damages in similar future floods or storms. However, estimates must be adjusted for local characteristics. For example, levy failure caused much of the flooding in New Orleans due to Katrina. Hence, with improved levy conditions and changes made in the location of future structures, the damage estimates from past data would need to be adjusted to reflect these changes for future estimates. Also, estimates for the cost of damages from future landslides in one region may differ greatly from a similar site in a different region due to the specific location of local structures relative to the landslide risk, local building code differences, and differences in local planning. Note that inflation factors may need to be used to help us project damages from one time period to another.

For major weather related events, granularity in the data may be difficult to achieve for small regions. The bulk of the data may be available for large areas rather than smaller ones. Unfortunately for most hazards, sufficient information does not exist to accurately quantify the likelihood of a future occurrence of the disaster to a high degree of confidence. This is especially true for those occurring infrequently or those occurring in no apparent pattern such as earthquakes, droughts, terrorism, or nuclear accidents.

Ranking of Risks

Quantitative Data

For quantitative data, the relative ranking of risk can be obtained by numerical calculation. We have seen that certain risks may be quantified by the numerical formula $Probability \times Consequence$. Hence, for a list of local hazards that are quantifiable numerically, their relative risks can be ranked and compared. The EPA uses this type of relative ranking of risk in their assessment of the inland waterways oil spill hazard. In (Etkin 2006), this risk is assessed in aggregate and relative to oil type, EPA region, and transportation mode. For example, consider the assessment of risk of inland waterways spills by oil type as shown in Figure 5-11. Etkin provides the following data summary:



Oil Type	Number of Spills	Probability of Spill	Avg. Spill size (gal)	*Approx Cost per gallon	Relative Risk
Crude	11,809	0.2581	11,445	384	1,133412
Light Fuel	21,220	0.3754	2,152	533	430,569
Volatile Distillate	7,417	0.1256	7,661	423	406,724

Figure 5-11: Risk of inland waterway oil spills by oil type

From this assessment it is clear that the greatest risk across oil types and EPA regions is from crude oil. Crude oil spills cost less per gallon, but the relative average size of the spills are large. Even though there are many more light fuel spills and their average cost per gallon is higher, the spill volume is about five times less than the average crude oil spill volume, lessening the overall measure of consequence for light fuel spills relative to crude oil spills. Hence, in using this analysis one may be led to focus on reducing the number and size of crude oil spills to reduce the overall risk. However, Etkin also performs a trend analysis that shows that the proportion of oil spills that are light fuel spills are increasing sharply relative to other types of oil spills. This indicates the need to also focus on reducing the number of light oil spills to mitigate future overall risk increases.

Likelihood - Consequence Matrix

Risk evaluation involves the determination of the relative seriousness of the risk of a hazard as they could affect an organization or a local community. Organizations and communities face a range of natural and technological hazards, each of which requires a different strategy to reduce the risk factors of likelihood or consequence. To facilitate the relative ranking of risks organizations should determine if a risk may be addressed by another agency; identify which risks require immediate attention; and clarify if the risk associated with a hazard requires further evaluation (Cameron 2002).

We can determine the relative ranking of risks associated with hazards facing our organization or community by considering the following factors:

- The likelihood and consequences of the hazard;
- The voluntary or involuntary nature of the risk (Smith 2004);
- Is there a benefit to cost ratios of mitigating different risks;
- Are there political and social ramifications of certain mitigation decisions.

The final output of risk evaluation is a prioritized list of risks, which will be used to decide treatment (mitigation) options.

In assessing risk, the first step is to identify the hazards of interest. We next assess the hazard for its level of likelihood and the impact or intensity of its consequence. We use quantitative values when possible. However, in order to apply the risk assessment matrix method for ranking risks, the likelihood and consequence variables must be categorical. Hence hazards that are known to exhibit a numerical range of likelihood and intensity values are assigned categorical values across the range of possibilities. Assigning these levels to likelihood and consequence allows for a direct comparison of the risks faced by a community.

It is common to use four or five categorical values for the probability of occurrence. A summary of five values and their description as given in the Army ROTC risk management worksheet is shown below (Army ROTC). In these descriptions, it is assumed that a time horizon is specified. The parenthetical values shown are also used.

Frequent – occurs often, continuously experienced;
Likely – Occurs several times;
Occasional (possible) – occurs sporadically;
Seldom (rare) – unlikely, but could occur at some time.
Unlikely – can assume it will not occur.

Values are also assigned to the severity describing the expected consequence of the event in terms of degree of injury, property damage or other impairments to the organization or community doing the assessment. The summary below uses the terms as specified in the Army ROTC worksheet with alternative values defined earlier for injury and death shown parenthetically.

Catastrophic – death or permanent and total disability, complete system loss, major damage or significant property damage, mission (organization) failure (or complete community disruption);

Critical (major) – permanent partial disability, temporary disability in excess of 3 months, major system damage or significant property damage, significant mission (organization or community) disruption;

Marginal (moderate) – Minor injuries, lost workday accident, minor system damage, minor property damage, some mission (organization or community) disruption;

Negligible (minor) – first aid or minor medical treatment, minor system impairment, little or no impact to the mission accomplishment (organization or community).

As seen in Figure 5-11, once the values have been assigned for the identified hazards, we can then summarize the likelihood and consequence for the risks associated with each hazard in the first column using the risk description category.

Hazard	Likelihood	Consequence	Risk
Flood	possible	major	extreme
Drought	likely	minor	low
Extreme heat	possible	moderate	high
Extreme cold	possible	moderate	high
Thunderstorm/lightning	almost certain	minor	high
Tornadoes	likely	major	extreme
Severe snowstorms	likely	moderate	high
Ice storms	unlikely	major	high
Land subsidence	rare	minor	low
Earthquake	rare	major	high
Transportation accidents	possible	catastrophic	extreme
Hazmat transportation accidents	unlikely	moderate	moderate
Closure of critical transportation routes	unlikely	moderate	moderate
Power failures	possible	moderate	high
Water/sewer line failure	unlikely	moderate	moderate
Telecommunications failure	unlikely	minor	low
Computer systems failure	possible	minor	moderate
Gas line break	unlikely	minor	low
Stored chemical leak/accident	unlikely	moderate	moderate
Sabotage/intentional destruction	possible	major	extreme
Biological communicable disease (plague)	possible	major	high
Laboratory accidents	possible	major	extreme
Building collapse	rare	catastrophic	high
Building fire	unlikely	catastrophic	extreme
Epidemic	unlikely	major	high
Widespread poisoning	unlikely	major	high
Water/air contamination	rare	major	high
Contaminated medical facilities	possible	major	extreme
Terrorism	unlikely	major	high
Terrorism-federal and international property-destruction	possible	major	extreme
Protest	possible	minor	moderate
Riots	possible	moderate	high
Strikes	possible	minor	moderate
Crime	almost certain	moderate	extreme
War	rare	major	high

Figure 5-12: Likelihood Consequence Matrix

Pine, J.C. (2014). *Hazards Analysis: Reducing the Impact of Disasters.* Taylor Francis Publishers.

To compare hazards, the values in the fourth column can be determined through the use of a risk matrix. A risk matrix plots the likelihood and consequence of hazards together in various combinations, with one risk component falling on the X--axis and the other on the Y--axis, similar to how a multiplication table is laid out. By plotting these values on the matrix, individual boxes representing unique combinations of likelihood and consequence can be determined. Each hazard listed in the likelihood-consequence matrix can then be placed in the box of the risk matrix that best reflects its risk.

Figure 5--13 provides a risk matrix for assessing the likelihood and consequences of risks presented by natural hazards. The labeling of the boxes with the risk categories, extreme, high, moderate, and low may vary with the organization. In Figure 5-13 the classifications as defined by the Emergency Management Australia (EMA) are used. The cells down and just above the diagonal are labeled high risk with the cells just below the diagonal labeled moderate risk. The cells in the upper right-hand corner with high likelihood and catastrophic severity are labeled extreme risk and the cells in the lower left-hand corner of the matrix are labeled low risk. The risk categories are then assigned risk mitigation priorities as shown.

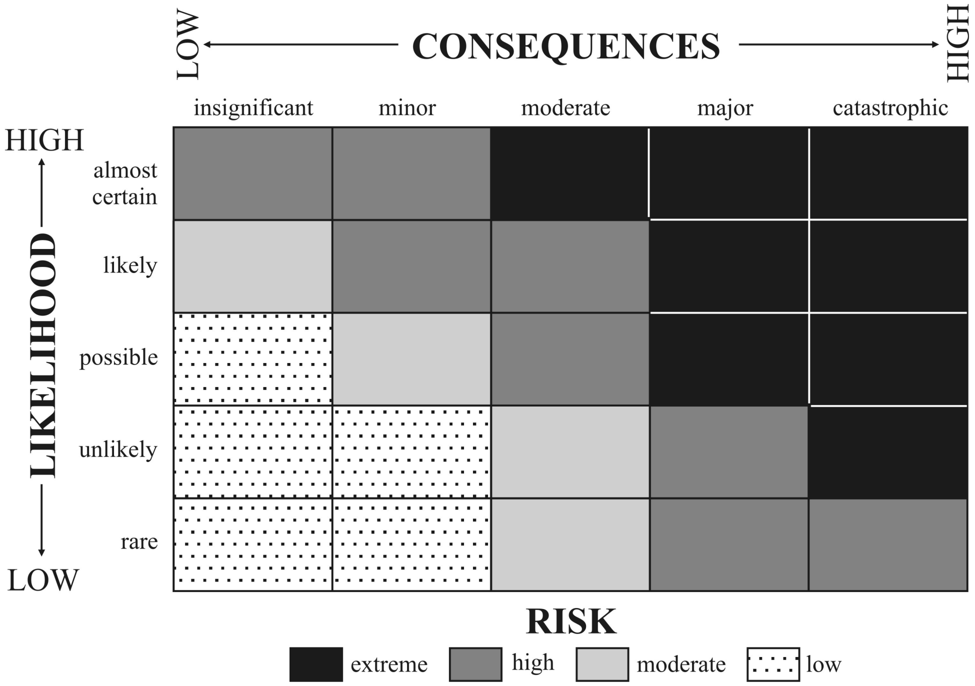


Figure 5--13: Risk Matrix

The following definitions are used for the risk description categories:

Extreme --	High-risk condition with highest priority for mitigation and contingency planning (immediate action).
High --	Moderate-to-high-risk condition with risk addressed by mitigation and contingency planning (prompt action).
Moderate --	Risk condition sufficiently high to give consideration for further mitigation and planning (planned action).
Low --	Low-risk condition with additional mitigation contingency planning (advisory in nature).

FEMA classifies risks in a similar way in their "MultiHazard Identification and Risk Assessment" publication using the following categories.

Class A: High-risk condition with highest priority for mitigation and contingency planning (immediate action). **High Likelihood and High Consequence Block**

Class B: The likelihood of a risk is high but the consequence low. Risk addressed immediately by mitigation and emergency preparedness and contingency planning (prompt action).

Class C: Risk likelihood low but consequences high. Consideration for mitigation and preparedness critical.

Class D: Low-risk condition with additional mitigation contingency planning (advisory in nature). **Low Likelihood and Low Consequence Block**

Because a 'risk level' may be assigned to more than one matrix box, an ordered list of risk priorities in not created, but rather several categories of risk with several hazards falling within each category group. For instance, if a 50-year flood was determined to be a Class C risk, and an accident involving a truck carrying hazardous materials was determined to be a Class C risk, then these two would be considered equal risks according to the risk matrix.

The evaluation can then combine these categories into a spreadsheet to reflect:

- Likelihood: is the hazard likely to occur;
- Consequences: what is the seriousness of the impacts of the hazard;
- Level of risk as determined by evaluation on the risk matrix (Extreme Risk, High

Risk, Moderate Risk, and Low Risk);

- Additional considerations including:
  - Other organizations or entities that are impacted by the hazard (potential partnerships, resources, or interdependence of risk management or hazard mitigation strategies);
  - Manageability: adequacy of existing or potential risk management or hazard mitigation measures or controls;
  - Acceptability: is the risk acceptable from social, political, economic or environmental impacts and
  - Change in the risk from the hazard: will the risk remain the same priority rating (Lunn 2003).

Risk Strategies

The strategies used to mitigate or eliminate risks involve decisions about what risks to treat, what risks to prevent at all costs, and what risks can be disregarded because of either low consequence, low frequency, or both. The Risk Analysis process is not working in a vacuum. There are many factors such as political, social, or economic systems that could affect the determination of what risks are acceptable, and what risks are not.

Once hazards have been identified, analyzed and evaluated, a priority list of risks that must be considered for treatment is generated. Ideally, communities would treat all risks in a way such that nobody would have to worry about them ever again, but that risk-free world scenario is inconceivable despite modern technology and engineering. While most risks can be reduced by some amount, few can be completely eliminated, and rarely do the funds exist to reduce all of the risks by an amount that is acceptable to all people in the community.

Another factor in the problem of risk acceptability and mitigation relates to the benefits associated with almost every risk. It is almost universally true that a benefit enjoyed by a community or organization requires some acceptance or tolerance of an associated risk. Locating a business near a water feature used as a major transportation route may expose it to flooding. Locating a subdivision in or near a forest may be desirable to future homeowners but could expose the residents to a wild-land fire hazard. To completely eliminate the risk will in many cases eliminate associated benefits as well.

Eliminating certain risks may directly or indirectly create new ones. That is, one problem may be solved only to create another. For instance, to completely eliminate the risk from nuclear power generation plants, those plants would need to be dismantled and taken out of service. The resulting shortage of power would require that fossil fuel burning plants increase their production, which in turn would create increased carbon-based pollution likely resulting in increased health and environmental risks.

With these concerns in mind, a thoughtful response to the assessed risks must be determined. This response becomes the organization's risk strategy. The risk strategy for a particular risk depends upon the risk level for that risk. A mandatory risk level indicates a risk requiring immediate attention, whereas, a De minimis risk level may only require continued observation and data collection. It may also be determined that the risk is acceptable.

Mandatory Risk Level

This type of risk is considered one that is so great that it is mandatory that action be taken to deal with it. It is viewed as an "obnoxious risk" which cannot be ignored and strategies to reduce vulnerability to it are mandatory. In practice, this level is generally set at 1 in 10,000 risk per vulnerable individual. This practice is often cited in regards to second hand smoke exposure or accidents in the workplace where safety measures or procedures are required.

Extremely Low Likelihood of Risk

A "De Minimis" risk level suggests that the statistical probability of a specific risk from a hazard is so low that concern is not merited. This level is often set at either 1 in 100,000 or 1 in 1,000,000, and is set either for a one year period, or for a lifetime (70 years). The term De Minimis is a shortened version of the Latin phrase "de minimis non curat lex" which means "the law does not care about very small matters". This concept is widely used to set guidelines for levels of risk exposure to the general population such as the chance of personal injury in an airline crash or train derailment or a reaction from an over the counter medication. For instance, the Environmental Protection Agency has set de minimis risk levels for human lifetime risk from pesticides at 1 in 1,000,000 over a 70-year lifetime. The FDA (Food and Drug Administration) and the USDA (US Department of Agriculture) are working on similar regulations of risk for food safety.

Accept the Risk

One option is to simply accept the risk given the present situation and resources of the community. A specific hazard event may have a very low probability of occurrence and as a result spending any amount of money to mitigate it would be counterproductive considering some greater risk reduction that could be achieved by using the money to treat another more probable or severe hazard. The risks that fall within the lowest category of both consequence and likelihood are generally the risks that are considered as acceptable. Members of a community may also believe that the level of a risk can be mitigated so as to reduce the most adverse consequences. Homeowners who have invested in reducing the vulnerability of their homes and businesses that have spent funds reducing the vulnerability of their business property may believe that they can withstand a disaster event with limited property damage. Therefore, they accept the current level of risk to their property.

Critical Thinking: What steps could a homeowner or business owner do in your area to reduce the vulnerability of their property to the risk of a local hazard? In general, how do we transfer our financial exposure to risk in a modern economy to a willing party?

Determining Risk Acceptability

Personal, political/social, and economic factors influence the determination of risk acceptability. While the three are interrelated, different processes drive each of them.

Personal

Differences in individual acceptance between risks that are voluntary or involuntary in nature are greatly determined by what we see as the benefit from the risk. An individual is more likely to accept a voluntary risk if he or she perceives that the benefit is great. Many recreational activities and sports involve considerable levels of personal risk entered into voluntarily. Indeed the thrill of the risk may be part of the enjoyment of the recreation. When the benefits of a risk outweigh the costs then the perception of the risk is reduced. In this case the threat level may be considered acceptable. In some cases, a high risk may be accepted voluntarily and a lower risk imposed from outside may not be acceptable. Skydivers are normally well acquainted with the risks in their activity but find the experience extremely rewarding. In 2007, the U.S. parachute association data suggests about 4 out of 10,000 jumps resulted in injury and 1 out of 100,000 jumps resulted in death (Hsu 2009). Hsu says that this death rate is roughly equivalent to the death rate of women in childbirth. However, a woman will only give birth to one child in a given year while a skydiver may take as many as 10 jumps in a single day, thus greatly increasing the chance of their involvement in an accident and hence increasing the risk. In this case, the skydiver is clearly willing to tolerate the voluntary risks associated with their activity.

On the other hand, our personal experience and knowledge of a risk or hazard may lead us to reject voluntarily accepting the risk. We may have seen first-hand the potential outcomes from accepting a voluntary risk and believe that the likelihood of harm is so great or the consequence is so severe that we avoid the risk all together. Consider an individual who was once at ease swimming in the ocean who then witnesses a shark attack. Their perception of the risk of a shark attack may be altered by the experience if not their voluntary acceptance of it.

In addition to our willingness to accept risk voluntarily, risk may be associated with our individual values, educational experiences, exposure to the media coverage of risk and our individual tolerance of risk.

Political/Social

Because of the differences in the makeup of different communities and populations, risk acceptance will not be universal in all communities and cultures. Risk acceptance is likely to change from place to place, from time to time, and from hazard to hazard (Alesch 2004). Acceptability is likely to change even within individual communities over time as the makeup of that community changes. It is these differences that make the wide public participation in the hazards analysis process so important. Communities that have recently experienced the impacts from a disaster will likely be more willing to learn more about the hazard that caused the disaster, and take some type of action, including risk assessment and risk mitigation.

Economic

Economic considerations of risk are viewed by federal agencies such as the U. S. Army Corps of Engineers from a cost-benefit perspective. The costs of reducing a risk will need to be compared to the benefits (actual risk reduction) that would result. Regulatory agencies such as the U.S. Department of Energy, Transportation, or Environmental Protection assess risk for private enterprises, which directly deal with the hazardous substances. Their consideration includes cost factors, but the overall public health and environmental sustainability is a higher priority. Local governmental agencies that have building departments issue permits and conduct inspections to enforce building codes and promote safety. Cost-benefit may be a consideration in the initial adoption of the regulations, but extreme events such as hurricanes can motivate public officials to strengthen the codes to provide more protection for people and property. Hence, cost considerations may not be the primary driver of the new standards.

Critical Thinking: Cost-benefit analysis is a tool that can be helpful in understanding the implications of risk where alternative risk strategies and their costs are examined. The benefits gained by the funds expended are examined. Associated with a cost-benefit analysis is the cost effectiveness assessment that examines the minimum unit cost to reduce a maximum level of risk. Consider the risks associated with flooding in a flood zone for existing homes. Suppose a house is constructed using a slab on grad foundation. How might the unit cost of raising the house using piers be reduced? What modifications to oil carrying tankers have been introduced to reduce the cost associated with oil spill impact? Do these modifications make sense relative to a cost-benefit analysis?

Hazard Models

In 1994, a FEMA report entitled, "Assessment of the State of the Art Earthquake Loss Estimation Methodologies (FEMA 249), summarized the current state of methodologies used in the estimation of earthquake losses. This report led to the development of a catastrophe model, Hazard U.S. or HAZUS. This catastrophe model helped to standardize how hazard losses are estimated. It has since been extended to wind and flood hazards. (Grossi and Kunreuther 2005)

The end result of the catastrophe model can either be a GIS map of potential losses or an exceedance probability (EP) graph. The EP graph gives the probability that a given level of loss will be exceeded. For example, for a certain inventory of covered buildings by an insurer, the EP graph may tell the insurer that there is a 2% chance that losses will exceed $5 million. The insurer can then use this information to help judge if insuring this inventory poses an unreasonable risk to the company.

Grossi and Kunreuther (200i) identify four components that must be quantified for a catastrophe model, the hazard, the inventory, vulnerability, and finally the loss. The hazard component includes the probability or frequency of occurrence as well as different characteristics of the hazard. The inventory includes the physical structures and property in the geographic area being assessed. The vulnerability component then takes the hazard component and inventory component as inputs to quantify the impact of the hazard on the inventory elements. This may include damage curves for buildings or other structures, property damage, contents damage, or business interruption expenses. From the vulnerability output potential losses are then assessed and a risk category can be assigned to the inventory element.

Uncertainty

No matter the methodology used to assess the risk of a hazard, there remains the uncertainty to consider. Uncertainty can exist in two forms. There is uncertainty in the natural hazard itself. This type of uncertainty reveals itself in the randomness of occurrence as well as the randomness in the severity of the event when it does occur. This uncertainty is normally captured through constructing probability distributions, which are then used in the risk assessment. This type of uncertainty cannot be reduced, but it can be quantified and better understood. A second type of uncertainty is due to our limited or incomplete data related to the hazard and limited or incomplete understanding related to the science describing the hazard. This type of uncertainty can be reduced or mitigated through more thorough data collection, data collected over a longer period of time, and advancement in the areas of science related to understanding the events underlying the hazard. We will describe three ways that the uncertainty can be incorporated into the risk assessment, logic trees, simulation, and use of the probability distributions.

Logic Tree

The logic tree analysis method as used in hazard risk assessment is a special case of event tree analysis (ETA). In event tree analysis, engineers studying the risk of a system's failure, will break the system into component events. A particular component in the system may fail or not fail or possibly be in one of several states with each state having a certain probability of occurring. A logic tree is then constructed showing all possible outcomes. The probability of a path occurring is then found by taking the product of the probabilities of the individual events in the path. For example, suppose an engineer wishes to study the failure of system with components A and B. The components have the following failure characteristics:

Component	Failure (F)	Success (S)
A	0.03	0.97
B	0.05	0.95

Figure 5-14: Component Failure

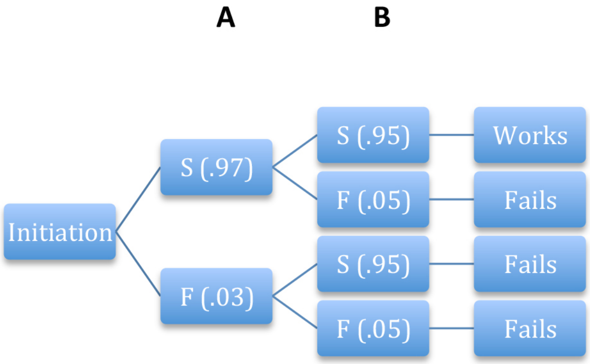


Figure 5-15: Logic Tree for System Success

To construct the logic tree diagram the first stage after initiation represents the state of component A and the second stage represents the state of component B. In the above logic tree diagram the system only works if both components are successful in performing their function. Hence, the system works only if the top branch illustrates the system's functionality. The probability of the system working is 0.97 x 0.95 = .9215 or 92.15%. The other three branches: SF, FS, FF show the three ways in which the system can fail.

In order to apply the logic tree to risk assessment, we define the component events as either intermediate events or procedures leading to the final outcome of a hazard event or as model parameters leading to the final model result. For example, suppose the risk being assessed is a nuclear terrorism event. Event A may represent the type of attack (a nuclear explosion or a nuclear dispersion), event B may represent the type of material (high half-life, low half-life), event C may represent density of population in affected area, etc. Or suppose the event being assessed is the risk of fatalities from a category 3 or higher hurricane striking a particular land area in the Gulf of Mexico. To illustrate the logic tree model, a simplified version of an example given in chapter 3 of the book *Quantifying and Controlling Catastrophic Risks* by B. John Garrick is constructed (2008). The reader may wish to consult (Garrick 2008) for a more detailed and comprehensive discussion of the hurricane impact model. Also, Grossi and Kunreuther (2005) apply the logic tree method to demonstrate the incorporation of uncertainty into landslide risk pp. 74 – 79. The parameters in the logic tree diagram are defined as follows:

A – the time the hurricane spends in the gulf before landfall [<48hr, 48-72hr, >72hrs]
B – whether the hurricane impacts the area being studied [Yes, No]
C – the category of the hurricane [3, 4, 5]
D – The type of evacuation prior to landfall.[Minimal, Medium, Full]

To fully utilize this method in obtaining a numerical value for risk, a consequence with damage estimation for each branch of the logic tree needs to be determined. Garrick (2008) uses 6 damage states for the final stage in his logic tree assessment for hurricane fatalities affecting New Orleans. He labels his damage states 1 through 6 with 1 being the most severe. Therefore, damage state 1 would occur if there was a category 5 hurricane in the gulf for less than 48 hours with minimal evacuation that affected New Orleans. Whereas damage state 6 would occur if there was a category 3 hurricane in the gulf for more than 72 hours before landfall with full evacuation that affected New Orleans. In our illustration, we will refer to the damage states as impact states and reverse the meaning of the numbers and use lower impact states for less consequence.

To provide a numerical example, we assume some hypothetical values:

A – the time the hurricane spends in the gulf before landfall [<48hr (.2) , >48hrs (.8)]
B – whether the hurricane cat 3 - 5 impacts New Orleans [Yes (.05), No (.95)]
C – the category of the hurricane [3 (.6), 4 (.4) , 5 (0)]
D – The type of evacuation prior to landfall.[Minimal , Medium, Full]
E – Impact state [0 – 0 lives, 1 - 50 lives, 2 - 750 lives, 3 – 1,500 lives , 4 – 10,000 lives],

The probabilities appear in parenthesis. Since we are simplifying the example, we have assigned a probability of 0 to a category 5 storm. Hence it will not appear in the logic diagram. For simplicity, the probability for type of evacuation will only be a function of the time the storm spends in the gulf before landfall. Of course, in reality, this probability will depend on many events including the size of the storm reported and the action of state and local officials. For our example, we use the following table of values:

Time spent in Gulf	Minimal	Medium	Full
<48hr	.8	.2	0
>48hr	.2	.8	0

Figure 5-16: Evacuation Success Probabilities for Time the Hurricane Spends in the Gulf

The Impact state [IS] (expected number of fatalities) will be function of the size of the storm and type of evacuation according to the table:

Category	**Minimal**	**Medium**	**Full**
3	3	2	1
4	4	3	2

Figure 5-17: Impact States by type of Evacuation

Finally, the initiation event is the moment a major hurricane is reported to appear in the Gulf of Mexico. The logic tree describing this model is shown in Figure 5-18. The stages in the logic tree model beyond initiation illustrated from left to right are the time spent in the gulf (TIME), whether it will impact New Orleans (IMPACT), the category (CAT), the evacuation success (EVAC), and the storm impact status (IS).

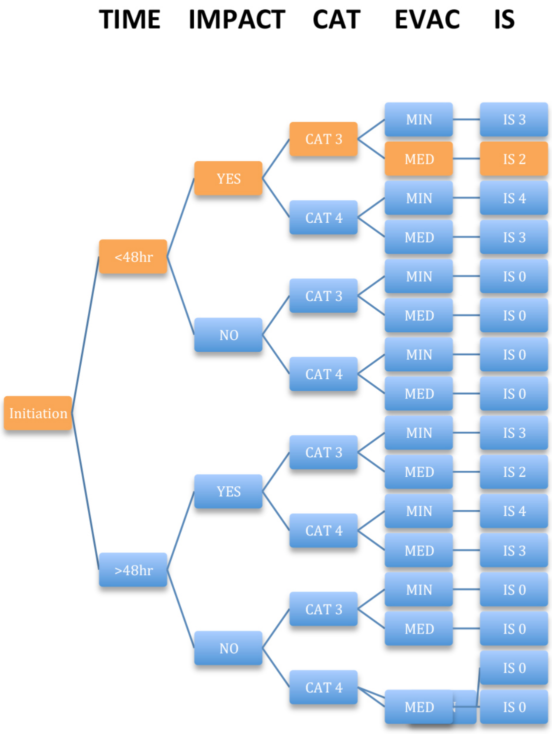


Figure 5-18: Logic Tree for Hurricane Impact

We can now use the logic diagram to calculate probabilities as well as to quantify the risk. For example, following the branch in the diagram in a lighter shade of orange, after a major hurricane appears in the gulf, the probability of the storm appearing in the gulf less than 48 hours before land fall (0.2), impacting New Orleans (0.5), being category 3 (0.6), with medium evacuation success (0.2) is

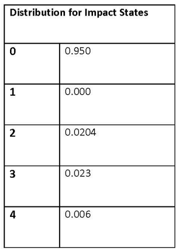
$$\mathbf{0.2\times 0.05\times 0.6\times 0.2 = 0.0012}$$

Since the scenario of a category 3 storm with medium evacuation success yields impact state 2, the fatality risk for the stated scenario is $0.0012\times 750 = 0.9$. Notice we have calculated the risk for one of sixteen possible scenarios. To calculate the total risk, we add the risk from all sixteen paths.

We can also calculate the distribution of probabilities for the impact states from the logic tree. For example, there are two paths in the tree leading to impact state 2:

1. **<48 hours, YES, CAT3, MED :** $\mathbf{0.2\times 0.05\times 0.6\times 0.2 = 0.0012}$
2. **>48 hours, YES, CAT3, MED:** $\mathbf{0.8\times 0.05\times 0.6\times 0.8 = 0.0192}$

Therefore, the probability that after a storm enters the gulf it will lead to impact state 2 in New Orleans is 0.0012 + 0.0192 = 0.0204. This can be done for each impact state yielding the distribution for the impact states Figure 5-19.



Distribution for Impact States	
0	0.950
1	0.000
2	0.0204
3	0.023
4	0.006

Figure 5-19: Distribution for Hurricane Model Impact States

Critical Thinking: Describe the four paths in the logic tree leading to impact state 3. Calculate the probability that after the storm enters the gulf that it will lead to impact state 3 and compare your solution to the probability in Figure 5-19.

Monte Carlo Method or Simulation

After constructing a model for all of the inputs to our hazard analysis, which may consist of probability distributions, calculus type models, or probabilities for categorical descriptions, we can in theory determine the risk of the hazard. We could simplify the uncertainty involved by making enough simplifying assumptions to construct a logic diagram as previously shown. However, modern technology also allows us to simulate the hazard event. Using random values to simulate the value for a model or a model parameter is called a Monte Carlo method.

For example, in the hurricane model above, either before or at the time the storm enters the gulf, we may use historical data to arrive at the probability that the storm will impact New Orleans. However, modern hurricane models make projections as to where the storm will make landfall using probability distributions. The probability that the storm will affect New Orleans will not remained fixed. It will change as the storm progresses through the Gulf of Mexico. At a point in time, computer models may indicate a probability distribution for the storm to impact New Orleans. For a numerical example, suppose that distribution is given by Figure 5-20.

Probability	**Cumulative Probability**	**Chance of N.O. Landfall**
0.75	0.75	0%
0.13	0.88	5%
0.07	0.95	30%
0.05	1.0	50%

Figure 5-20: Distribution for landfall

Reading the table given in Figure 5-20, there is a 0.75 probability of no landfall in New Orleans; there is a 0.13 probability of a 5% chance of landfall; etc. The second column is the cumulative distribution. We use the cumulative distribution to perform the simulation. In this case, the computer program will choose a random integer from 1 to 100. If the random integer is between 1 and 75, inclusive then a 0% chance would be used for the hurricane making landfall in New Orleans. If the integer is between 76 and 88, inclusive then a 5% chance would be used for the hurricane making landfall in New Orleans. If the integer is between 89 and 95, inclusive we would use 30% and if it is between 96 and 100, inclusive then we would use 50%. Each choice of a random number will provide a probability of landfall to use in determining the risk from the storm. For example, suppose the random integer 23 is generated. Then a probability of 0 impacting New Orleans is used rather than 0.05 (5%) in the logic tree above. In this case the only relevant impact state would be 0. However, if the integer 90 is generated, then a probability of 0.3 (30%) impacting New Orleans would be used rather than 0.05. A large number of scenarios can then be used, such as 10,000, with the risk calculated for each scenario. The final result will be a distribution of values for either the damage state or the risk.

The previous example shows how to perform the simulation in the case of one input having uncertainty. This method can be further extended in the case simulation is needed for more than one input or model parameter.

Uncertainty Expressed in Interval Estimates

Suppose the damage states for the hurricane model represent the consequence in terms of structural loss, recovery expense, and other economic losses rather than loss of lives. Using damage states 1 - $0 through 9 - $10M with each damage state representing $1.25M more damage than the previous damage state, we may obtain a distribution of losses due to a category 3 hurricane striking a specified city as shown in the table in Figure 5-21.

DS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Probability	0	.04	.06	.07	.11	.18	.25	.19	.1
Cost	$0	$1.25M	$2.5M	$3.75M	$5M	$6.25M	$7.5M	$8.75M	$10M

Figure 5-21: Distribution for Hurricane Model Damages

We can also view this distribution graphically in the form of a histogram, Figure 5-22. In this graph the damage states are on the horizontal axis and the probabilities on the vertical axis. The height of the bar above the damage state shows the probability the damage state will occur. For example, the height of the bar above damage state 7 is 0.25 indicating a probability of 0.25 that there will be $7.5 M in damage if a category 3 storm should strike this particular city. Since each bar in the histogram has width 1, it is also convenient to view the area of each bar as the probability of the occurrence of the damage state.

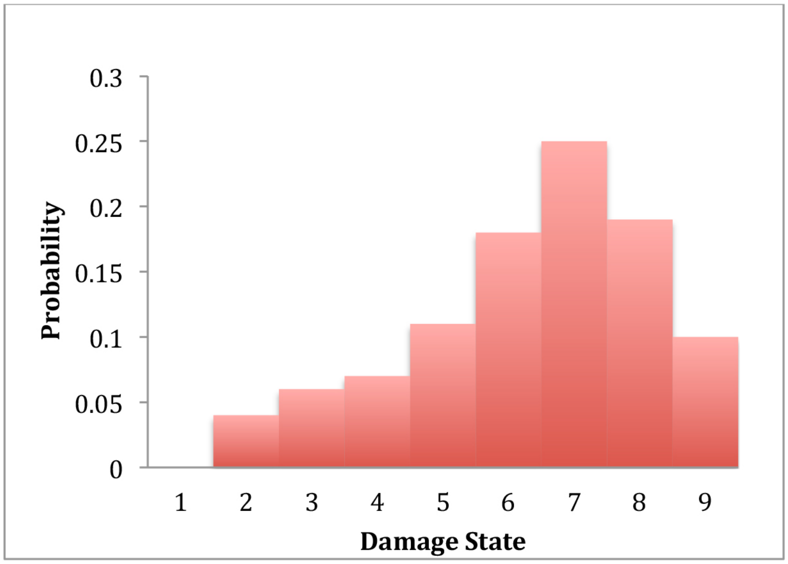


Figure 5-22: The Histogram for the Distribution for Hurricane Model Damages

The expected damage can be calculated by multiplying each damage value by the probability of its occurrence and summing over all of the damage states. The expected damage from the distribution above is Cost times Probability for each Damage State or $1.25 \times .04 + 2.50 \times .06 + 3.75 \times .07 + 5.00 \times .11 + 6.25 \times .18 + 7.50 \times .25 + 8.75 \times .19 + 10.00 \times .10 = \$6.675M$.

$6.675M can then be used as the consequence in calculating the risk, however, the distribution of damages provides more information than just the expected damage. It may also be used to express the uncertainty in the estimates. For example, there is a 0.54 probability that the category 3 hurricane will cause damage in the interval [$5M, $7.5M]. We obtain this probability by adding the probabilities for damage states 5, 6, and 7. We can view this and its probability graphically by observing the area of the bars over damage states 5, 6, and 7 in the histogram (area between the vertical bars) as shown in Figure 5-23. Using this distribution, we can also conclude that there is a 10% chance of damage being $10M. Therefore, in this example, $8.75M (damage state 8) is called the 90th percentile since the probability that the damage will be less than or equal to $8.75M is 0.9.

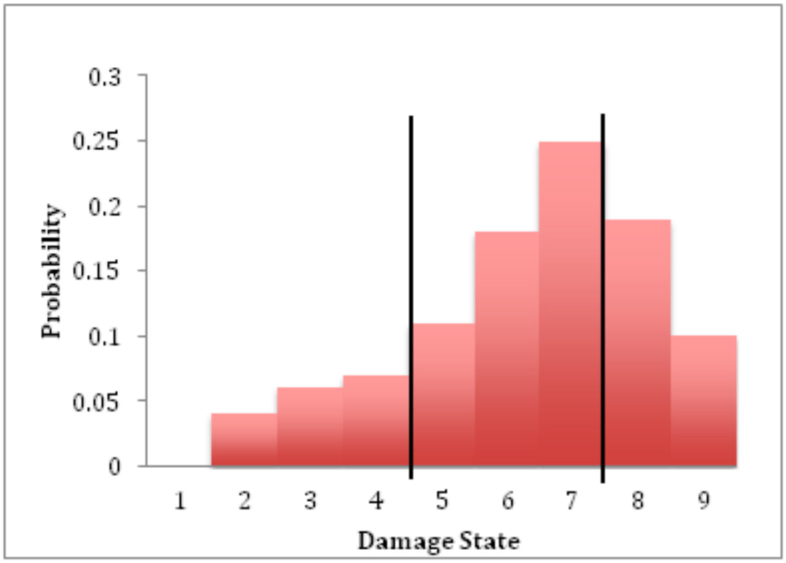


Figure 5-23: The Histogram View for the Interval of Estimation [$5M, $7.5M].

When calculating parameter values from historical data, it is common to use the sample mean for the parameter as the point estimate for the true mean of the parameter value and use the 95% confidence interval for the interval estimate. In this case, if the data set is large, then the sample mean has an approximate normal distribution that can be used to identify the interval estimate. In general, if $\bar{x}$ denotes the sample mean, σ denotes the sample standard deviation, and these statistics are calculated from n data values then the 95% confidence interval for the parameter as measured in the data set is given by

$$\left[\bar{x} - 1.96\frac{\sigma}{\sqrt{n}}, \bar{x} + 1.96\frac{\sigma}{\sqrt{n}}\right]$$

For example, in an earthquake hazard model suppose a parameter in the model is the average time a 3.0 earthquake lasts at a particular fault. If historically there are 60 such earthquakes recorded for this fault and the average duration is 45 seconds with a sample standard deviation of 12.4 seconds, then the 95% confidence interval estimation for a 3.0 earthquake average duration is

$$\left[45 - 1.96\frac{12.4}{\sqrt{60}}, 45 + 1.96\frac{12.4}{\sqrt{60}}\right] = [41.9, 48.1].$$

We interpret this interval of estimation by stating that we are 95% confident the true mean duration of 3.0 earthquakes at this particular fault is between 41.9 seconds and 48.1 seconds. Notice, if we base our estimate on fewer data values, this causes a wider interval estimation reflecting the fact that we should view our point estimate for the parameter as having less precision. Hence if the statistics above were the same, but based upon 25 data values, our interval becomes

$$\left[45 - 1.96\frac{12.4}{\sqrt{25}}, 45 + 1.96\frac{12.4}{\sqrt{25}}\right] = [40.1, 49.9],$$

indicating more uncertainty about the true parameter value.

Landslide hazards present a complex scenario to analyze. Among the complexities identified by Glade (2003) and Uzielli et. al. (2008) is the site-specific nature of the phenomena and the difficulty in quantifying the spatial aspect of the hazard. To help overcome these difficulties, in landslide hazard analysis it has become accepted practice to divide consequence into two components, vulnerability (V) and the cost of items at risk (C_I). Hence, the risk equation becomes $= P \cdot C = P \cdot V \cdot C_I$. The vulnerability is then defined both in terms of landslide intensity and the susceptibility of the inventory at risk $V = I \cdot S$ (Uzielli et. al. 2008). This enables the authors to develop separate and independent models for the landslide intensity and the susceptibility of the local structures, which are of varying ages and subject to local building codes and construction techniques. Further in a follow-up paper the authors explore the uncertainty in the vulnerability component by providing upper and lower thresholds resulting in an interval of estimation for vulnerability (Kanya et. al. 2008).

Summary

We have explored how experts analyze risk in human and natural caused hazards. Experts identify hazards that are probable to impact a location. The structures and inhabitants in that location are assessed for their vulnerability to each risk. This assessment relies upon historical data, current data, socio-economic data, local demographics, and judgment. In some cases hazard models are constructed in order to incorporate scientific and statistical information into the assessment. Software packages such as GIS can provide insight into the spatial distribution of the risk being considered. The amount, quality and the depth of the data are important factors in establishing parameter values, inputs for hazard models, as well as providing a basis for decisions made about risk strategies. In the risk analysis process, both quantitative and qualitative analysis are utilized. If the probability and consequence of a hazard event occurrence can be numerically established, then the risk for that hazard event can be calculated as the probability times the consequence. Tools such as the risk-matrix help to place each risk into categories such as low, medium, high, or extreme. Using this relative ranking of risks, risk managers can then formulate risk strategies appropriate to each hazard. These strategies may include simple risk mitigation measures for low and medium risks, risk acceptance for some risks, and planning or immediate action, such as recommendations for regulation, for more extreme risks. Further, the risk managers and experts are faced with the challenge of communicating this technical information and its interpretation to the public and policymakers. As was said in the beginning, the goal is to provide decision-makers with the right information, at the right level of complexity, at the right time.

Advanced instrumentation for collecting the data and the increase in scientific knowledge and technology have most certainly contributed to a more accurate assessment of risks and its communication to decision-makers. However, hazard events seem to regularly catch us off our guard and cause billions of dollars in damage as well as cause human suffering and loss of life. This reminds us that knowing the chance of something happening does not tell us when or where it will happen or even whether it will happen. Much of our expectations about the present and future are based upon past trends and occurrences. However, we must explore more thoroughly whether past trends will continue or will change into new trends. Many hazards affecting large portions of world populations are climate related, such as droughts, floods, destructive storms, a rising sea level, long-term temperature changes, insect infestation, and potable water availability. The earth's climate is a dynamical system, difficult to model, and changes in climate are difficult to predict. It changes through natural cycles and due to natural causes as well as the impact of human activity. As human impact on the climate increases, some changes may be accelerated or even be different than expected. The emission of green house gasses and its environmental impact has been receiving increased attention as our consumption of carbon-based fuels continues to rise. As an example of how climate change affects our knowledge of a hazard, consider the coastal flooding hazard associated with a change in sea level. According to NOAA's ocean facts, in 2010, 39% of the US population lived in coastal counties with a population density six times that of inland counties. This is consistent with the estimates that 40% of the world's population lives within 100 kilometers of the coast. For these residents, rising sea levels pose an alarming problem. The source of this problem lies in the thermal expansion of warming ocean waters and the melting ice sheets. Both of these factors are related to a warming climate. The IPCC (Intergovernmental Panel on Climate Change) regards ice sheet melting as the major unknown factor to predicting future sea level rises (Quaile 2013). Just a generation ago, it was difficult to imagine an ice-free artic summer. With satellite data, scientists are now predicting an ice-free artic summer within decades. Erik Ivins, who coordinated a new study for NASA on ice sheet melting, says that the rate of ice loss from the Greenland ice sheet has increased five-fold since the mid-1990's, and the melting ice from both poles is responsible for one - fifth of the global rise in sea level (Quaile 2013). Clearly historical trends in coastal flooding and its causes will not be as useful in assessing this risk in the future. Hence the challenges facing risk assessors and risk managers include the past challenges of data collection and mining, building or using models and new technology, and effectively communicating their results to decision makers and the public, as well as the new challenge of how to utilize our knowledge of a changing climate.

Discussion Questions

Would you classify a risk as voluntary or involuntary where changes in factors influencing the frequency and severity of local flooding have changed without the knowledge of the community?

What risks would be included as obnoxious where mandatory action is required?

What risks do you consider to be unacceptable where others have determined that they can live with the hazard? What personal views, values, beliefs, or your personality contribute to this conclusion associated with a risk?

Applications

Using the risk matrix categories included in Figures 5-11 and 5-12, examine the hazards in your community and categorize their likelihood and damage consequences from low to extreme.

Web Sites

The ERPG guidelines are clearly defined and are based on extensive, current data. The rationale for selecting each value is explained, and other pertinent information is also provided.
http://www.aiha.org

National Climatic Data Center (NCDC) http://www.ncdc.noaa.gov/oa/about/ncdcwelcome.html

Storm Prediction Center, Norman, OK http://www.spc.noaa.gov/archive/index.html

National Hurricane Center, Colorado State University http://www.nhc.noaa.gov/pastall.html

NOAA information on coastal populations:
http://oceanservice.noaa.gov/facts/population.html

Earthquakes Epicenter: Council of National Seismic Systems
http://quake.geo.berkeley.edu/cnss/

Catalog of Significant Earthquakes. National Geophysical Data Center
http://www.ngdc.noaa.gov/seg/hazard/eqint.html

Earthquake research Institute, the University of Tokyo, Japan.

http://www.eri.u-tokyo.ac.jp/eng/

Watershed Flood Monitoring Program: http://cfpub.epa.gov/surf/locate/index.cfm

Environmental Research Consulting: http://www.environmental-research.com/publications.php

USGS River Gauges in the U.S. for active stations: http://water.usgs.gov/waterwatch

Damage Estimation: http://www.westegg.com/inflation/

References

Alesch, D. J., J. Holly, E. Mittler, and R. Nagy (2001). *Organizations at Risk: what happens when small businesses and not-for-profits encounter natural disasters?* Fairfax: VA Public Entity Risk Institute.

Amendola , A. (2004). Management of Change, Disaster Risk, and Uncertainty: an Overview. *Journal of Natural Disaster Science. 26(2), 55-61*

Army ROTC. Sample Risk Management Worksheet. Accessed Nov. 4, 2013. http://www.google.com/#q=rotc+risk+management+worksheet

Benson, M.A. (1967). "Uniform Flood-Frequency Estimating Methods for Federal Agencies." *Water Resources Research.* U.S. Geological Survey. 4(5), 891-908.

Breslin, S. (2013). Many Coastal Residents Still Unprepared for Hurricanes. The Weather Channel, Hurricane Central, Nov. 4, 2013. http://www.weather.com/news/weather-hurricanes/few-coastal-residents-prepared-hurricane-season-study-finds-20130618

Cameron, G. (2002). "Emergency Risk Management: What Does It Mean?" ATEM-AAPPA 2002 Conference, Brisbane, Australia. http://www.aappa.com/infoservices/papers/2002_AAPPA_Brisbane/G_Cameron.pdf.

Cutter, S. L. (2001). "Charting a course for the next two decades," *American Hazardscapes: The Regionalization of Hazards and Disasters.* Susan L. Cutter Ed., Joseph Henry Press.

Darier, E. C. Gough; B. De Marchi, S. Funtowicz; R. Grove-White; D. Kitchener; Â. Guimarães Pereira; S. Shackley; B. Wyn (1999). Between democracy and expertise? Citizens' participation and environmental integrated assessment in Venice and St. Helens. *Journal of Environmental Policy & Planning,* 1(2), 103 --- 120.

Derby, S. L., R. L. Keeney (1981). *Risk Analysis: Understanding "How Safe Is Safe Enough?"* Risk Analysis. 1(3), 217-224.

De M. B. and J. R. Ravetz (1999). Risk management and governance: a post-normal science approach*. Futures.* 31(7), 743-757.

Emergency Management Australia (2001). *Decision Making Under Uncertainty in the Emergency Management Context.* Workshop held at the Australian Emergency Management Institute, August 27-28.

<http://www.ema.gov.au/ema/rwpattach.nsf/viewasattachmentPersonal/4B0DF4E7C3945DB0CA256C85001E2B56/$file/DECISION_MAKING_UNDER%20UNCERTAINTY_IN_THE_EM_CONTEXT.PDF>

Etkin, D. S. (2006). Risk assessment of oil spills to US inland waterways. Proc. 2006 Freshwater Spills Symposium. http://www.environmental-research.com/erc_papers/ERC_paper_16.pdf

Federal Emergency Management Agency (2001). *Understanding Your Risks: Identifying Hazards and Estimating Losses*. FEMA. Washington, DC.

Federal Emergency Management Agency (2002). *Mitigation Planning Workshop for Local Communities*. Instructor Guide. DMA 2000 State and Local Plan Interim Criteria. FEMA. Washington, DC. <http://www.fema.gov/fima/planning_toc4.shtm>

Federal Emergency Management Agency (1997). *MultiHazard: Identification and Risk Assessment*. FEMA. Washington, DC.

FEMA 249 (1994) Assessment of the State of the Art Earthquake Loss Estimation Methodologies, June.

Frosdick, Steve (1997). The techniques of risk analysis are insufficient in themselves. *Disaster Prevention and Management.* 6(3), 165-177.

Garrick, J. B (2008). *Quantifying and Controlling Catastrophic Risks*. Academic Press. Burlington, MA.

Glade, T. (2003). Vulnerability assessment in landslide risk analysis. *Erde*, *134*(2), 123-146.

Kanyia, A.M., M. Papathoma-Kohle, B. Neuhauser, K. Ratzinger, H. Wenzel, Z. Medina-Cetina (2008). Probabilistic Assessment to Vulnerability to Landslide: Application to the Village of Lichtenstein, Baden-Wurttemberg, Germany. *Engineering Geology.* 101, 33 – 48.

Grossi, P. and H. Kunreuther, D. Windeler. 2005. An introduction to Catastrophe Models and Insurance. In *Catastrophe Modeling: A New Approach to Managing Risk.* P. Grossi, P. Grossi and H. Kunreuther (editors). Springer. New York, NY.

Hsu, J. (2009). The Truth About Skydiving Risks. Livescience website, March 26, 2009. http://www.livescience.com/5350-truth-skydiving-risks.html.

ISDR Secretariat (2003). *Living with Risk: Turning the tide on disasters towards sustainable development. Geneva*: United Nations.

Interagency Advisory Committee on Water Data (1982). *Guidelines for Determining Flood FlowFrequency.* Bulletin 17B of the Hydrology Subcommittee, Department of Interior, U.S. Geological Survey. Office of Water Data Coordination. Reston, VA.

Jardine, C. G., and S. E. Hrudey, Mixed Messages in Risk Communication, Risk Analysis, 17(4), 489-498..

Kirkwood, A. S. (1994). "Why do we worry when scientists say there is no risk?" *Disaster Prevention and Management, An International Journal.* 3(2), 15 – 22.

Lunn, J. (2003). "Community Consultation: The Foundation of Effective Risk Management." *Journal of Emergency Management.* 1(1), 39-48.

Marzocchi, W. and G. Wee (2009). Principles of Volcanic Risk Metrics: Theory and the Case Study of Mount Vesuvius and Campi Flegrei, Italy. *Journal of Geophysical Research.* 114(B03213), doi:10.1029/2008JB005908

NOAA (2013). National Coastal Population Report: Population Trends from 1970 to 2020. website checked: Nov. 4, 2013. http://stateofthecoast.noaa.gov/features/coastal-population-report.pdf

NWS NHS 47, NOAA Technical Memorandum, updated by J. Beven (1997). The Deadliest Atlantic Tropical Cyclones, 1492 – 1996. website checked: Nov. 4, 2013. http://www.nhc.noaa.gov/pastdeadly.shtml

Quaile, I. (2013). Polar Ice Sheets Melting Faster Than Ever. Deutsche Welle, Naomi Conrad, editor. website checked: Nov. 4, 2013. http://www.dw.de/polar-ice-sheets-melting-faster-than-ever/a-16432199

Ries, K.G., III, and Crouse, M.Y., (2002). *The National Flood Frequency Program, Version 3: AComputer Program for Estimating Magnitude and Frequency of Floods for Ungauged Sites, 2002: U.S. Geological Survey Water-Resources Investigations Report 02-4168.*

Royal Society (1992). *Risk Assessment, Report of a Royal Society Study Group.* The Royal Society, London.

Rejeski, D. (1993). GIS and Risk: A three-Culture Problem. In *Environmental Modeling with GIS.* Goodchild, Michael F., B.O. Parks, and L. T. Steyaert. Oxford University Press: New York.

Rosenthal, U. and A. Kouzmin (1997). Crises and Crisis Management: Toward Comprehensive

Government Decision Making. *Journal of Public Administration Research and Theory: J--PART*. 7(2), 277--304.

Schrader--Frechette, K. (1985). *Risk Analysis and the Scientific Method: Methodological and Ethical Problems in Evaluating Societal Hazards*, Reidel, Dordrecht.

Slovic, Paul, Baruch Fischhoff, and Sarah Lichtenstein (1979). *Rating the Risks*. Environment. 21(3), 14020, 36--39.

Smith, K. (2004). *Environmental Hazards: Assessing Risk & Reducing Vulnerability*. Routledge. New York.

Thomas, D. S. K. (2001). Data, data everywhere, but can we really use them? Cutter, S.L. (ed.) *American Hazardscapes: The Regionalization of Hazards and Disaste*rs. Joseph Henry Press, Washington, D.C. *American Hazardscapes.* Ed. S. Cutter.

United Nations (2006). *The Millennium Development Goals Report.* Department of Economic and Social Affairs. New York, NY. website checked: Nov. 4, 2013. http://mdgs.un.org/unsd/mdg/Default.aspx

USGS, Hawaiian Volcano Observatory (2012). Volcano Watch, December 20, 2012. http://hvo.wr.usgs.gov/volcanowatch/view.php?id=155

Uzielli, M., N. Farrokh, L. Suzanne, A. Kanyia (2008). A Conceptual Framework for Quantitative Estimation of Physical Vulnerability to Landslides. *Engineering Geology*, 102, 251 – 256.

Wilson, R. and A. Shlyakther (1997). “Uncertainty and Variability in Risk Analysis.” In *Fundamentals of Risk Analysis and Risk Management.* CRC Press. Pp. 33--44.

Zimmerman, R. and V. Bier (2002). “Risk Assessment of Extreme Events.” Columbia--Wharton/Penn Roundtable on Risk Management Strategies in an uncertain World. April 12--13, 2002. website checked: Nov. 4, 2013. http://www.ldeo.columbia.edu/chrr/documents/meetings/roundtable/white_papers/zimmerman_wp.pdf

Zimmermann, K. A. (2012). Hurricane Katrina: Facts, Damage, and Aftermath. *Livescience* website, Nov. 4, 2013. http://www.livescience.com/22522-hurricane-katrina-facts.html